COARSE DRY COAL CLEANING

R. Q. Honaker

University of Kentucky
Department of Mining Engineering
Lexington, Kentucky, USA 40506-0107

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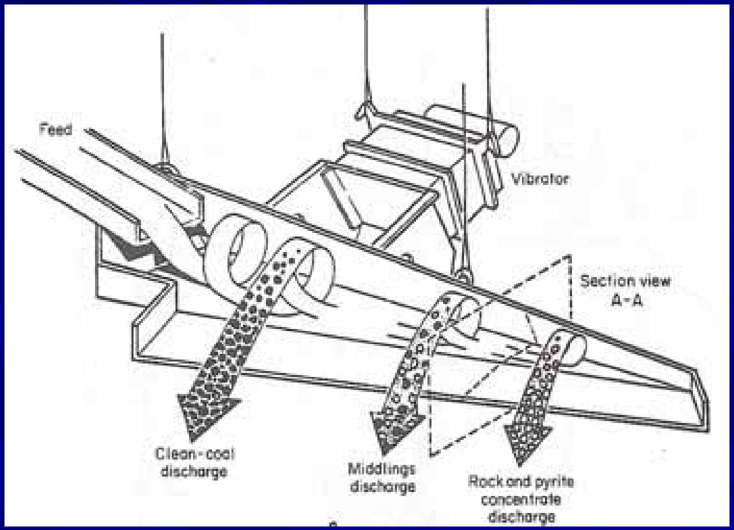
U.S. Dry Coal Cleaning History

- Dry coal cleaning was popular from 1930 – 1990.
- Peak production was 25.4 million tons annually in 1965.
- Largest all-air cleaning plant was 1400 tph in Pennsylvania (1968).
- Several commercial technologies developed in the period of 1900 – 1950.
- Decline was due to the need for efficient low density cuts and environmental health concerns (underground & surface).
- Recent U.S. resurgence is in large part due to the need to reduce transportation costs and clean western U.S coals.
- Alminerals modified the Stomp jig to provide a completely automated commercial unit.
- Allair jig has been commercially successful (Mining Engineering, 2007).

FMC Separator (1940)



Alminerals Allair Jig

Potential Dry Cleaning Applications

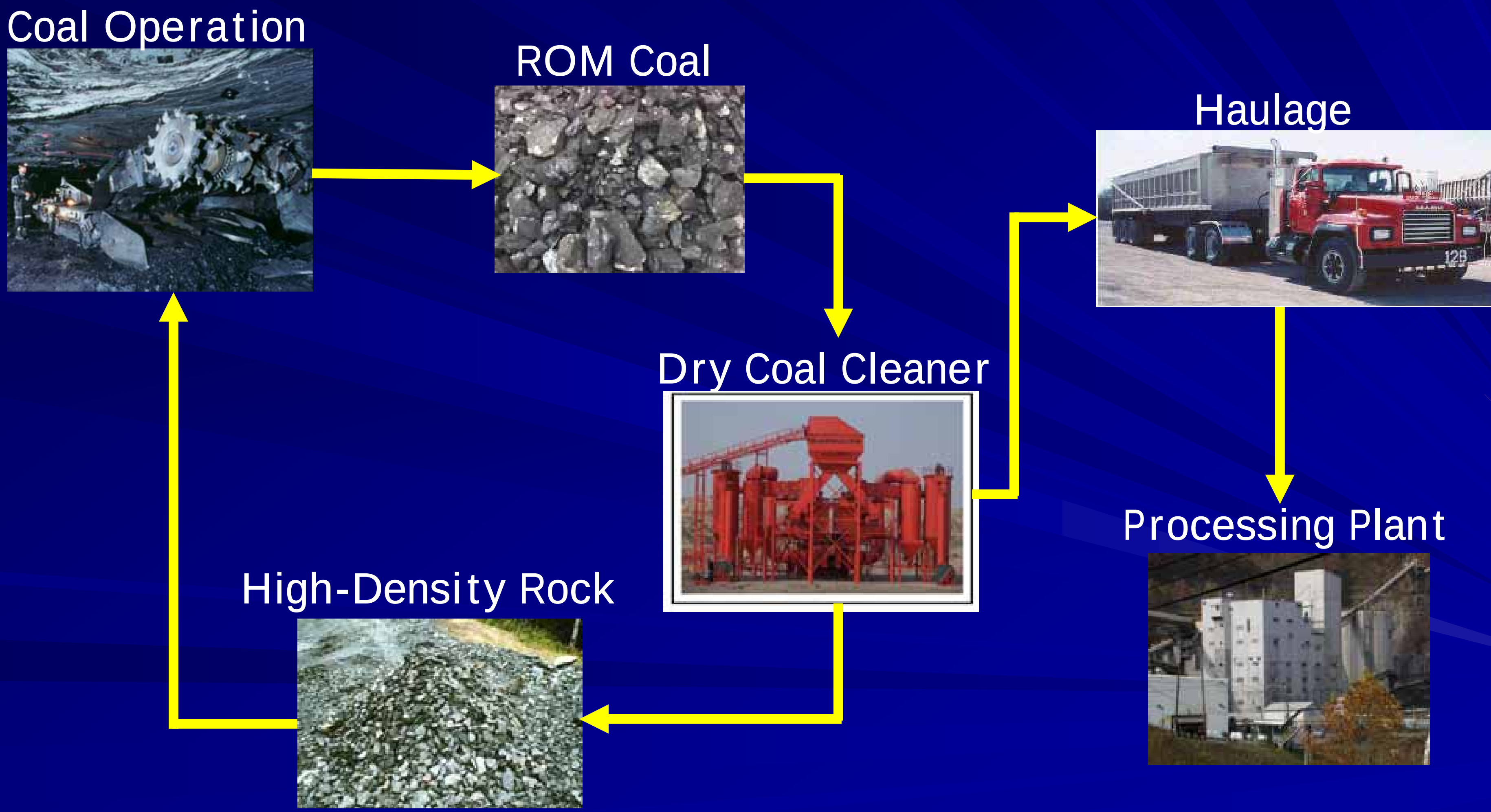
- Dry coal cleaning technologies effectively achieve density separations > 1.85 RD.
- Separations at relatively high densities to remove 'nearly' pure rock is referred to as ***deshaling***.
- Dry deshaling technologies are less expensive than wet cleaning processes:
  - Capital Cost: $6,200/tph versus $13,000/tph
  - Operating Cost: $0.50/ton versus $1.95/ton.
- Deshaling can be applied at the mine site prior to loading and transportation to the end user.

ROM Coal

Dry Coal Cleaning Technology

High-Density Rock

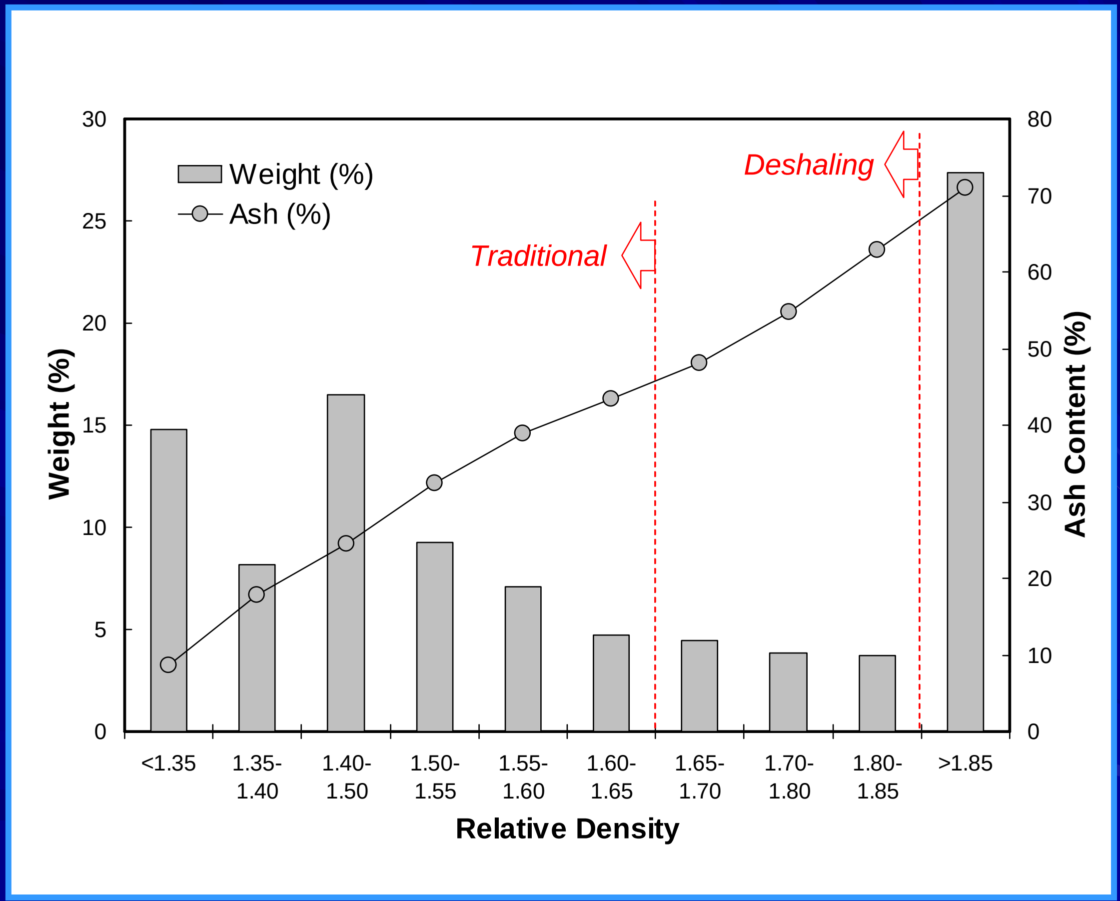
Coal Deshaling Concept



Dry Coal Cleaning Applications in India

- Many coals located <1000 km away from the utility are not cleaned.
- As a result, 40%-45% ash coals are transported and used in utilities designed for 25%-35% ash coal.
- For a relatively easy-to-clean India coal, dry cleaning has the ability to reduce the ash from 41% to 30%.

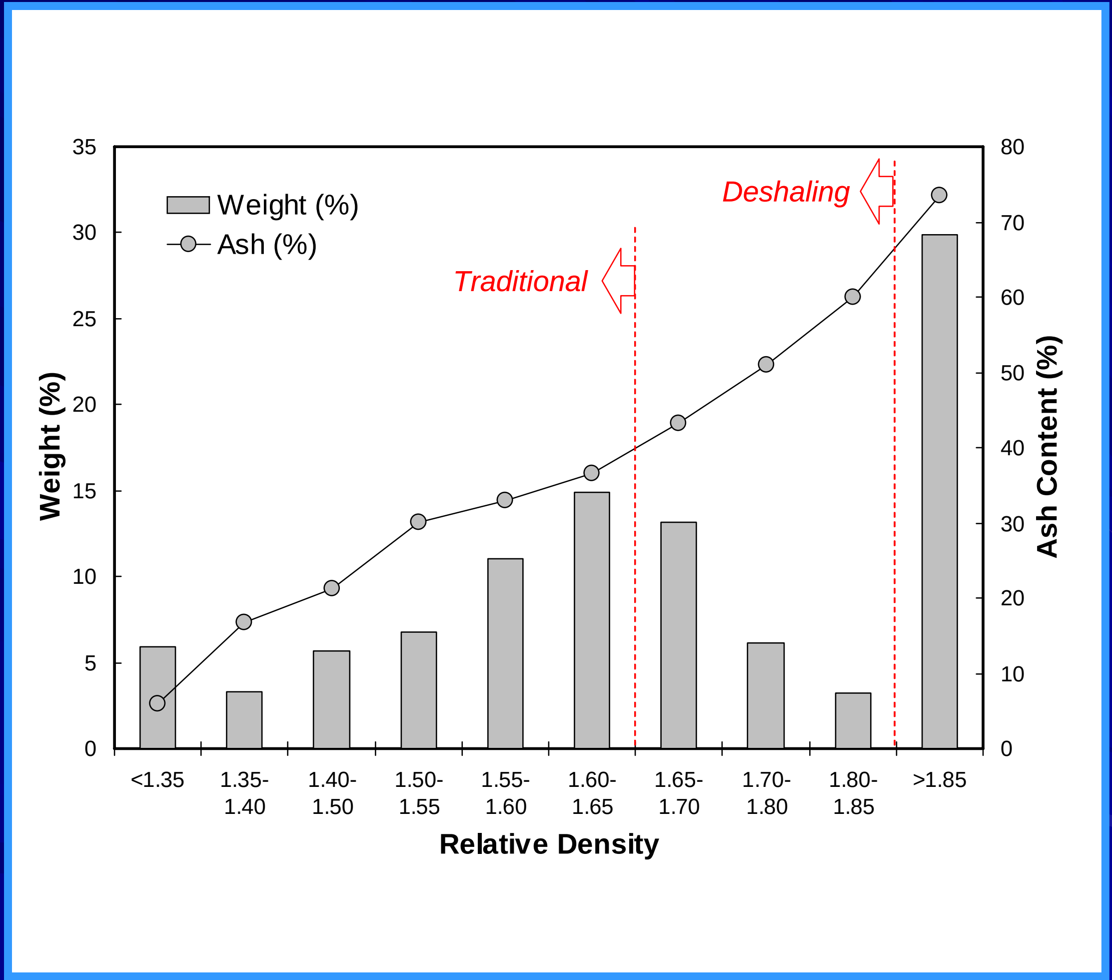
Easy-to-Clean India Coal



Difficult-to-Clean Coal Application

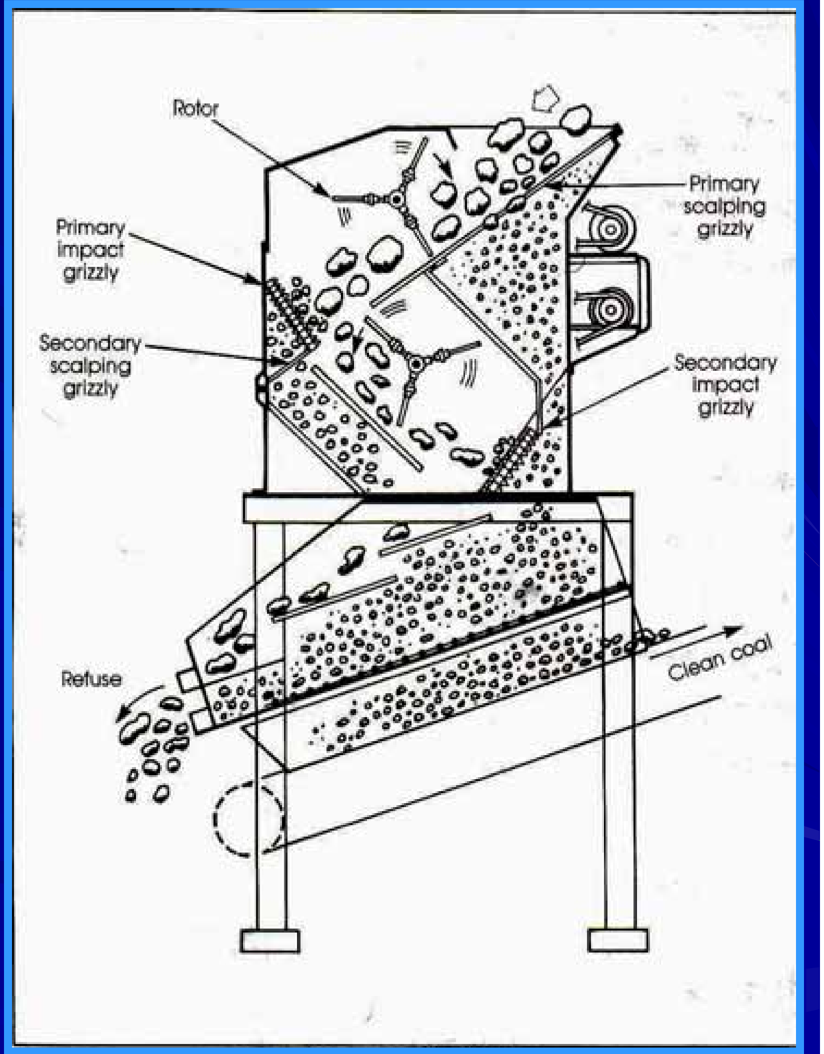
- Most India coals have cleaning characteristics that are difficult.
- The most efficient wet-based coarse cleaning technologies have difficulty in achieving effective ash reduction.
- Dry deshaling concentrates on the density fractions that are easy to remove.
- Using deshaling, ash reduction for a difficult coal could be from 45% to 34%.

Difficult-to-Clean India Coal

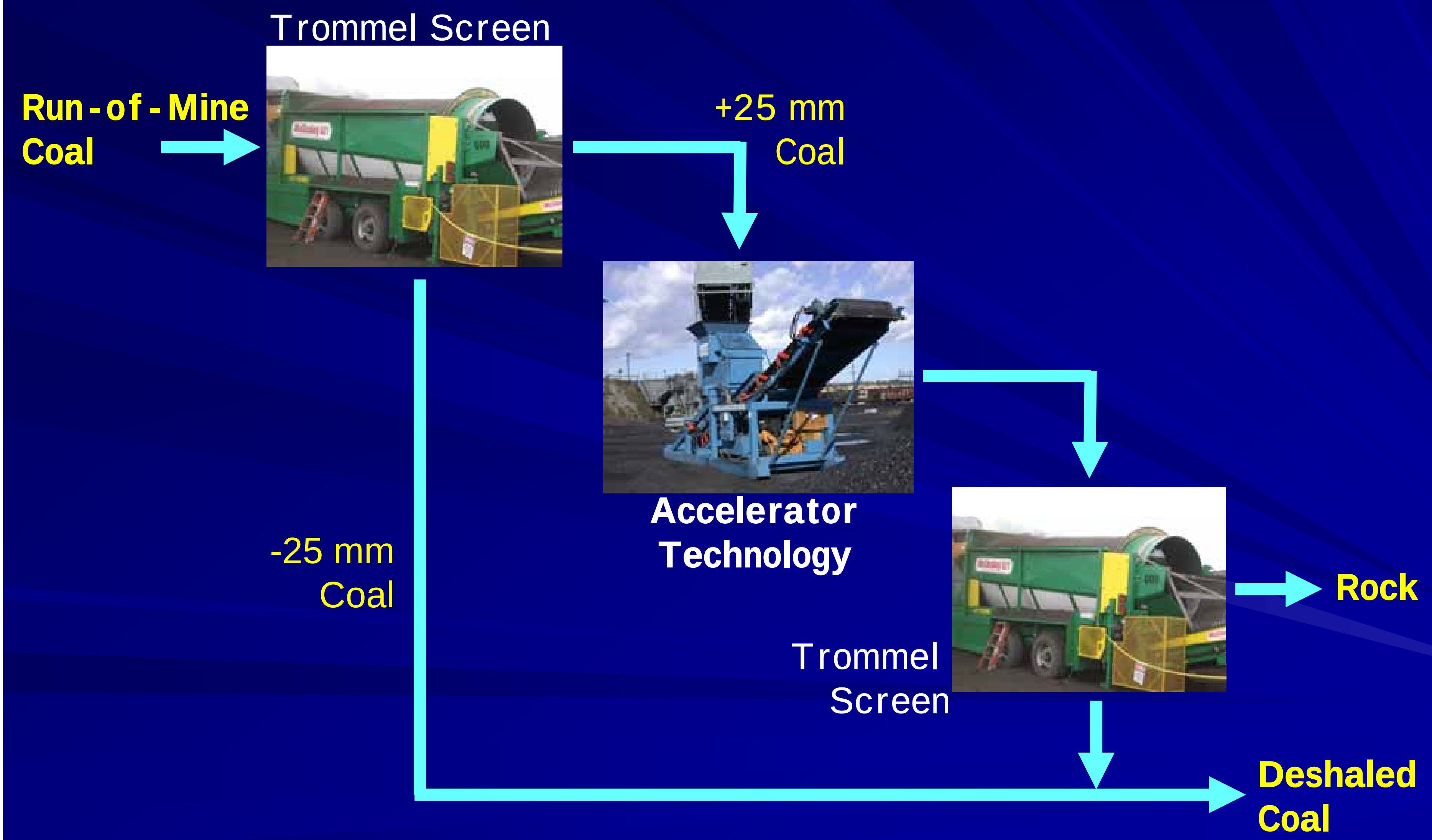


Accelerator Technology

- Selective breakage technology.
- Unlike the Rotary Breaker, the amount of breakage can be operator controlled.
- Reduces 250 x 25 mm ROM coal to a more uniform -25 mm product.
- The raw material passes across a scalping grizzly to bypass coal finer than 25 mm.
- The remaining material is then propelled by variable-speed rotor assemblies into pointed impact-sizing grids.
- Coal that has fractured to a 25mm size then passes through a second scalping grizzly.
- The remaining material is hurled by the second rotor assembly into another set of impact grids.



Accelerator Application



U.S. Bituminous Coal Results

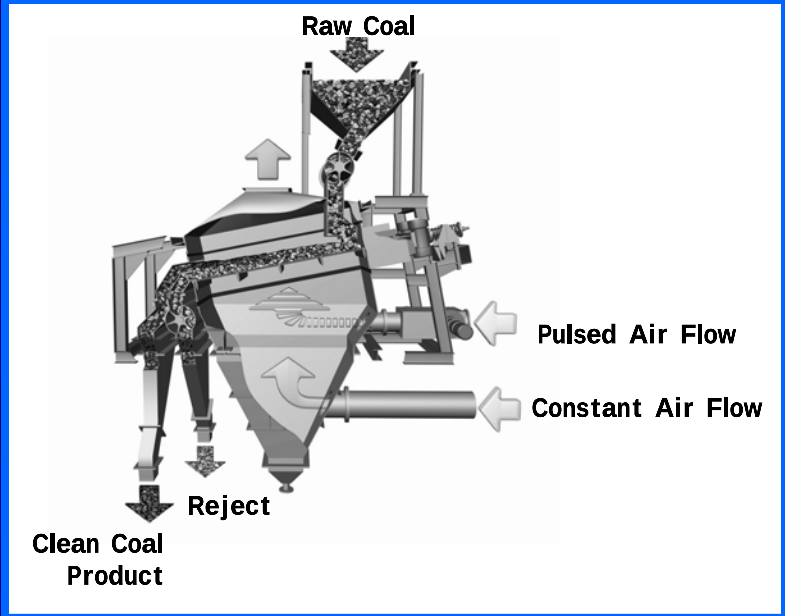
Hazard No. 4 Seam Coal (Medium Volatile Bituminous)		
Size	Weight (%)	Ash (%)
+ 3"	10.62	96.62
3" x 2"	8.27	95.65
2" x 1"	40.40	86.92
1" x 1/2"	19.88	69.41
1/2" x 1/4"	9.35	64.94
1/4" x 0	11.48	61.69

Alma Seam Coal (Bituminous)		
Size	Weight (%)	Ash (%)
+ 3"	10.39	90.43
3" x 2"	12.74	87.88
2" x 1"	38.65	74.59
1" x 1/2"	17.45	58.56
1/2" x 1/4"	9.34	54.65
1/4" x 0	11.43	55.59

Results obtained from a 250 tph unit evaluated at various mine sites in central Appalachia.

All-Air Jig: Density-Based Separation

- The All-Air Jig is a unit modified from the Stomp Jig.
- Coal is fluidized by a constant flow of air across a perforated table.
- Pulsating air provides the jigging action.
- Nuclear density gauge used to assist the control of reject rate.
- Units up to 100 tph are available.



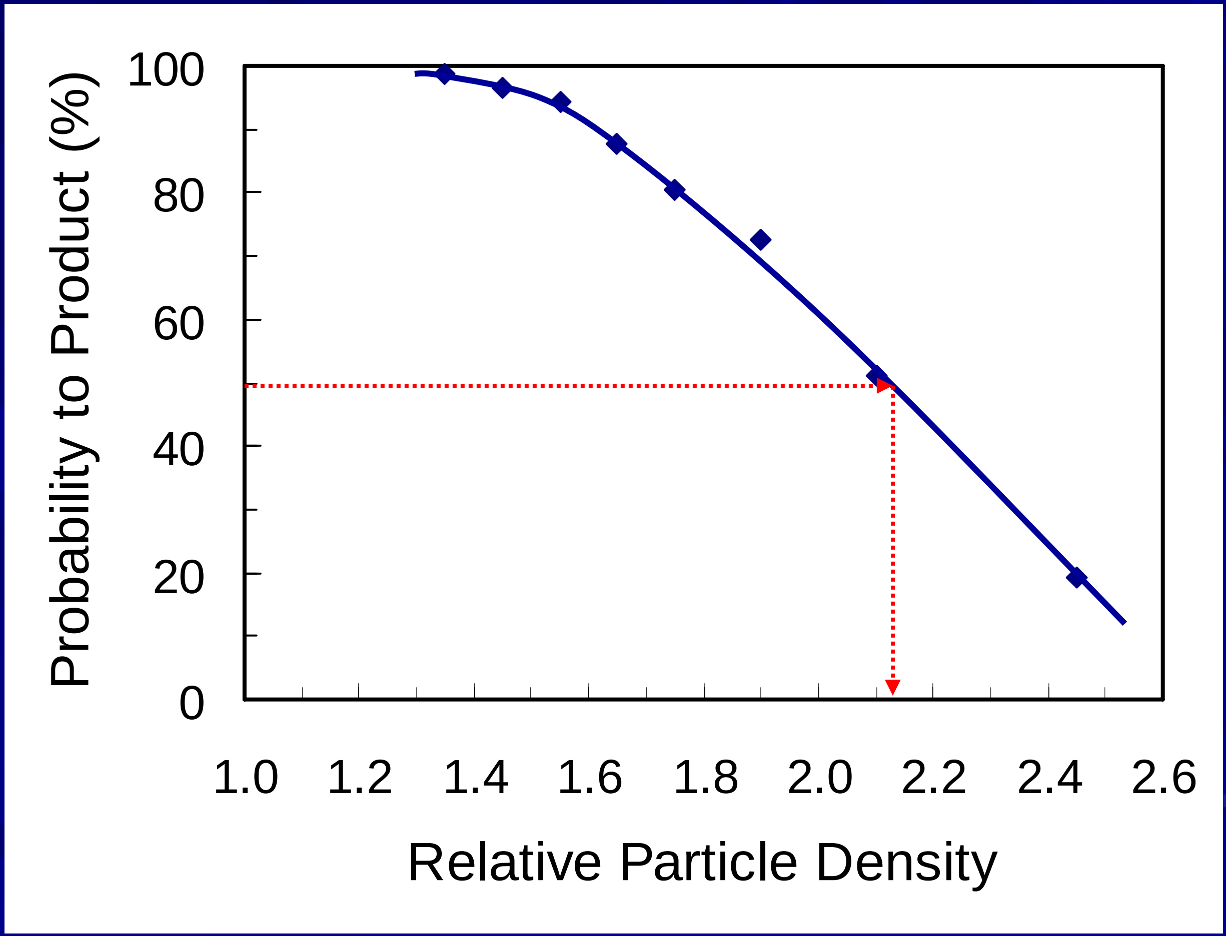
100 tph All-Air Jig Performance

Coal Type	Feed Ash (%)	Product Ash (%)	Tailings Ash (%)	Mass Yield (%)
1	23.93	13.73	68.12	81.10
2	10.14	7.37	49.89	93.49

Coal Type	Feed Sulfur (%)	Product Sulfur (%)	Tailings Sulfur (%)	Mass Yield (%)
1	6.05	3.77	8.06	81.10
2	4.33	3.17	22.79	93.49

All-Air Jig Partition Curve (50 tph Unit)

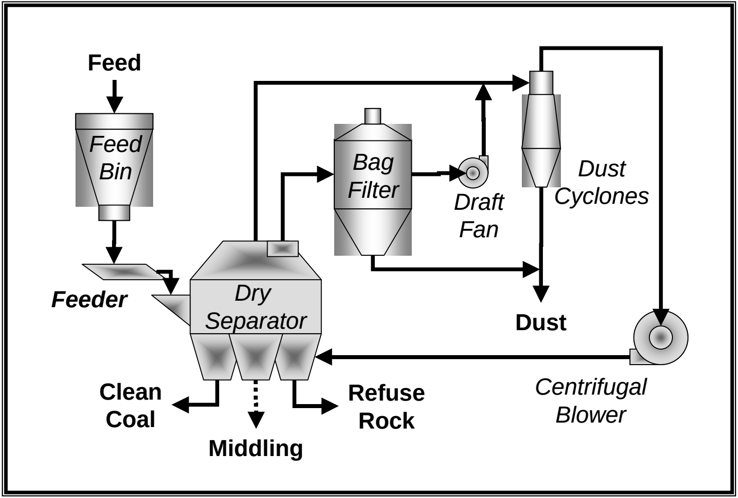
- Relative separation density = 2.12.
- Probable error = 0.26
- 82% rejection of high density rock.



FGX Separator

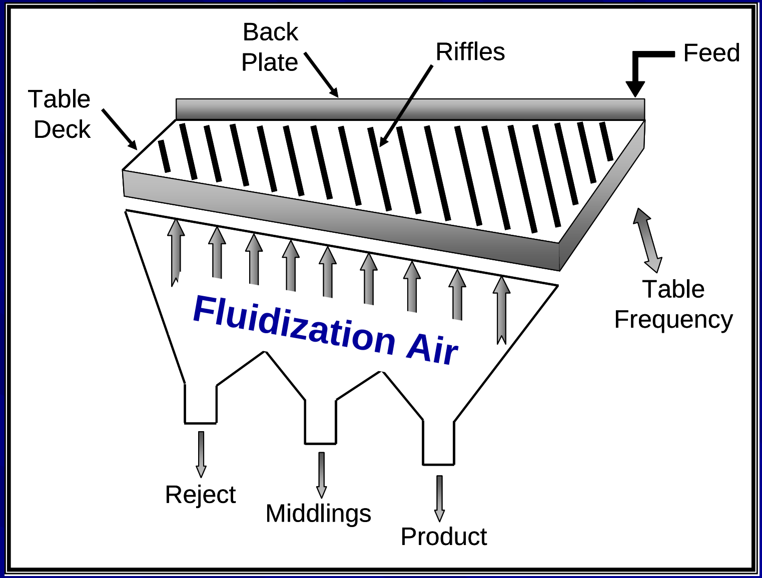
- Separation based on riffling table principles with air as medium.
- Processes 75 x 6 mm coal; however, -6 mm may cleaned separately.
- 10%-20% minus 6mm material needed as an autogenous medium.
- Less than 7% surface moisture.
- High separation densities; ~2.0 Relative Density (RD).
- Probable error (Ep) values between 0.2–0.3.
- Chinese Technology based on previous designs. (10 – 480 tph units).
- Eriez Manufacturing represents the technology in the U.S..

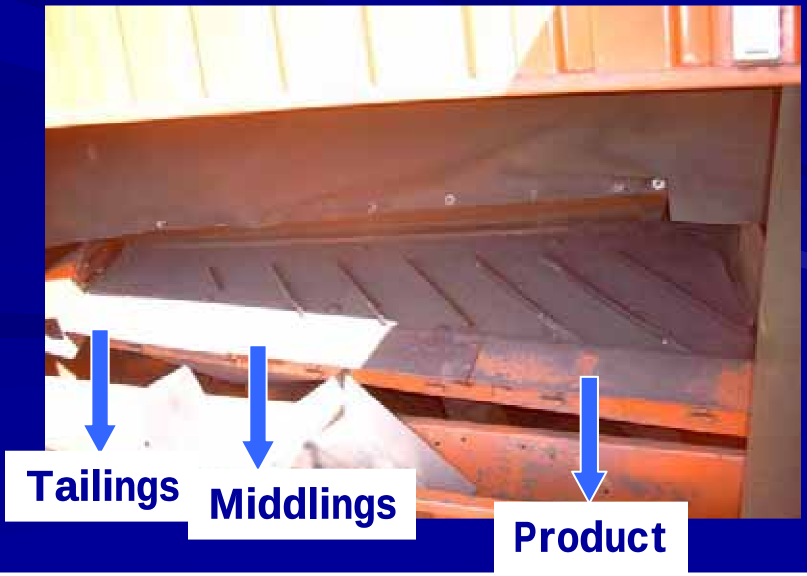
240 tph Commercial Unit



Operating Principles

- Feed enters the table from the far right corner.
- Fluidization air is injected through holes in the table.
- Light particles (coal) becomes fluidized with the assistance of autogenous medium (i.e., -6mm material)
- Fluidized coal is transported toward the front of the table and discharged on the right side.
- High-density material remains in contact with the table.
- Vibration motion moves the heavy material back and to the left.
- Product, middling and tailing streams can be generated.





Test Program

- 5 tph mobile FGX unit tested at each site.
- 1 m^2 table deck
- Coal was prescreened to achieve a 25 x 6 mm feed.
- Recent tests focused on - 25mm inch and 6mm coal cleaning.
- Parametric test design performed at each site.
- At several sites, the material exiting the table was split into six different fractions along the length of the table.

Central Appalachia Deshaling Evaluation

- Objective: Maximize the rejection of high density rock from run-of-mine coal prior to transportation.
- Mobile 5-tph Air Table tested.
- Run-of-Mine bituminous coal.
- Raw coal was prescreened at 6 mm.
- 15 tests performed over a range of operating conditions.
- Timed samples of feed, product, middlings and tailings stream.

FGX Deshaling Performance

Deshaling Performance: 33.5% Reject Rate

Test No.	Feed Ash (%)	Product Ash (%)	Middlings Ash (%)	Reject Ash (%)	Yield (%)
1	50.00	19.46	83.38	89.03	53.5
2	51.69	34.05	87.08	89.51	66.5
3	54.88	29.09	78.19	87.75	48.4
4	48.27	25.75	80.42	89.92	55.9
5	51.58	25.97	78.41	91.37	58.8
6	46.70	17.87	68.21	88.34	44.5
7	50.84	16.84	55.11	87.30	34.6
8	54.33	15.53	62.70	87.02	34.0
9	38.05	29.02	82.04	89.80	58.5
10	50.18	19.69	78.26	90.09	51.1
11	45.88	34.50	86.30	91.09	66.7
12	49.93	12.88	72.51	90.13	46.1
13	47.14	13.96	57.02	88.90	37.3
14	51.69	14.78	71.90	87.95	43.4
15	47.87	12.63	73.30	89.38	42.9
Aver.	49.27	21.47	74.32	89.17	49.5

Note the ability to reduce ash from 49.3% to 12.6%

Central Appalachia Bituminous Coal (Site No. 2)

- West Virginia underground coal containing around 60% ash.
- Yield to the reject & 1.6 RD float-sink performed.

Test Number	Middlings & Reject Combined		Reject Only	
	% of Feed	% Float 1.6 RD	% of Feed	% Float 1.6 RD
1	50.7	3.71	35.9	1.51
2	49.5	2.82	33.0	0.90
3	55.1	3.72	36.6	1.32
4	52.4	2.73	36.4	0.78

Economic Benefit

- Unit Capacity = 500 tph
- Yield to Reject = 36.4%
- Reject Amount = 500 x 0.364
  = 182 tph
- Annual Operating Hours
  = 6000 hrs/yr
- Total Reject left at mine
  = 182 tons/hr x 6000 hrs/yr
  = 1,092,000 tons

Transportation Savings

- Transportation Cost
  = 0.30 $/ton*mile
- Mine-to-Plant Distance
  = 20 miles
- Transportation Cost/ton
  = 20 x 0.30 = $6.00/ton
- Reduction in Tons Hauled
  = 1,092,000 tons/yr
- Annual Transportation Savings
  = 1,092,000 x $6 =
  = $6,552,000

Lost Coal Cost

- Total Deshaler Reject
  = 182 tons/hr
- % 1.60 Float in Reject
  = 0.78%
- Total Coal Loss
  = 182 x 0.0078 = 1.42 tph
- Annual Coal Loss
  = 1.42 x 6000 hrs/yr
  = 8518 tons
- Sales Price = $50/ton
- Lost Coal Cost
  = 8518 x 50 = $425,880/yr

Summary Economic Benefit

- FGX Operating Cost
  = $0.50/ton
- Annual Operating Cost
  = $0.50 x 500 x 6000
  = $1,500,000/yr

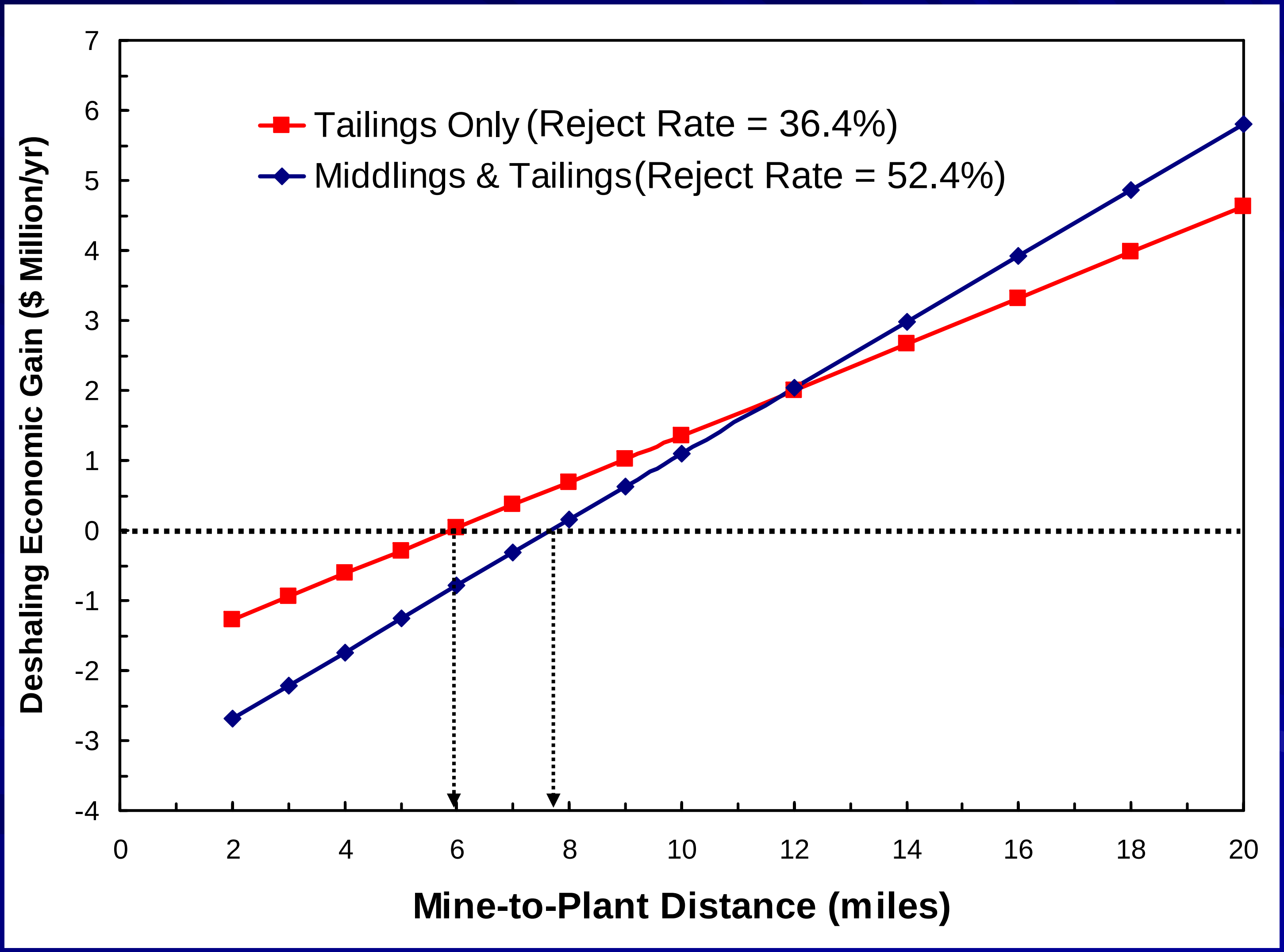
- Summary:

Transportation Savings = $6.55M
Coal Loss Cost = $0.43M
Operating Cost = $1.50M

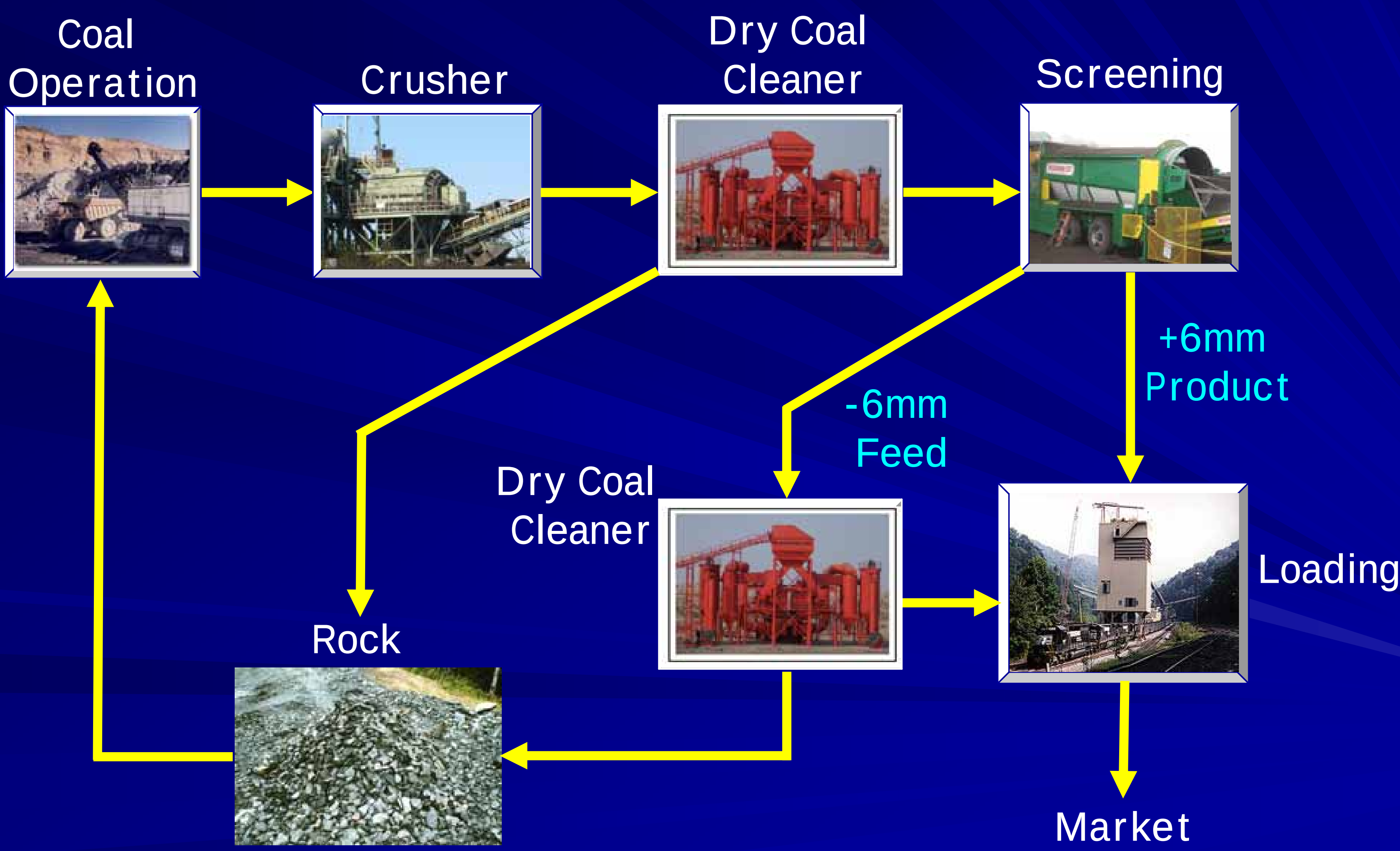
Net Profit Gain = $4.62M

Capitol Cost = $3200/tph
500 tph unit = $1.6 M

Economic Benefit vs. Haulage Distance

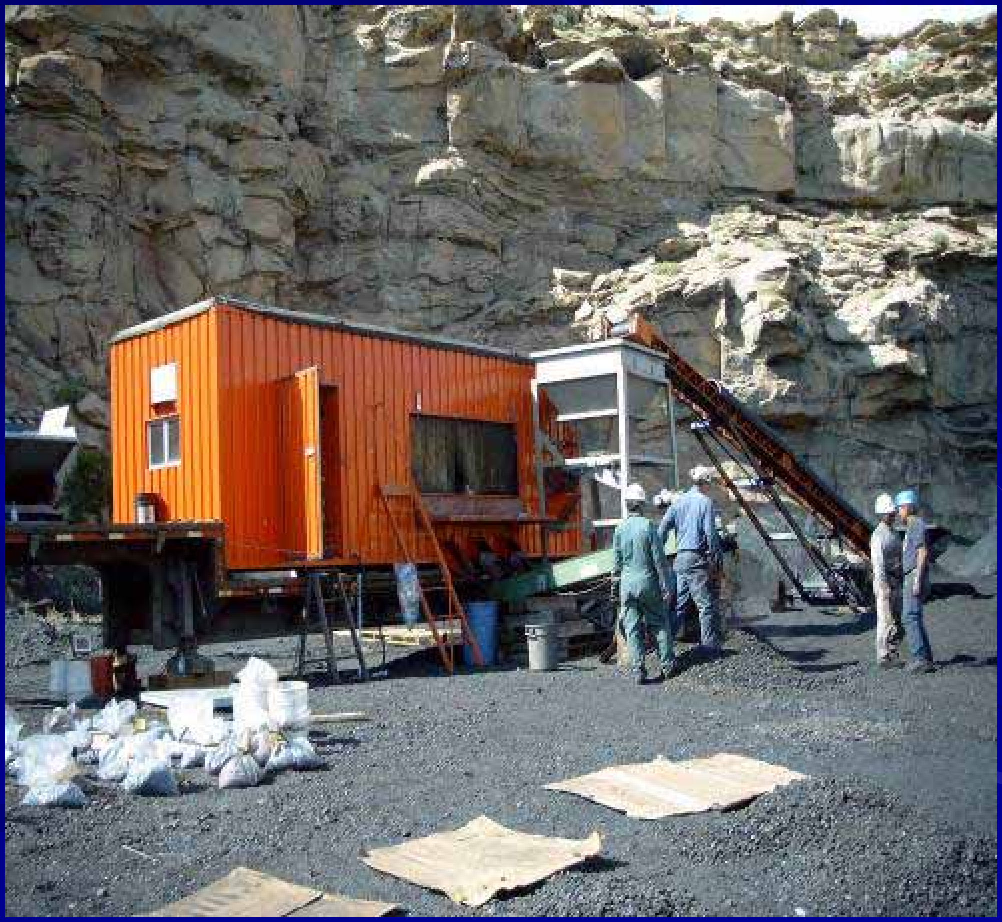


Production of Marketable Coal



Utah Bituminous Coal

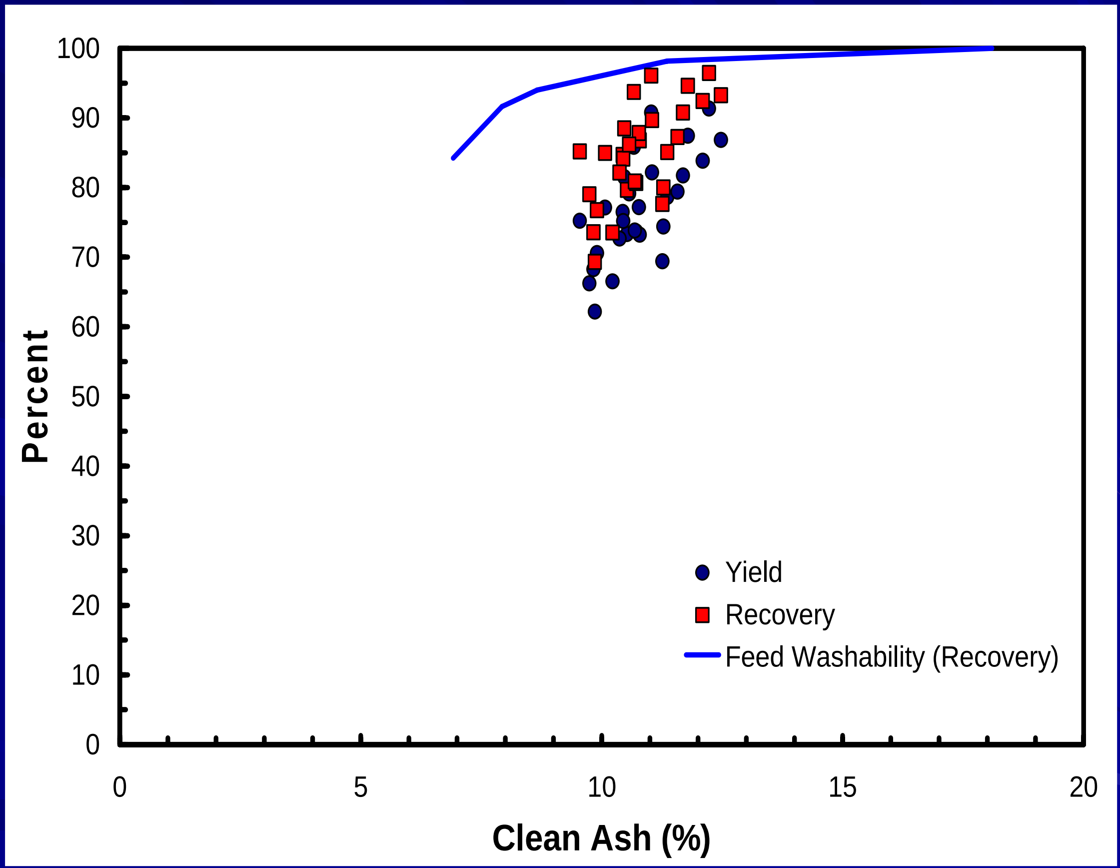
- In-field testing conducted at a bituminous coal mine.
- +6mm raw feed coal was treated.
- Objective: Produce a marketable product.
- Parametric test program was conducted to evaluate and optimize the operating parameters.



Mobile 5 tph FGX Unit and Test Setup

Utah Coal Performance

- 32 tests.
- 4 parameters evaluated.
- Average Feed Ash Content = 18.2%.
- Average Clean Coal Ash Content = 10.8%.
- Average Tailings Ash Content = 72.9%.
- Average Yield to the Product = 76.8%.

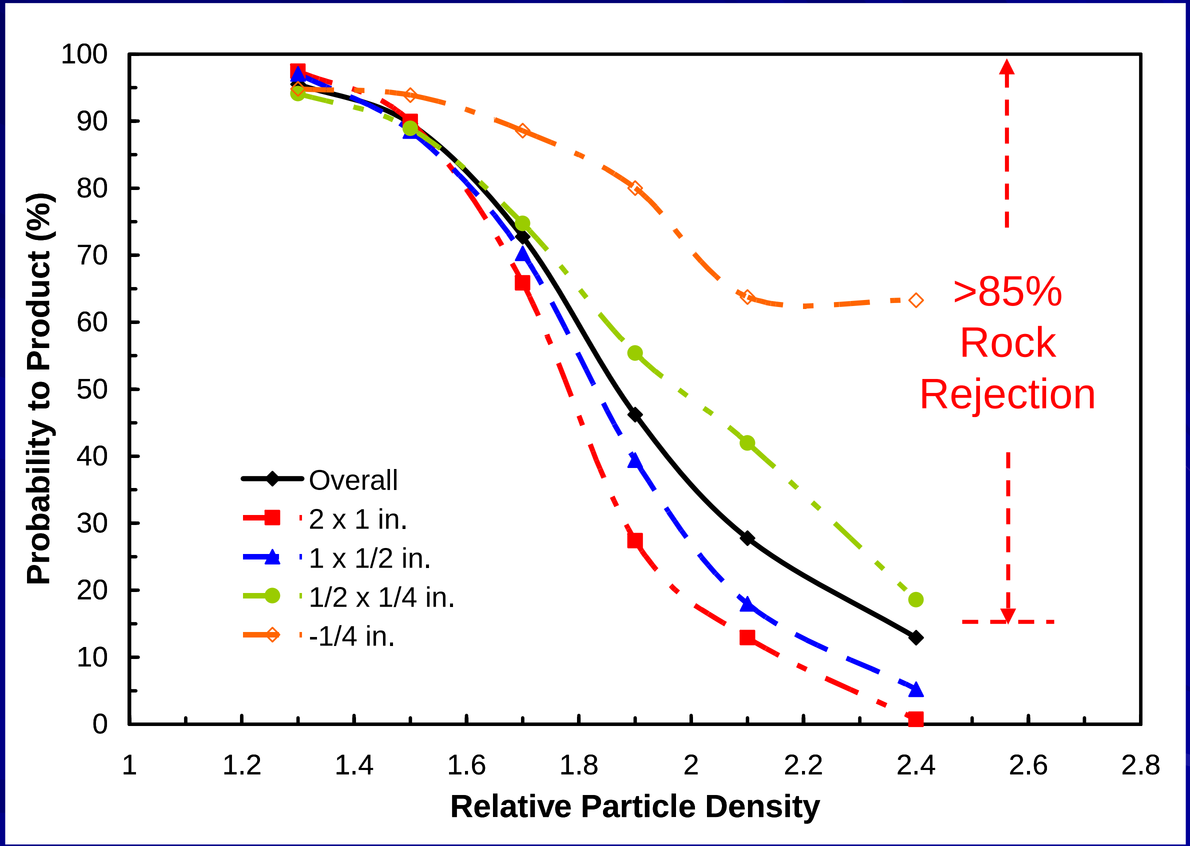


Middlings stream considered as part of tailings stream.

FGX Table Distribution

Size-by-Size Partition Curves

- ρ_{50} = 1.87 RD
- Ep = 0.24
- Small amount of 1.4 RD float material middlings stream reporting to tailings.
- Rock rejection >85%
- Improvement will be realized when middlings are recycled to the feed stream!



Middlings Recycle

Middlings Recycle

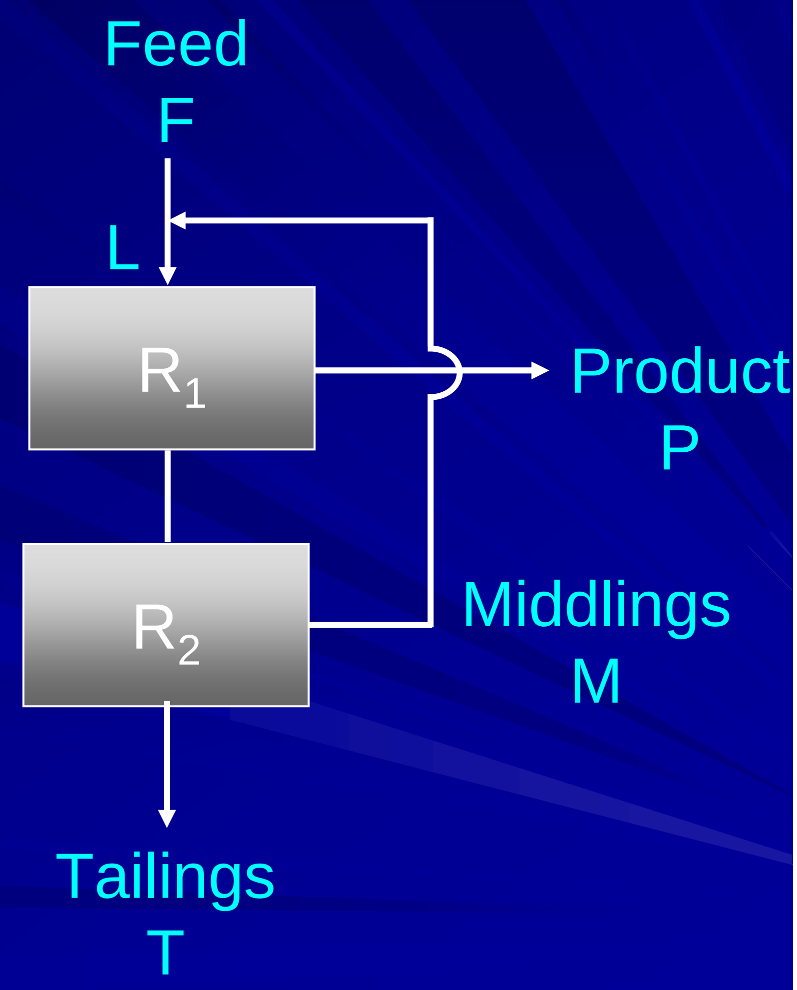
- To quantify the performance expected from middling recycle, linear analysis was performed.

$$P = LR_1$$

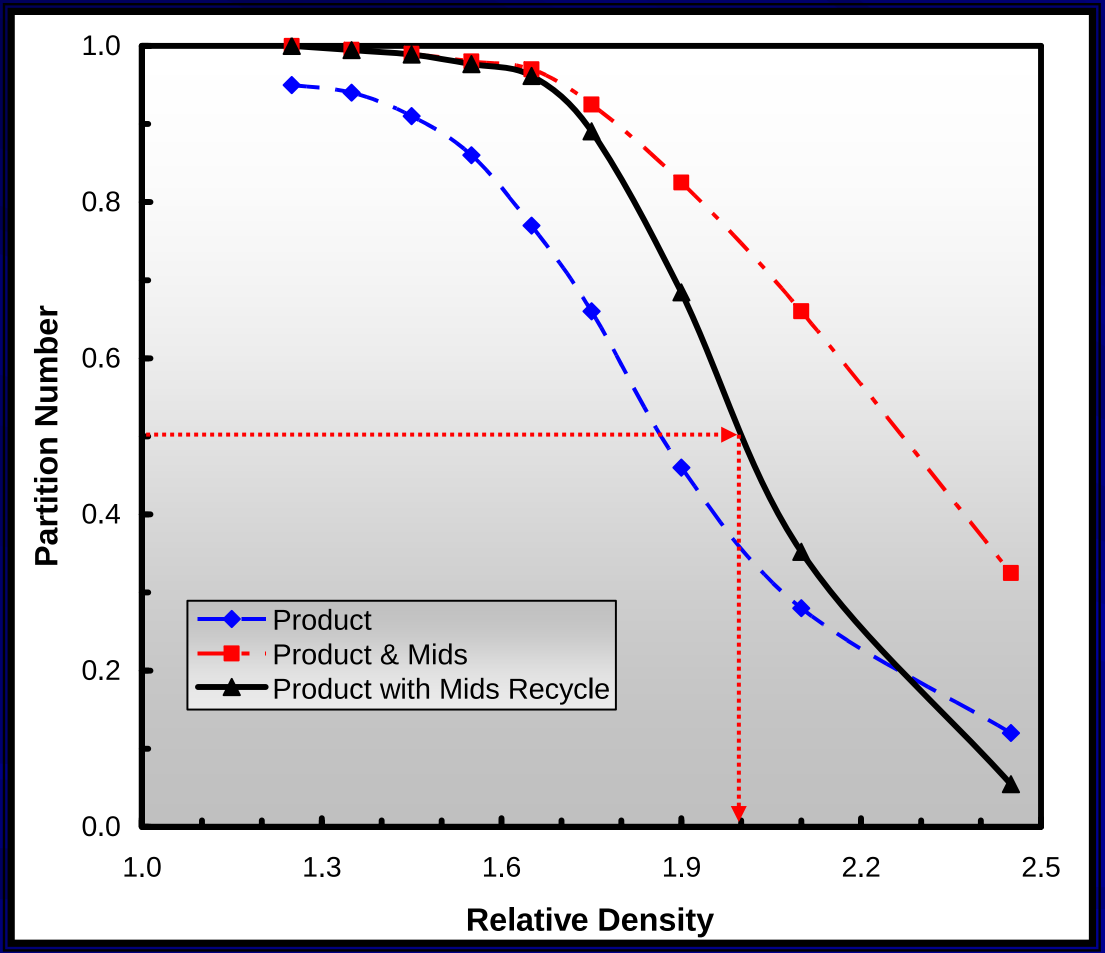
$$T = L(1 - R_1)(1 - R_2)$$

$$R_{overall} = \frac{P}{P+T} = \frac{R_1}{R_1 + (1 - R_1)(1 - R_2)}$$

where R_1 and R_2 are the probabilities of a particle reporting to the product and middlings stream, respectively.



Performance Scenarios



- Partition curves were generated from product, middlings and tailings data.
- The partition curves were based on two cases:
  - Product stream only to clean coal.
  - Product and middlings stream combined as clean coal.
- Linear analysis to evaluate Mids recycle revealed:
  - Density Separation = **2.0**
  - Probable Error = **0.17**

Powder River Basin Coal Application

- Sub-bituminous coal in the PRB is typically directly loaded without cleaning.
- During extraction, out-of-seam rock mixes with some coal on the rib. The contaminated coal is left in the pit.
- At a large operation, it is estimated that the amount of loss coal could total up to 10 million tons annually.
- Dry cleaning provides an opportunity for recovery.

Surface PRB Mine

Dry Coal Cleaner

End-Product

Sub-Bituminous Test Program

- Testing for cleaning sub-bituminous Powder River Basin Coal.
- Test program involved a parametric study of 15 tests.
- Six total samples splits were collected along the length of the table during each test.
- Thus, a yield versus product ash relationship was obtained for each test.
- Average feed ash content = 19.47%.
- Performance target was to produce clean coal in the +6mm fraction contain around 6% - 8% ash.

Ash Reduction Performance

- Ash reduction performance is based on the +6mm data.
- *Overall Yield* reflects amount of feed mass that is -6mm which will not be recovered.
- Feed ash content = 19.47%.
- In the summary, splits 1 – 3 were directed into the product stream and 4 – 6 to tailings.
- Several tests generated a product ash content less than 7% with mass yield values around 80%.

Test Number	Product Ash (%)	FGX Yield (%)	Overall Yield (%)
1	6.19	82.11	64.38
2	6.21	78.00	61.15
3	7.52	75.45	59.16
4	6.00	68.71	53.87
5	6.41	82.83	64.94
6	9.02	91.66	71.86
7	6.87	81.10	63.58
8	6.36	82.40	64.60
9	7.26	86.74	68.01
10	7.53	78.38	61.45
11	7.19	89.08	69.84
12	6.53	74.74	58.60
13	5.93	74.22	58.19
14	6.86	69.24	54.28
15	6.93	69.71	54.65
Average	6.85	78.96	61.90

Gulf Coast Lignite Testing

- In-field testing conducted to reduce sulfur and mercury content in a run-of-mine lignite coal.
- +6mm raw feed coal was treated.
- Parametric test program was conducted to identify optimum setting and performances.
  - Required significant variations in test conditions.

Mobile 5 tph FGX Unit and Test Setup

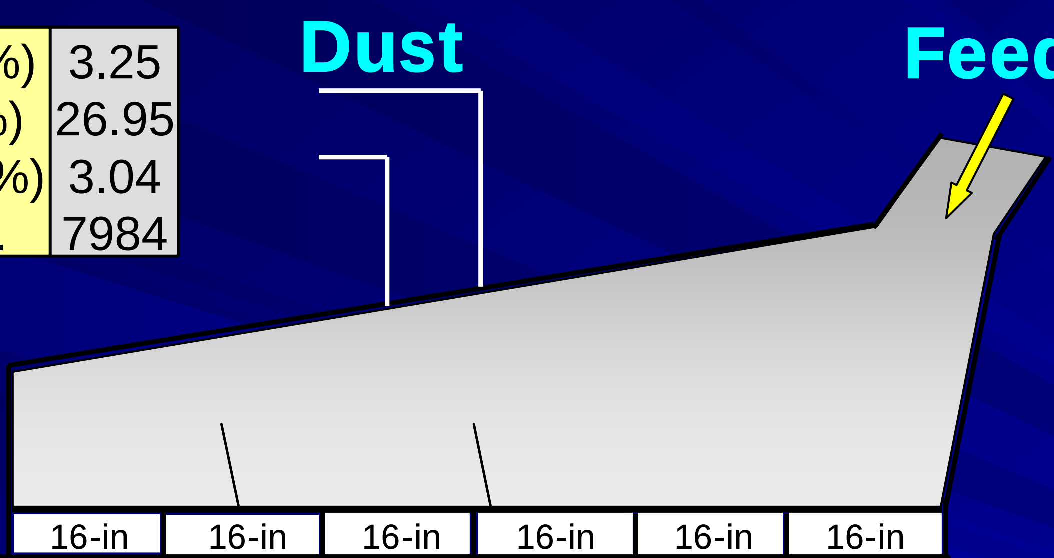
Lignite Separation Performances

Test	Product Ash %	Product Yield %	Ash Reduction %	Sulfur Reduction %	Mercury Reduction %
1	5.03	85.81	33.15	28.42	65.24
2	4.90	83.16	34.27	56.76	56.13
3	4.84	83.13	32.84	47.68	67.12
4	4.23	80.66	43.13	41.51	67.66

FGX Tailings Material

Weight & Quality Distribution

Yield (%)	3.25
Ash (%)	26.95
Sulfur (%)	3.04
Btu/lb.	7984



Yield (%)	100.00
Ash (%)	11.78
Sulfur (%)	3.17
Btu/lb.	7633

Sample No.	6	5	4	3	2	1
Yield (%)	1.29	2.58	5.16	16.77	32.25	38.70
Ash (%)	58.66	44.34	9.50	5.05	4.69	4.58
Sulfur (%)	5.36	5.90	2.70	1.31	1.18	1.12
Btu/lb	3744	5021	7559	7820	7956	7882

Coarse Gob Recovery

- Coal recovery from a coarse gob pile located in Phelps, KY.
- Material was pre-screened at 6mm.
- Target was a product calorific value of around 10000 Btu/lb.

Table Split Number	Incremental Values			Cumulative Values		
	Weight (%)	Ash (%)	Heating (Btu/lb)	Weight (%)	Ash (%)	Heating (Btu/lb)
1	12.19	31.32	10216	12.19	31.32	10216
2	17.91	34.83	9656	30.09	33.41	9883
3	10.96	33.28	9843	41.05	33.37	9872
4	3.44	29.57	10496	44.49	33.08	9920
5	16.01	49.24	7081	60.50	37.36	9169
6	39.50	81.53	1849	100.00	54.80	6278
	100.00	54.80	6278			

Summary & Conclusions

- Recent developments have lead to the redesign and commercialization of coarse density-based separators developed in the early twentieth century.
- Dry separation technologies can be installed and operated at the mine site to remove rock prior to loading and transportation to the end user.
- The ash content of run-of-mine India coals could be reduced to values in the range of 30% to 35%.
- Dry deshaling technologies provide a low cost alternative to wet-based technologies for achieving density separations greater than 1.85 RD.
- Units with capacities as high as 480 tph are available.
- Probable error values in the range of 0.20 to 0.30 are typically achieved which indicates an efficiency that is adequate for the high density separations.

Summary & Conclusions

- Recent testing with a 5 tph dry separator has demonstrated that:
  - Up to 36% of the rock can be rejected from an eastern U.S. coal while losing only 0.78% of the material that floats at 1.60 RD.
  - Waste sub-bituminous coal at a surface operation at a PRB site can be cleaned to reduce the ash content from around 30% to less than 7% ash.
  - High sulfur (40%) and mercury (60%) reductions can be achieved for lignite coal.
  - The heating value of coarse waste can be upgraded from 6000 Btu/lb to values approaching 10000 Btu/lb.
- The Accelerator technology has the potential to provide selective breakage and allow for the rejection of 10% or more of the run-of-mine coal appearing as high density rock.

Comments/Questions?