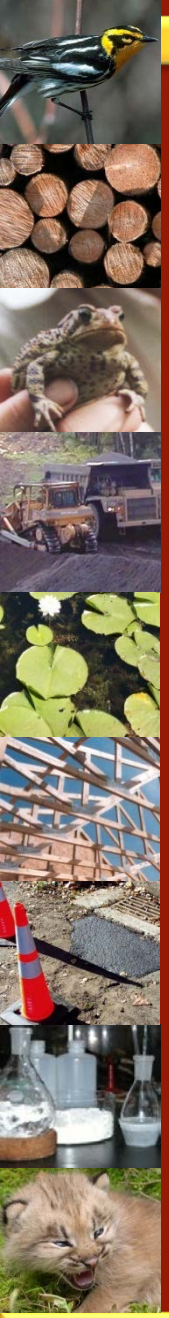


Driving a Future for Iron Ore Mining – What Pathways Are Possible?

Rolf Weberg
Director

Donald Fosnacht
Associate Director,
Technology Development

January 13, 2016

Natural Resources Research Institute
University of Minnesota Duluth
Driven to Discover℠

Steps to enhance Minnesota iron mining

Reduction of mining cost

- ✓ enhanced iron yield from harvest of both hematite and magnetite

Diversify product mix

- ✓ transition to value-added metalized products
  - participate across the US steel industry (BF + **EAF**)
- ✓ produce DR-grade pellets as initial step
- ✓ develop heat-efficient DRI process
  - take advantage of low price natural gas
- ✓ capitalize on product quality
  - provide flexibility to EAF customers
- ✓ provide secondary product support – *immediate impact*
  - high quality aggregate for use in highway surfaces

Define new opportunities

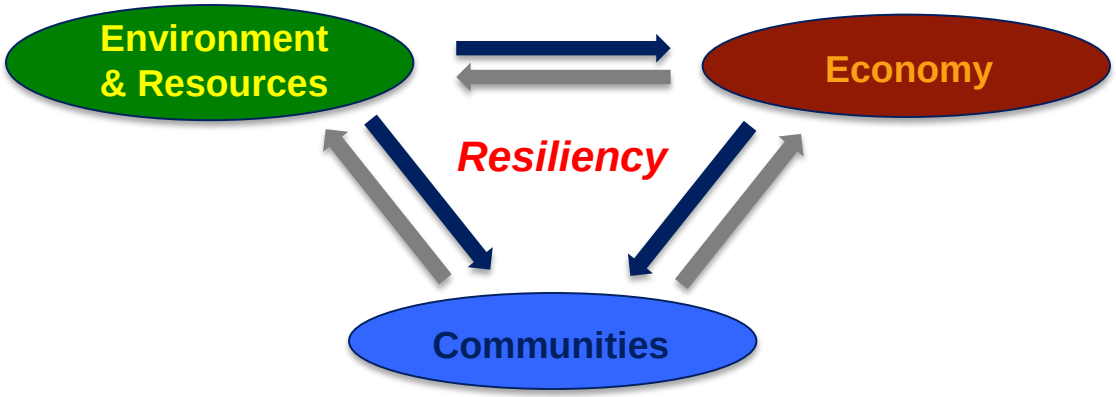
- ✓ Lean ore stockpile reclamation
- ✓ Ilmenite ore demonstration
- ✓ Other non-ferrous

The NRRI Mission

The Natural Resources Research Institute Charter

To foster the economic development of Minnesota's natural resources in an environmentally sound manner to promote private sector employment

Minnesota State Legislature, 1983



Deliver research solutions to balance our economy, resources and environment for resilient communities

Approach

Broad collaboration

- ✓ Industry, agencies, stakeholders

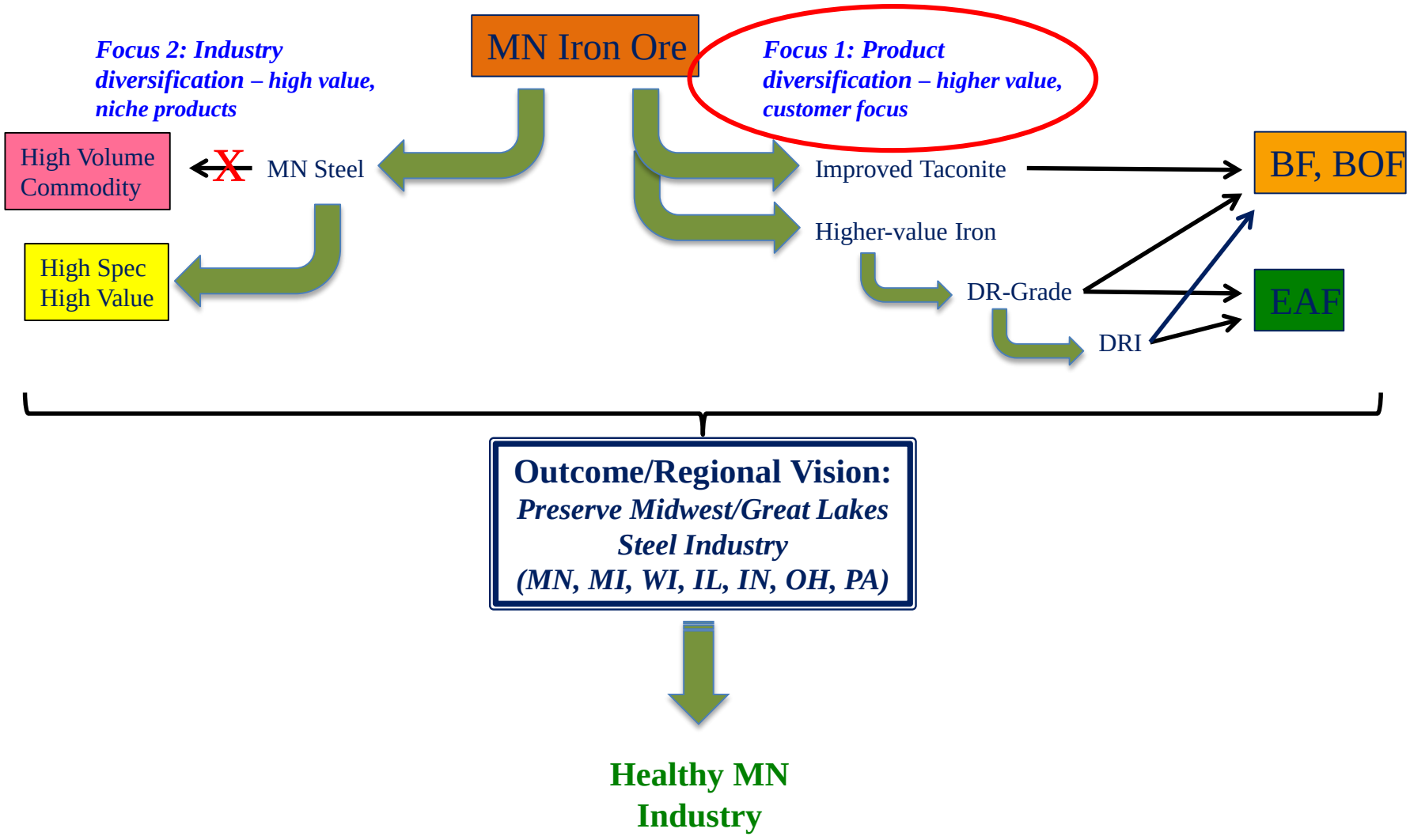
Build upon long-standing relationships & location

- ✓ leverage broad expertise and 30+ years experience in NE MN
- ✓ understand integration between resource-based industries
  - relationship between iron provider and steel manufacturer
  - relationships between energy, mining, timber
- ✓ Coleraine Lab presence on Iron Range

Anticipate & Innovate

- ✓ improved iron ore processing
- ✓ ilmenite ore demonstration
- ✓ DRI process opportunities

MN Iron Mining Industry – Balanced Portfolio

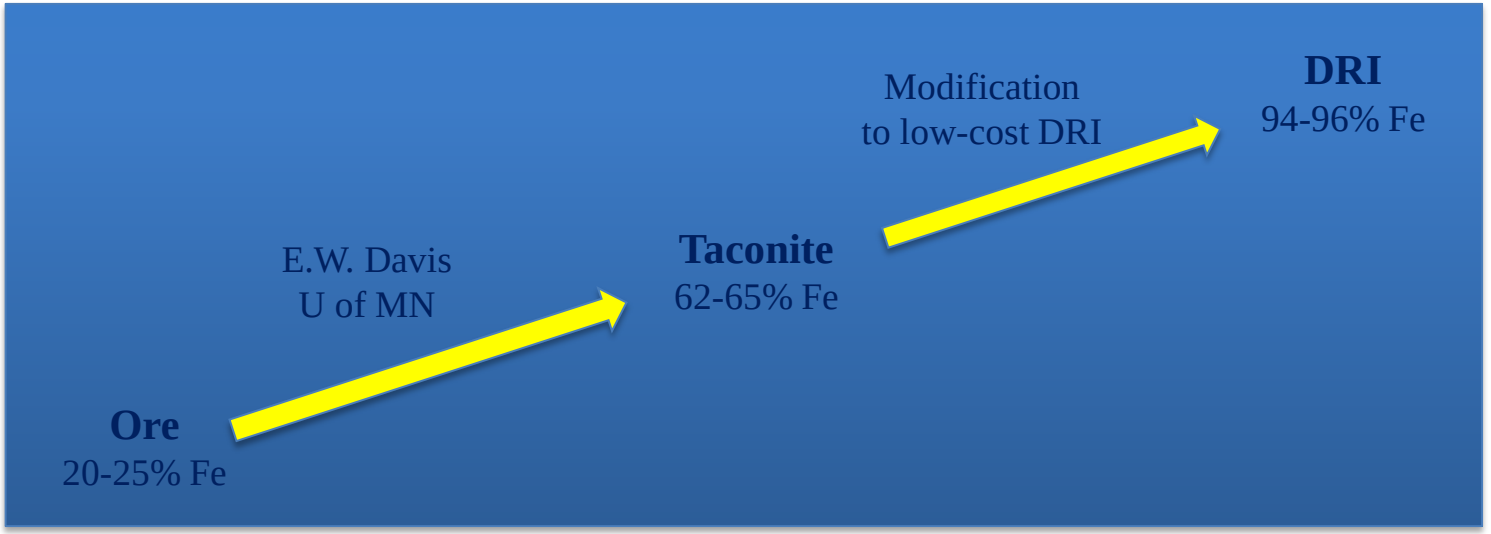


How can Minnesota seek to participate in >60% of today's US steel industry (non-BF) vs. global competition?

Diversify the offering:

- ✓ Produce higher value metallic products (DRG, DRI)
- ✓ Highlight differentiating high product quality (low P, S, alkalinity, fines, impurities); identify process & recycle flexibilities to customers
- ✓ Define competitive delivery & price

Steps in Minnesota "Iron Innovation"



Key Factors Impacting Future Iron Ore Use

- ✓ Magnitude of Imports – Displacement of US Produced Steel Including Indirect Trade
- ✓ Increased Fuel Economy Standards for US Automobiles and Light Trucks (Material Substitution)
- ✓ Elimination of older Blast Furnace Capacity in Favor of Electric Arc Steelmaking (e.g., Fairfield Works)
- ✓ Sale of BF Focused Iron Ore versus a more Metallized Product or EAF Grade Iron Ore
- ✓ Cost to Mine in MN versus Elsewhere

US Steel Production by Product

2014 USA Steel Statistics (metric tonnes) and Projected 2015			
Source: Worldsteel.org			
Type	**Amount**	**% 0f Total 2014**	**2015 Projection****
Overall Crude Steel Production	88,174,000		
Hot Rolled Products			*-10,000,000*
Before Conversion	**89,130,000**	100	**79,787,000**
Hot Rolled Flat Products	**63,866,000**	**71.7%**	**57,171,284**
Plate	6,550,000	*10.3%*	5,951,294
Hot Rolled Coil, Sheet & Strip < 3mm	20,688,000	*32.4%*	18,791,470
Tin Mill Production	1,754,000	*2.7%*	1,593,206
Other Coated	1,255,000	*2.0%*	1,139,950
Galvanized	16,510,000	*25.9%*	14,996,479
Estimated Cold Rolled	14,810,000	*23.2%*	13,452,323
Welded Tubes	2,299,000	*3.6%*	1,250,000
Hot Rolled Long Products	**24,150,000**	**27.1%**	**21,618,490**
Rail	1,178,000	*4.9%*	1,080,903
Heavy Sections	5,571,000	*23.1%*	5,111,810
Light Sections	1,870,000	*7.7%*	1,715,865
Reinforcing Bars	6,997,000	*29.0%*	6,420,272
Other Bars	4,483,000	*18.6%*	4,113,489
Wire Rod	2,153,000	*8.9%*	1,975,539
Seamless Tubes	2,419,000	*10.0%*	1,200,000

2014 import/Export Situation

Import/Export Picture		Comment
Semi-Finished & Finished		**Iron ore**
Steel Exports	**11,961,000**	use
Semi-Finished & Finished		**Iron ore**
Steel Imports	**41,369,000**	use
Ingots and Semi Exports	295,000	
Ingots and Semi Imports	**9,562,000**	**Iron Ore Use** **it**
Exports of Long Products	2,846,000	
Imports of Long Products	**7,147,000**	
Exports of Flat Products	6,545,000	
Imports of Flat Products	**15,640,000**	**Iron Ore Use** **it**
Exports of Tubular Products	1,947,000	
Imports of Tubular Products	**8,493,000**	

Apparent Steel Use

Overall (crude steel)	**121,600,000**
Per capita (kg/p)	**381**
Overall (finished products)	107,000,000
Per capita (kg/p)	**335**
***DRF Estimates Use with Caution*	

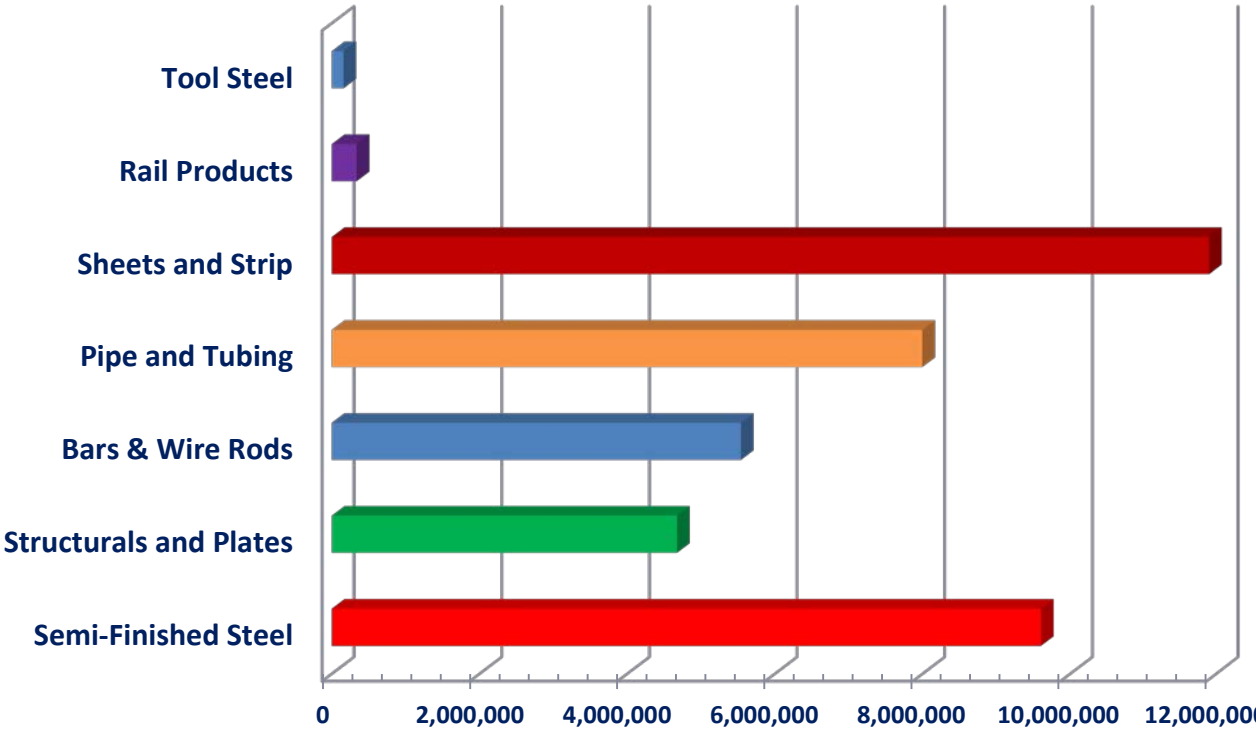
Predicted Manufacturing Margin for HRC & HDG 10/1/2014 to Current

Item -- HRC	$/t 10/1/14	$/t 8/9/15	$/t 11/23/15
Cost to Manufacture	$452	$407	$387
HRC-EXW- Indiana	$705	$465	$375
Manufacturing Margin	$253	*$58*	*-$12*

Item -- HDG	$/t 10/1/14	$/t 8/9/15	$/t 11/23/15
Cost to Manufacture	$611	$567	$547
HDG –Ex-Mill Midwest	$920	$660	$570
Manufacturing Margin	$309	*$93*	*$23*

Import Penetration (US Crude Steel: 88,347,000)

Imports of Carbon Steel Products in 2014 -- 40,222,845 mt (~Crude Equivalent = 47 M mt)



Major Impact On BF/BOF Producers

	Semi-Finished Steel	Structurals and Plates	Bars & Wire Rods	Pipe and Tubing	Sheets and Strip	Rail Products	Tool Steel
Series1	9,604,679	4,676,092	5,541,847	7,998,406	11,904,793	337,900	159,128

2013 Indirect Steel Net Imports = ~ 20 M mt

Impact of Material Substitution

Ford F 150 Switch to Aluminum for Body Outer

2015 Ford F150 All New Aluminum Body Light Truck

http://www.ford.com/ngbs-services/resources/ford/f-150/2015/gallery/photos/f1515_pg_005_ext_lg.jpg

Aluminum Substitution is Roughly Equivalent to displacement of 405,000 tonnes of steel/y or 503,000 tonnes of Iron Ore/y for the F150 model alone

Future Impact Other Light Trucks

If other manufacturers follow the Ford lead for Model Year 2018;

An additional, 1,676,000 mt is placed in jeopardy

Growth of Electric Arc Steelmaking in USA at Expense of BF Based Steel Making

Factors Impacting Blast Furnace Operation

- High Cost of Furnace Rebuilds (>$250 million/furnace)
- Very difficult to Throttle Furnace Production to Match Economic Conditions – Electric Arc Furnaces can be brought back on line with little difficulty after shut down
- Older, less efficient operations shuttered after merger activity
- Steel Manufacturing Bankruptcy leads to facility closure
- Environmental concerns associated with Coke Production

North American Blast Furnaces (2014 Production: 40.3 M mt)

Company	Division	Furnace Identifier	2014 Production	Status
Arcelor Mittal	Dofasco	2	692,752	Active
		3	722,181	Active
		4	1,233,953	Active
	Burns Harbor	C	1,994,094	Active
		D	2,099,156	Active
	Cleveland	5	1,363,887	Active
		6	1,283,385	Active
	Indiana Harbor	IH-3	1,569,919	Active
		IH-4	1,586,533	Active
		IH-5	0	Inactive
		IH-6	0	Inactive
		IH-7	2,614,394	Active
	Lazaro Cardenas	1	1,269,706	Active

Source: AIST, Iron and Steel Technology, March 2015, pp. 294-297

North American Blast Furnaces

Company	Division	Furnace Identifier	2014 Production	Status
AK Steel	Ashland	Amanda	1,141,306	Active
	Middletown	3	2,016,073	Active
Merger Acquisition	Dearborn	C	1,933,888	Active
AHMSA		5	2,441,826	Active
		6	1,566,947	Active
Essar	Algoma	6	0	Inactive
		7	2,105,565	Active
RG Steel (now Closed)	Sparrow Point	L	0	Inactive
	Warren	1	0	Inactive
	Steubenville	5	0	Inactive
Republic Steel (New EAF)	Lorrain	4	0	Inactive

Source: AIST

North American Blast Furnaces

Company	Division	Furnace Identifier	2014 Production	Status
US Steel	Fairfield	8	1,726,870	Active
	Gary	4	990,848	Active
	Gary	6	961,941	Active
	Gary	8	873,044	Active
	Gary	14	2,227,704	Active
	Granite City	A	855,863	Active
	Granite City	B	1,042,020	Active
	Great Lakes	B	1,112,340	Active
	Great Lakes	D	861,328	Active
	Mon Valley	1	987,488	Active
	Mon Valley	3	1,073,454	Active

New EAF Being Installed

WARN Notices

Source: AIST

Capacity Shut Down in Last 10 Years

Total Blast Furnace Capacity Idled or to be idled (10): 14,140,000 mt/y

- **Iron Ore no longer Needed: 20,503,000 mt/y**

Granite City Shut Down: A and B furnaces

- **Location: Granite City, Illinois**
- **2014 Production: 1,898,000 mt**
- **Potential Iron Ore Loss if they remain down: 2,750,000 mt/y**

Announced Future Shut Down: Fairfield No. 8

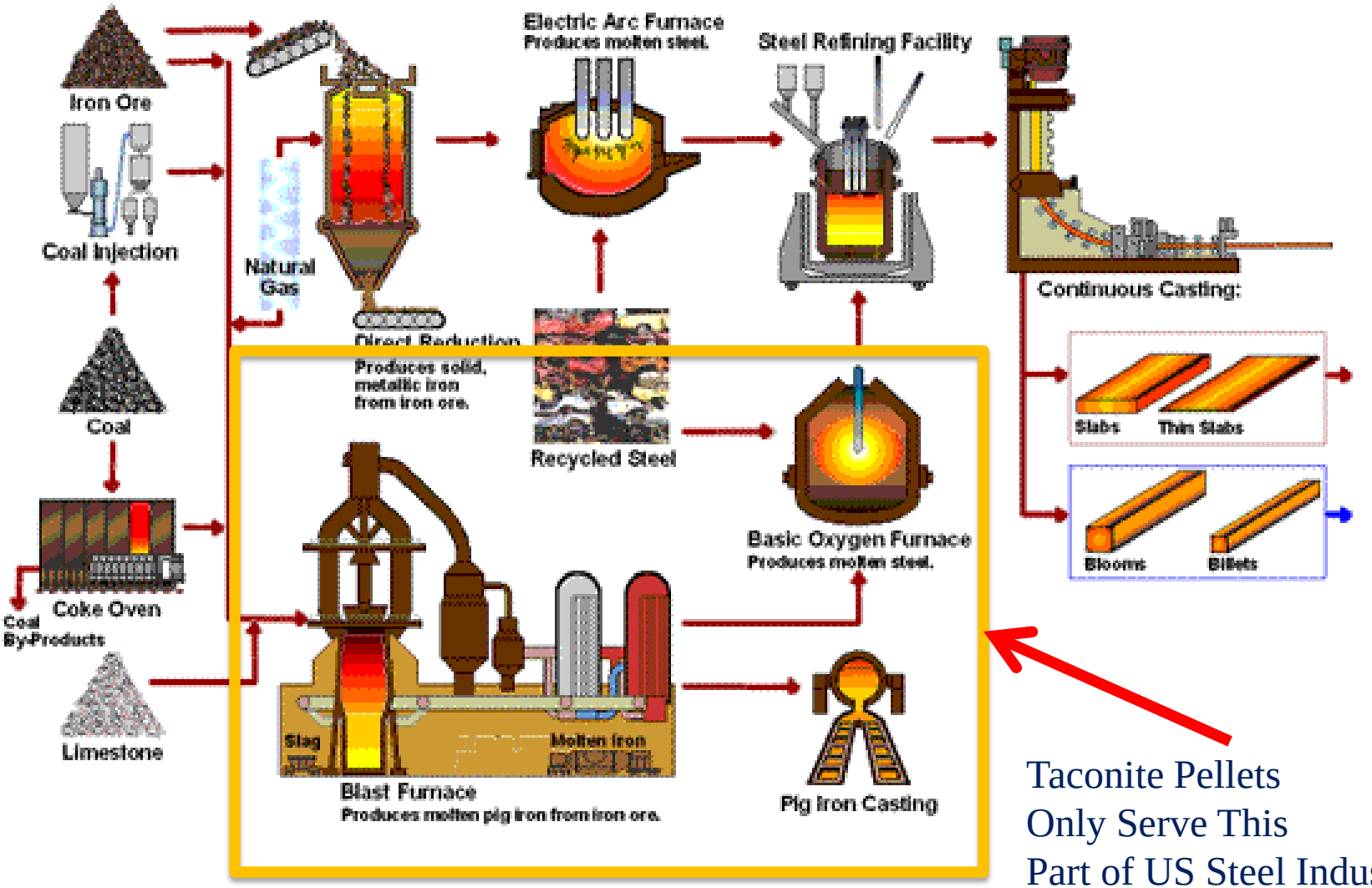
- **Location: Birmingham, Alabama (USS)**
- **2014 Production: 1,726,870 mt**
- **Potential Iron Ore Loss after Closure: 2,500,000 mt/y**
- **Total included in iron ore no longer needed**

Steel Production by Production Type in USA

Year	EAF	BF-BOF	Total	% EAF	Yr to Yr GR
2001	42,745,000	47,359,000	90,104,000	47.4%	Base
2002	46,124,000	45,463,000	91,587,000	50.4%	1.6%
2003	47,804,000	45,873,000	93,677,000	51.0%	2.3%
2004	51,968,000	47,713,000	99,681,000	52.1%	6.4%
2005	52,193,000	42,704,000	94,897,000	55.0%	-4.8%
2006	56,098,000	42,458,000	98,556,000	56.9%	3.9%
2007	57,003,000	41,098,000	98,101,000	58.1%	-0.5%
2008	53,062,000	38,288,000	91,350,000	58.1%	-6.9%
2009	35,933,000	22,263,000	58,196,000	61.7%	-36.3%
2010	49,338,000	31,157,000	80,495,000	61.3%	38.3%
2011	52,107,000	34,290,000	86,398,000	60.3%	7.1%
2012	52,414,000	36,281,000	88,695,000	59.1%	2.7%
2013	52,641,000	34,237,000	86,878,000	61%	-2%
2014	55,197,000	33,859,000	88,174,000	62.6%	1.5%

Source: worldsteel.org

Processes Used to Make Steel



Taconite Pellets Only Serve This Part of US Steel Industry

www.steel.org/Making Steel/How Its Made/Steelmaking Flowlines.aspx

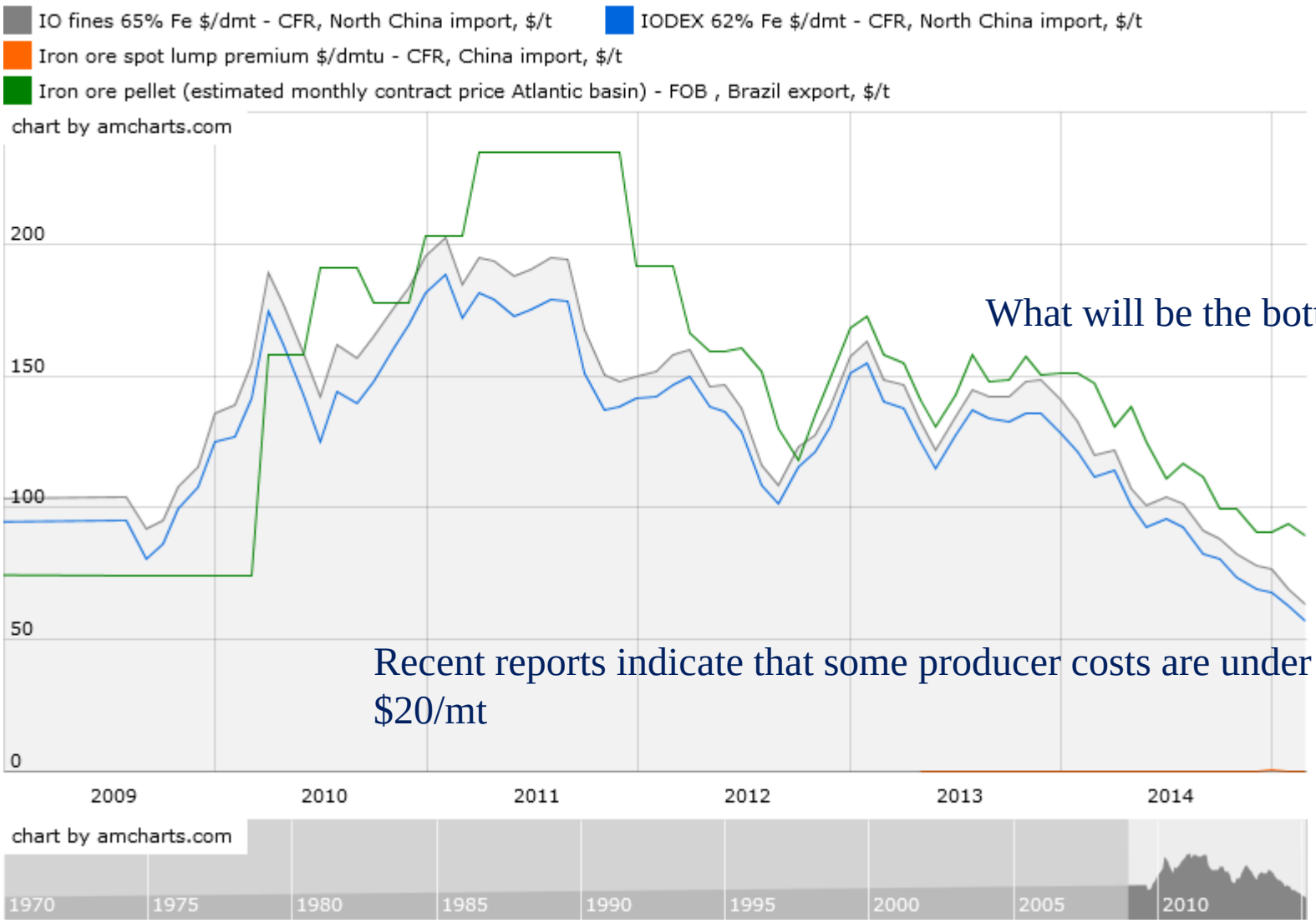
Electric Furnace Steelmaking (EAF) is Dominant in USA

- As can be seen in the previous chart, EAF steel production is approaching 2/3 of US production
- If Fairfield switch to EAF is completed, it will be over 2/3 of production

➢ **Taconite pellets in current form do not serve this large segment of North American Industry!**

- Certain EAF steel companies are looking for scrap substitutes to supplement scrap: Nucor and SDI
- Nucor has indicated that metallized iron is targeted for 30% of their metallic charge

World Pricing for Iron Ore (Source: Platts)



What will be the bottom?

Recent reports indicate that some producer costs are under $20/mt

Other Reported Cost Comparisons

Other Reported Operating Costs FOB Mine site

PPI[1] March, 2005 = 115.1; December, 2014= 214.1 Company	2005 Cost per Tonne*	*Projected Cost December, 2014*
Minnesota Taconite	**$28.94**	**$53.83**
Tilden (MI)	**$29.19**	**$54.30**
Iron Ore of Canada	**$30.39**	**$56.53**
United Taconite (MN)	**$30.85**	**$57.38**
Keewatin Taconite (MN)	**$31.10**	**$57.85**
Minorca Mine (MN)	**$31.83**	**$59.21**
Northshore Mining (MN)	**$32.04**	**$59.60**
Hibbing Taconite (MN)	**$33.08**	**$61.53**
Empire Mines (MI)	**$33.24**	**$61.83**
Quebec Cartier (Canada)	**$33.81**	**$62.89**
Wabush Mines (Canada)	**$33.95**	**$63.15**

*Source: Iron Ore Booming: More Growth Ahead, Peter J. Kakela, Dec. 2005

[1]: http://www.bls.gov/news.release/archives/ppi_04192005.pdf
http://download.bls.gov/pub/time.series/pc/pc.data.2.Mining

Cost Estimates for Various Producers

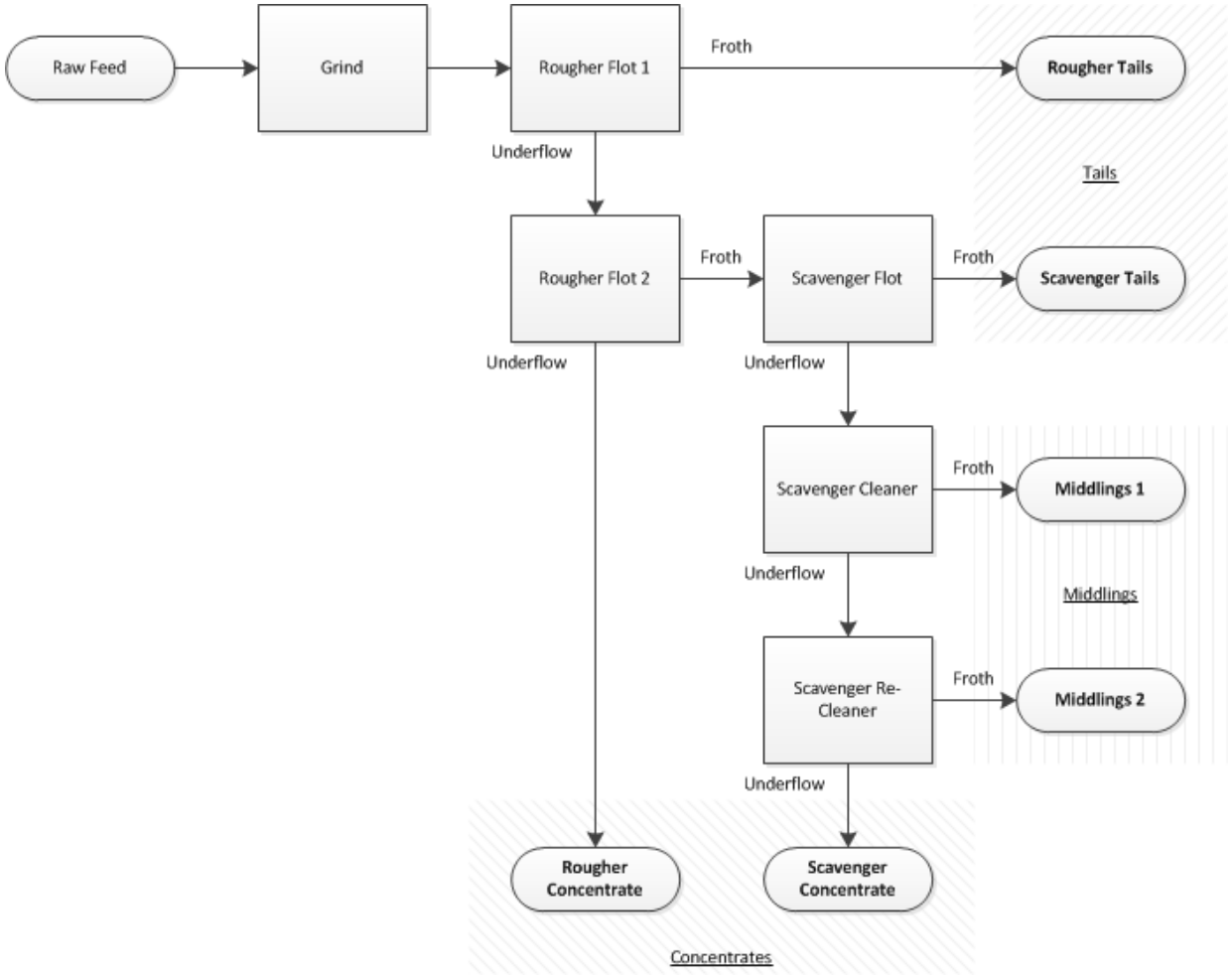
Producer	Estimated Cost per mt
Minnesota/Michigan Operations	$53 to $61 as pellets
Projected Labrador Trough	$30-$35 as pellets
Australian	$15 to $25 as sinter feed
Brazilian	$15 to $25 as sinter feed

How do we stop this bad news?

- ✓ Develop more efficient processing for our mines
- ✓ Capture value from all rock that is mined
- ✓ Add value to the iron ore that is shipped
- ✓ Convert some portion of our ore to materials that are needed by EAF industry
- ✓ Take advantage of energy situation by producing direct reduced iron or other advanced metallics

Reduce Costs of Iron Ore Production

Recover more iron from the Rock we process – modify existing processing to recover various iron containing minerals



Use more of our legacy resources

Capture iron Values from Existing Lean ore Piles

- Implement processing techniques to reclaim iron values
- Elimination of piled rock will ease sulfate related water issues
- Take advantage of already mined materials to reduce mining costs -- concentrator plants modified to accommodate different iron oxide minerals
- Magnetation already capturing iron values from tailings

Capture More Value from By-Product Rock

Encourage MNDOT to use taconite aggregate in state-wide road construction – *NRRI data characterizes as a superior material for highway use*

- **Wear course – high durability, less need to reconstruct roads**
- **Excellent friction properties for safer winter driving**

Market specialty products using by-product rocks

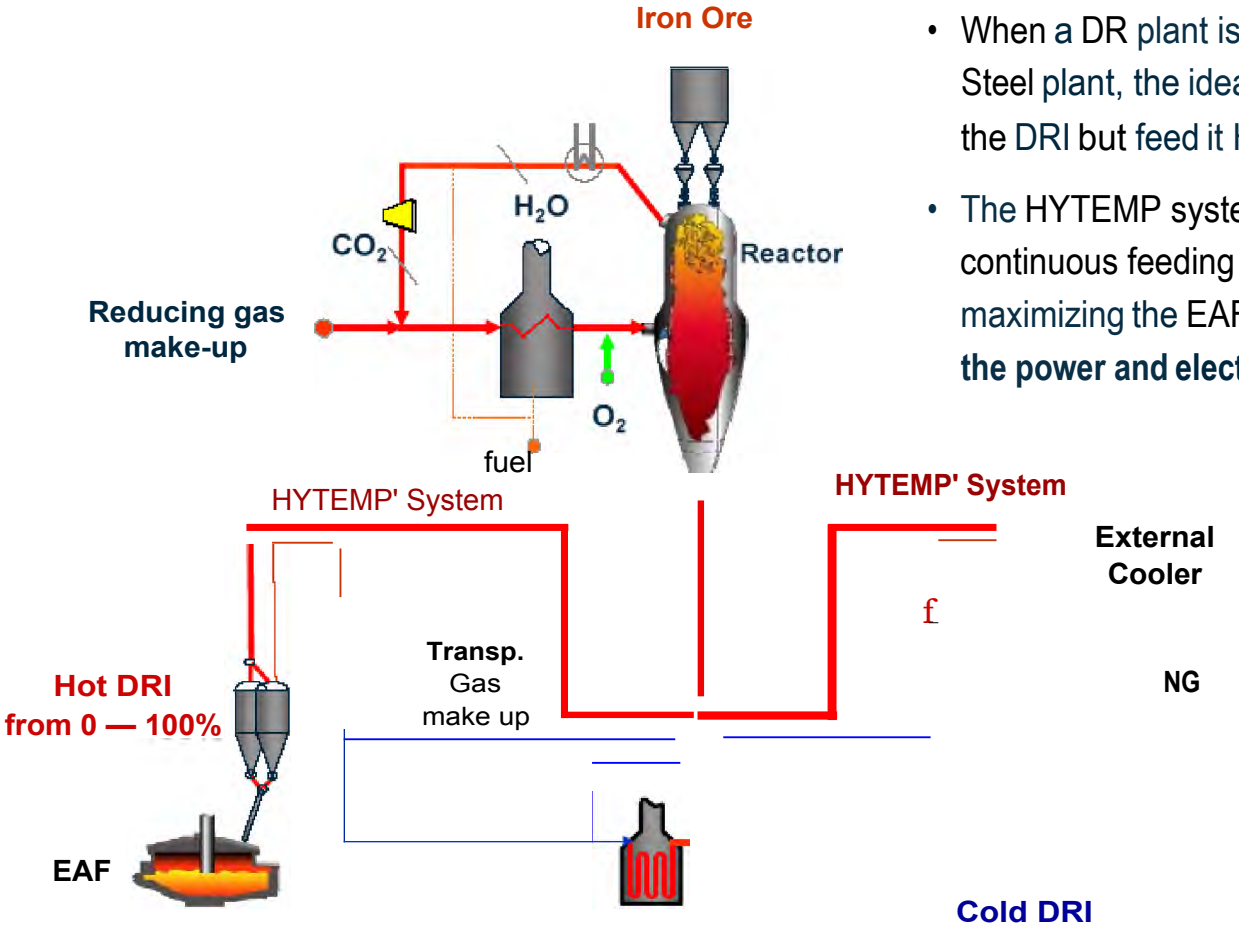
- **High temperature insulation**
- **Substitution of silica and iron oxides needed for portland cement manufacture**
- **Pot hole repair compounds using taconite based rocks**

Add Value to the Iron We Ship

Make products that can serve the EAF industry!

- **Produce EAF grade iron ore for conversion into DRI**
- **Produce EAF grade iron ore and install DRI capacity at our mines (Take Advantage of Natural Gas Situation) and sell product to EAF customers**
- **Make DRI and sell as scrap substitute to current customers**
- **Install DRI capacity & smelt the DRI to make marketable pig iron product**
- **Install DRI capacity at our mines and subsequently nuggetize the DRI using technologies to produce gangue free EAF charge materials**

Nucor Steel Adopted the ENERGIRON Process



- When a DR plant is located inside an integrated Steel plant, the ideal condition is not to cool down the DRI but feed it Hot to the EAF.
- The HYTEMP system takes full advantage of the continuous feeding of Hot DRI to an EAF maximizing the EAF productivity and minimizing **the power and electrodes** consumption.

Typical annual production ratio hot DRI/cold DRI: 90-95%/10-5%

ENERGIRON
THE INNOSATIVE DIRECT REDUCTION TECHNOLOGY

Estimating the Cost to Produce DRI Based On Energiron Process Using Keetac Pellets

Estimated Production Cost for 1 Metric Ton of DRI Using EAF Grade

Item	Unit	Consumption /t DRI	$Cost/Unit	Item Cost
Iron Ore Pellets	t	1.5	58	$87
Natural Gas	Gcal	2.4	15.9	$38
Oxygen	Nm^3	54	0.05	$2.70
Nitrogen	Nm^3	22	0.03	$0.66
Electricity Core including Materials Handling	kWh	77	0.07	$5.39
Electricity Auxiliary Facilities	kWh	13	0.07	$0.91
Water	m3	1.2	1	$1.20
Labor	m-h	0.15	25	$3.75
Total Estimated Cost				*$140*

Unit inputs based on Tenova HYL Brochure

Comparison of Steel Heat Costs for EAF

	Using Market Iron for DRI Production	Using Keetac pellets for DRI Production
All Scrap	**$315/t**	**$315/t**
30% DRI Use	**$307/t**	**$294/t**
95% DRI use	**$290/t**	**$249/t**

The 95% Use Level is most efficient if steel conversion is at the DRI production facility. If at the mine, Logistical costs would also be reduced. At the 95% level, and foamy slag practices very ductile steel can be routinely produced.

Ongoing Work at NRRI

- New processing for capturing iron lost (Can be Done)
- Produce new grades of iron concentrate (Can Be Done)
- Develop new value added processing strategy for region (Under study with key partners)
- Get revenue from waste rock from aggregate uses (shipments now well over 1 Million tons per year and growing)
- Use legacy resources to ***drive down*** mining costs (actively developing)
- Recover other key mineral values in Arrowhead region to diversify mining while protecting the environment (ilmenite and non-ferrous)
- Make final products in our region (new steel plant concepts under investigation)

Steps to enhance Minnesota iron mining

Reduction of mining cost

- ✓ enhanced iron yield from harvest of both hematite and magnetite

Diversify product mix

- ✓ transition to value-added metalized products
  - participate across the US steel industry (BF + **EAF**)
- ✓ produce DR-grade pellets as initial step
- ✓ develop heat-efficient DRI process
  - take advantage of low price natural gas
- ✓ capitalize on product quality
  - provide flexibility to EAF customers
- ✓ provide secondary product support – *immediate impact*
  - high quality aggregate for use in highway surfaces

Define new opportunities

- ✓ Lean ore stockpile reclamation
- ✓ Ilmenite ore demonstration
- ✓ Other non-ferrous

Thank You

Natural Resources Research Institute

UNIVERSITY OF MINNESOTA DULUTH

Driven to Discover