Worldwide Pollution Control Association

WPCA-Entergy

“Increasing Energy Efficiency of Existing Units” Seminar

January 22, 2014

WPCA

Visit our website at www.wpca.info

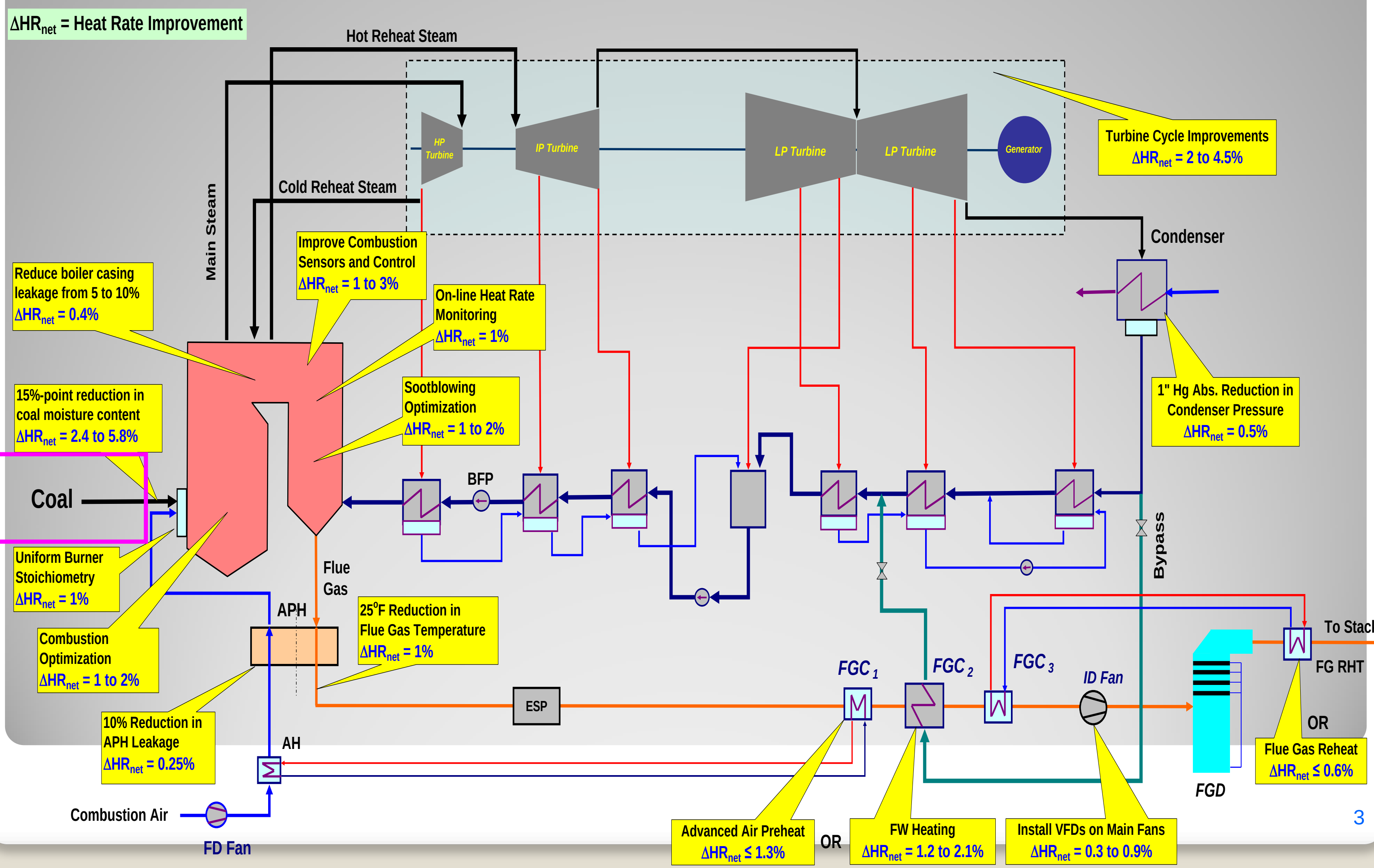
Efficiency by DryFining

WPCA/Entergy Seminar
The Woodlands, TX
Charlie Bullinger, PE
Great River Energy

Presentation Outline

- Efficiency at Great River Energy
- Drying effects
- DryFining background: why and how
- Commercial installation
- Performance and benefits ‘09 thru ‘13
- Summary

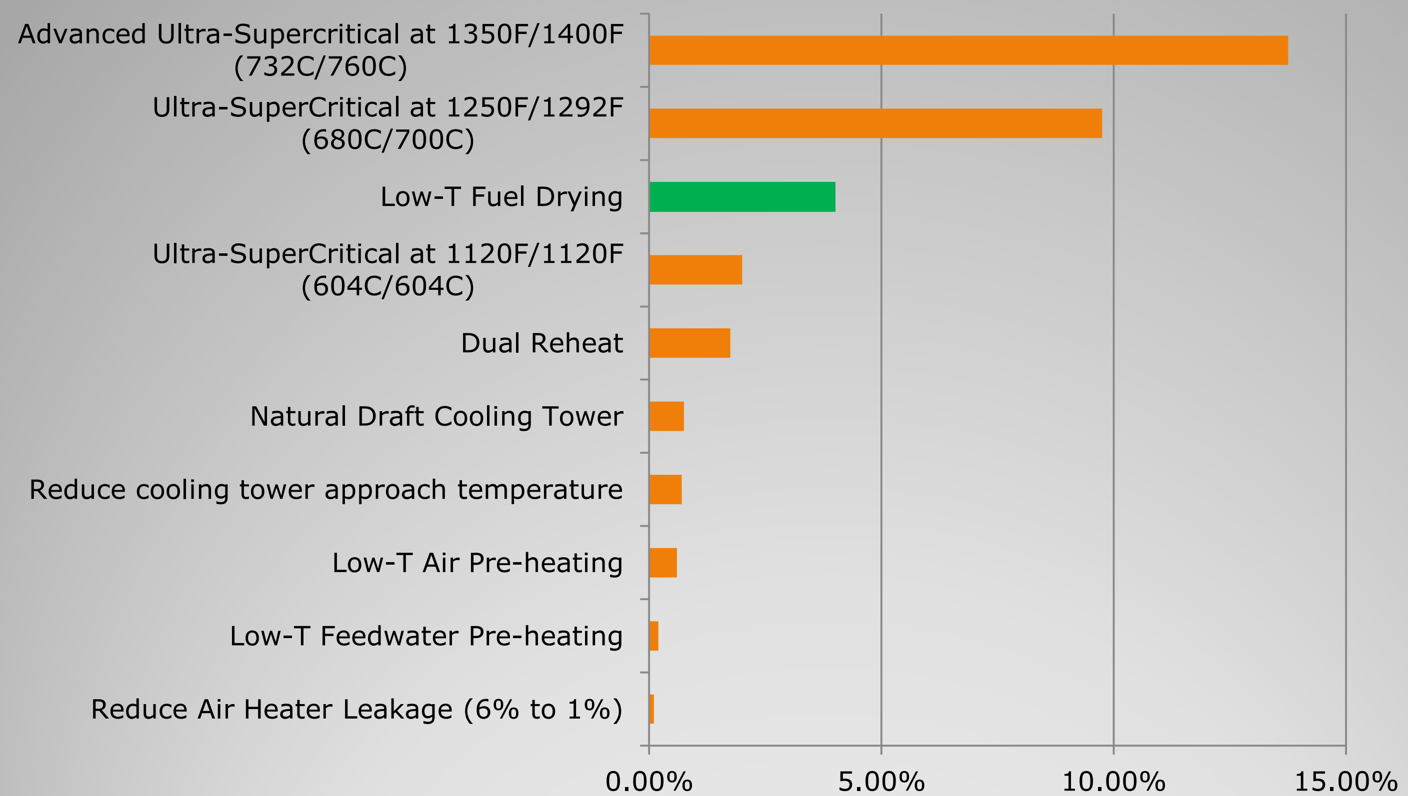
Heat Rate Improvement Opportunities



Efficiency Improvements: GRE

- Turbine blades
- Cooling Towers
- Simulator
- Ventilation
- Variable packing
- Coal Drying/beneficiation

- Fans
- Controls
- Leak detection
- Compressed air
- 605,771 tons CO_2
- 4%, 400,000 tons



Heat Rate Improvement Technology Comparison

EPRI Report: 1015698, CoalFleet Guideline for Advanced PC Power Plants

Heat Rate improvement calculation

Improve turbine cycle performance

$$HR_{net} = \frac{HR_{cycle}}{\eta_B \left(1 - \frac{P_{SS}}{P_G}\right)}$$

Station Service

Improve boiler efficiency

Reduce auxiliary power

Thermal drying of high-moisture coals has a positive effect on boiler efficiency , station service and turbine cycle performance.

Coal Creek Station

- Coal Creek Units #1 and #2…
  - 2 X 600 MW Natural Circulation
  - Tangentially Fired, Dual Furnace
  - 8 X 8 burners, plus SOFA
  - Eight Pulverizers per Unit
  - Mine Mouth, ND Lignite
    - 6,200 BTU/lb
    - 38% moisture
  - Commissioned 1979, 1981
  - Base Loaded
  - Wet FGD's, No SCR's
  - Closed Loop Cooling

Problem:

- Coal moisture has a large negative effect on boiler efficiency, station service power and unit heat rate.
- For a 600 MW lignite-fired unit, fuel moisture is responsible for:
  - 9% higher coal flow rate
  - 20 MW of station service power
  - 20% higher flue gas flow rate
  - Increased operating and maintenance cost
- Can a low-temperature waste heat be used to reduce fuel moisture?

GREAT RIVER ENERGY
A Touchstone Energy Cooperative

LEHIGH UNIVERSITY

North Dakota Industrial Commission

LIGNITE ENERGY COUNCIL

FALKIRK
THE FALKIRK MINING COMPANY

BARR

HEYL&PATTERSON

Lignite Fuel Enhancement

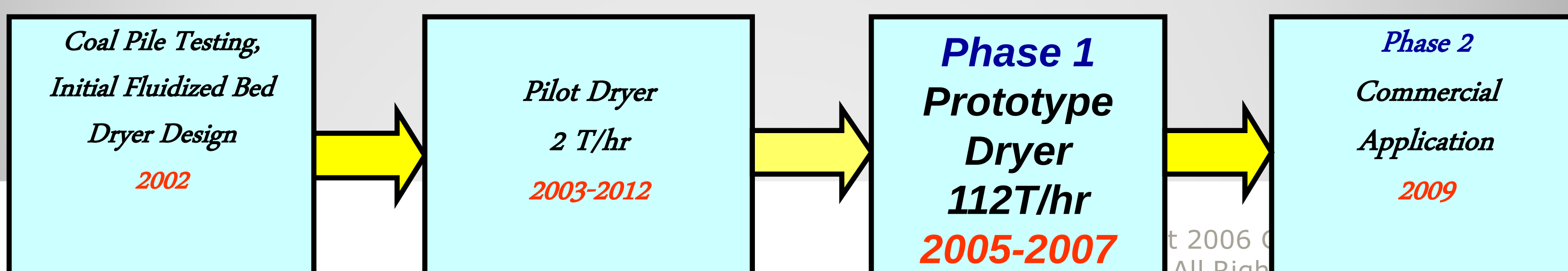
EPRI | ELECTRIC POWER RESEARCH INSTITUTE

U.S. DEPARTMENT OF ENERGY

Huge Collaborative Effort

Project Goals and Schedule

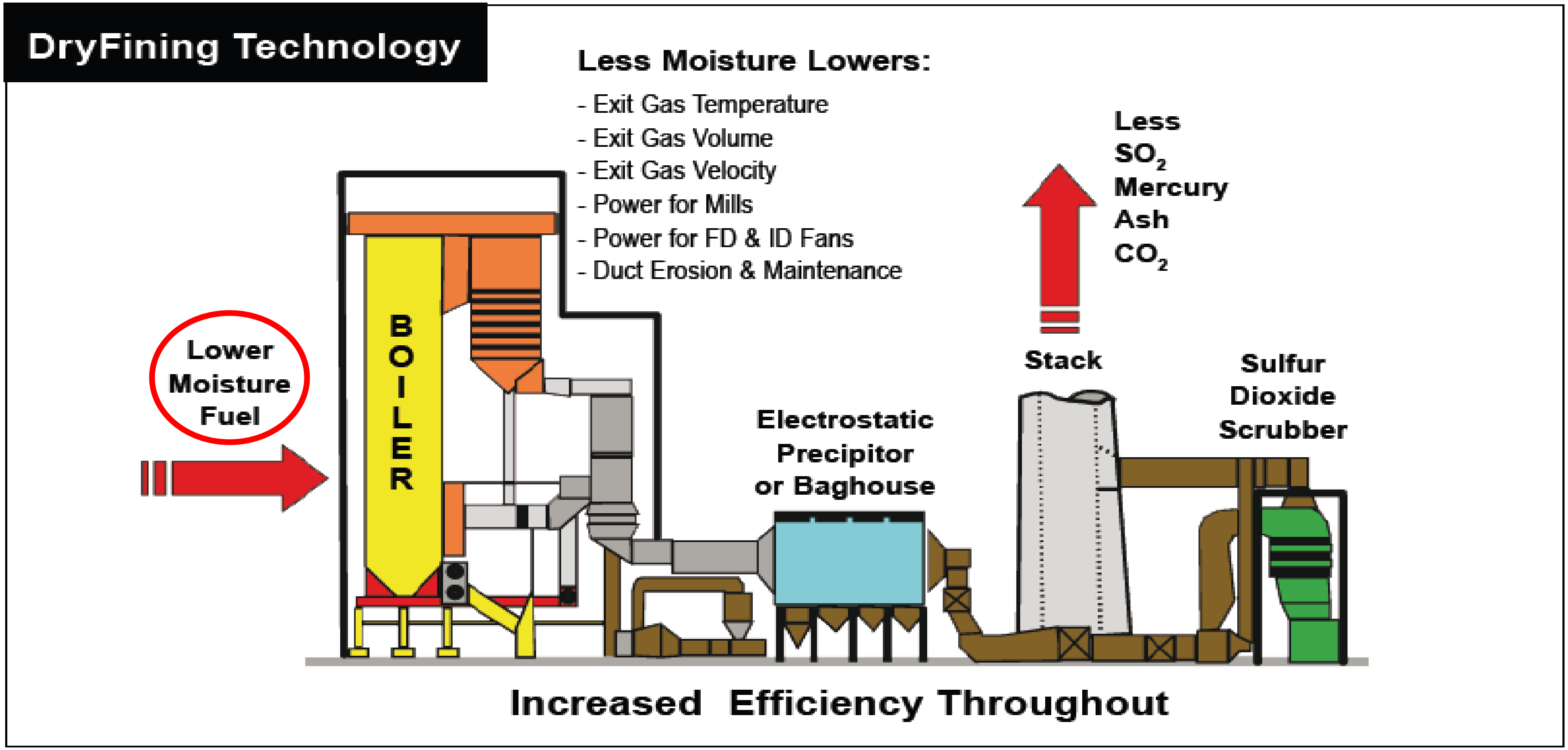
- **Goals and Objectives:**
  - Reduce moisture content of lignite, PRB, and other high-moisture fuels.
  - Use waste heat from the power plant.
  - Modify existing coal handling systems.
  - Increase competitive position of lignite-, PRB-, and other high moisture coal-fired power plants.
  - Reduce environmental impact of lignite-, PRB-, and other high-moisture coal-fired power plants
- **Project Phases and Schedule:**



Parameter	SE Bituminous	PRB	ND Lignite	Texas Lignite
Moisture %	6.4	28.5	37.1	32.4
Ash %	6.7	5.2	11	13.3
Nitrogen %	1.4	0.7	0.5	0.8
Sulfur %	1.6	0.5	0.7	1.33
HHV Btu/lb	13,387	8,740	6,310	6,840
Ash Softening °F	2,714	2,160	2,150	N/A

Properties of Low Rank Coals

DryFining™ process impacts



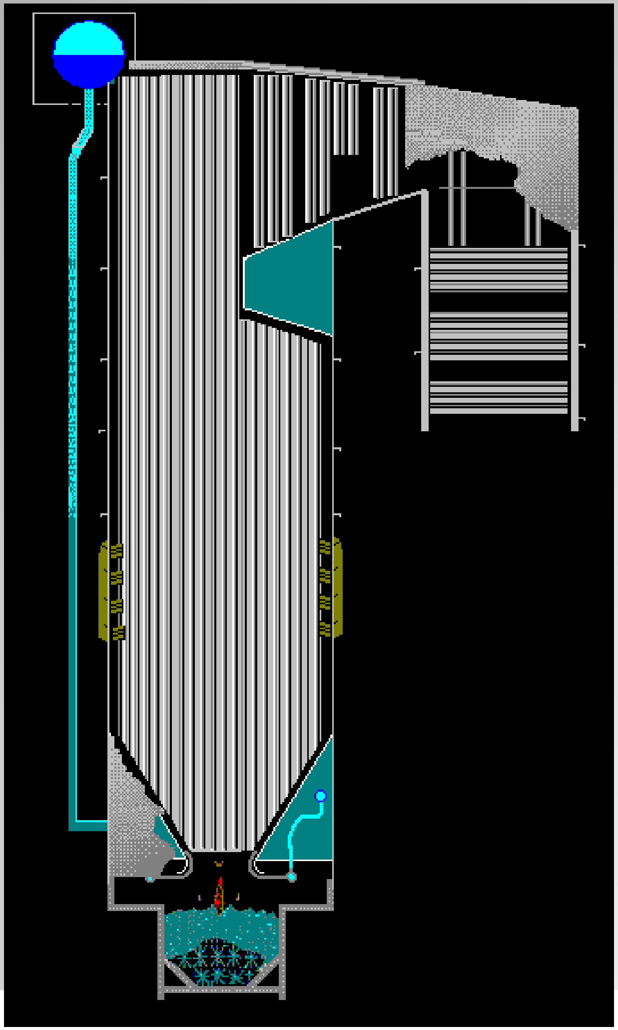
Effect of Coal Moisture on Plant Equipment

- **Mills**
  - Lower coal flow rate and moisture content → Lower mill power
  - Fewer mills need to be in service → Flexibility in mill maintenance
- **Fans**
  - Lower flue gas and air flow rates, lower drafts → Lower fan power
- **Air Preheaters**
  - Lower drafts → Lower ΔPs → Lower APH leakage
- **Coal Handling Equipment**
  - Less coal to handle → Lower maintenance and power requirements
- **Coal Pipes**
  - Lower coal and PA flows → Lower erosion and maintenance
- **Emissions Control Equipment**
  - Lower flue gas flow → Longer residence time → Better performance
- Cooling Tower
- Turbine

Positive, the magnitude depends on system integration (applies to Cooling Tower and Turbine)

- **Plant Availability**
  - Lower and more flexible maintenance → Higher plant availability

Effects of Dried Coal on Boiler

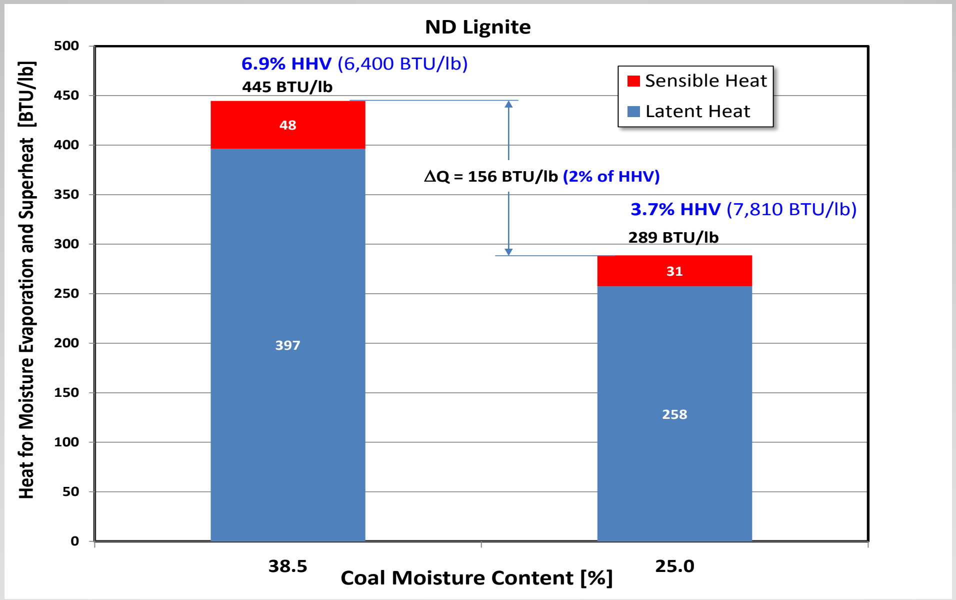


- **Boiler**
  - Reduce PA/SA ratio
  - Reduce total combustion air flow
  - Reduce superheat sprays
  - Enhance NO_x control
  - Reduce ash loading
  - Increase ash fusion temperature.
- **Air Preheater**
  - Reduced **ΔP**
  - Reduced Leakage
  - Reduced maintenance

$$X_{ratio} = \frac{C_{p,air} \times \dot{M}_{air}}{C_{p,\ flue\ gas} \times \dot{M}_{flue\ gas}}$$

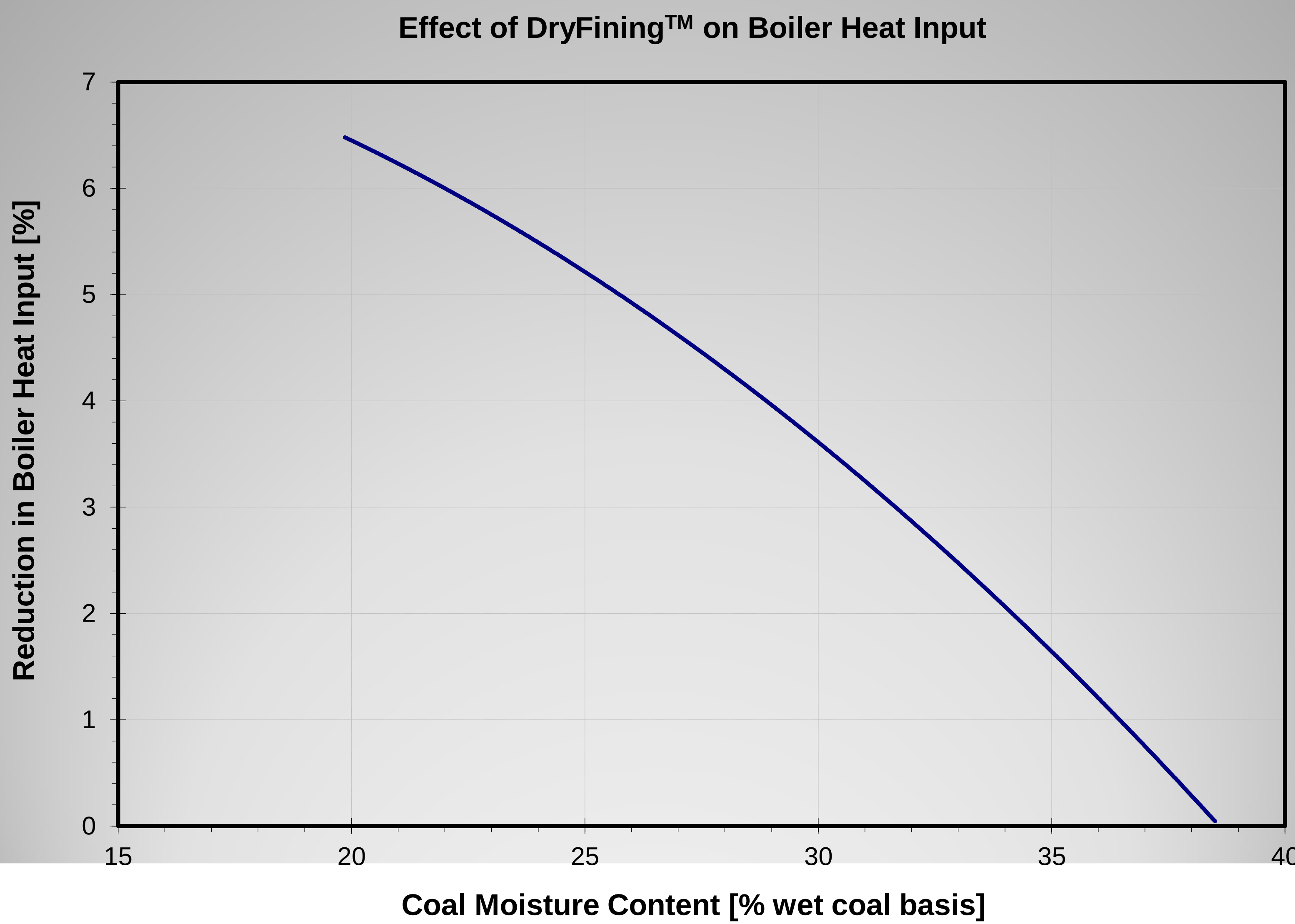
Coal Moisture effects furnace heat release

- When coal is combusted in the boiler furnace, part of the chemical energy stored in the coal is used to evaporate coal moisture

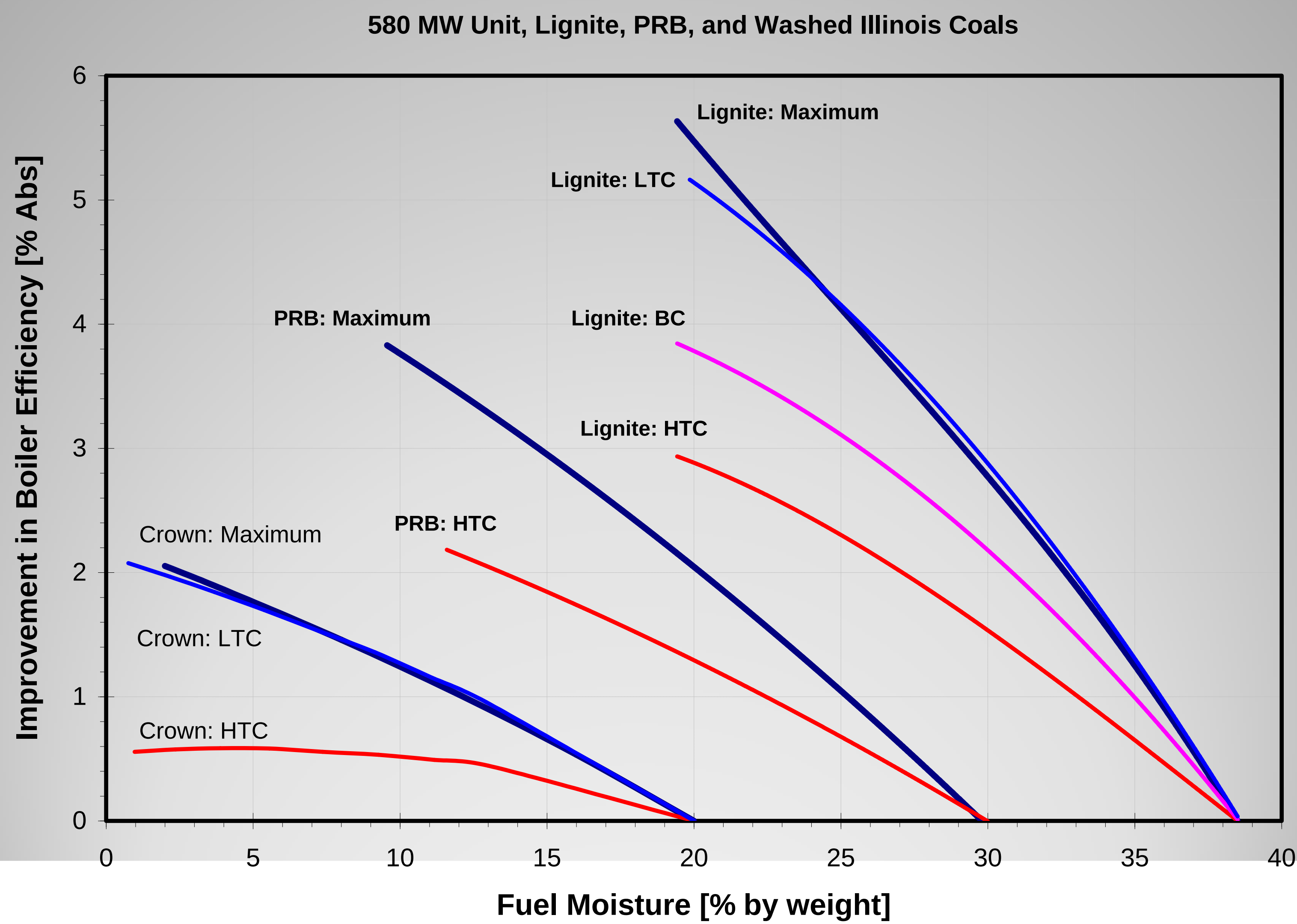


- The reduction in heat required for moisture evaporation results in increased heat release in the furnace and increased evaporation.
- For constant boiler evaporation rate (boiler thermal duty), the reduction in thermal energy required for evaporation of coal moisture results in **lower heat input** to the boiler and higher boiler efficiency.

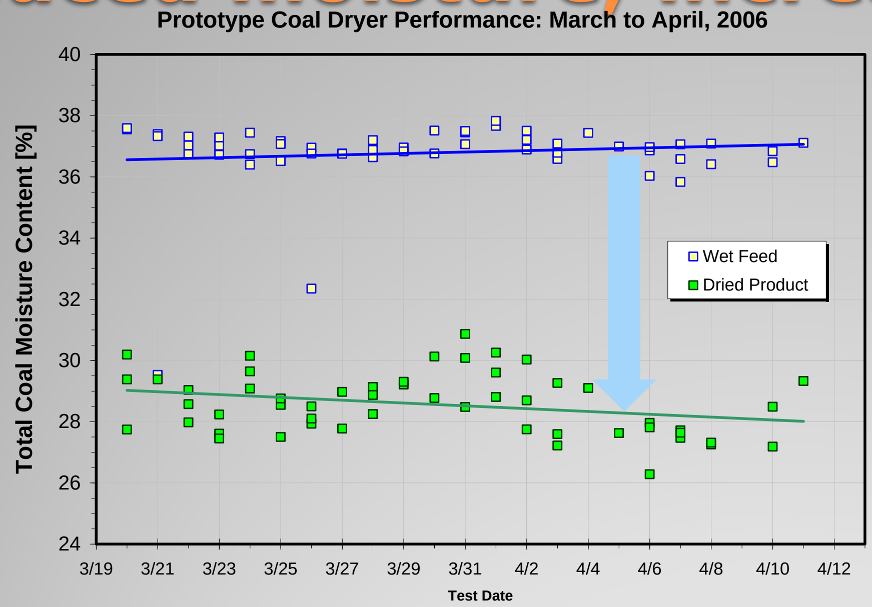
Effect of Coal Moisture on Boiler Heat Input



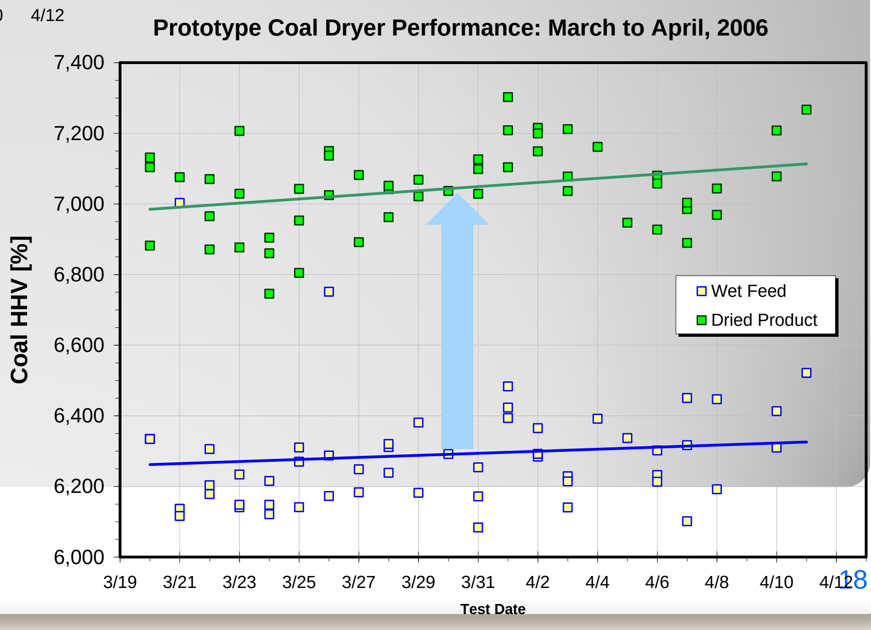
Effect of Coal Moisture on Boiler Efficiency



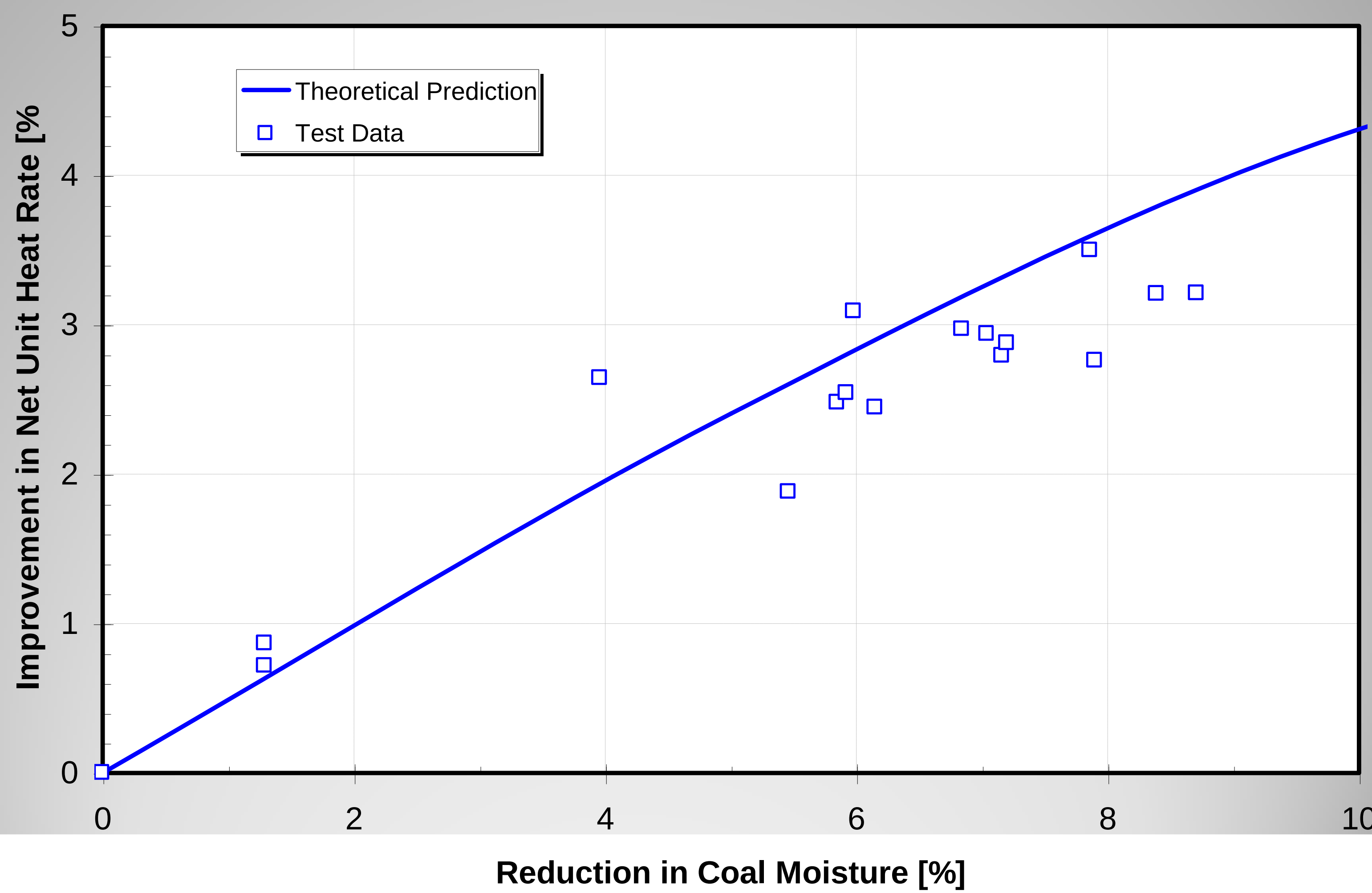
Reduced moisture, increased HHV



Improvement in coal HHV



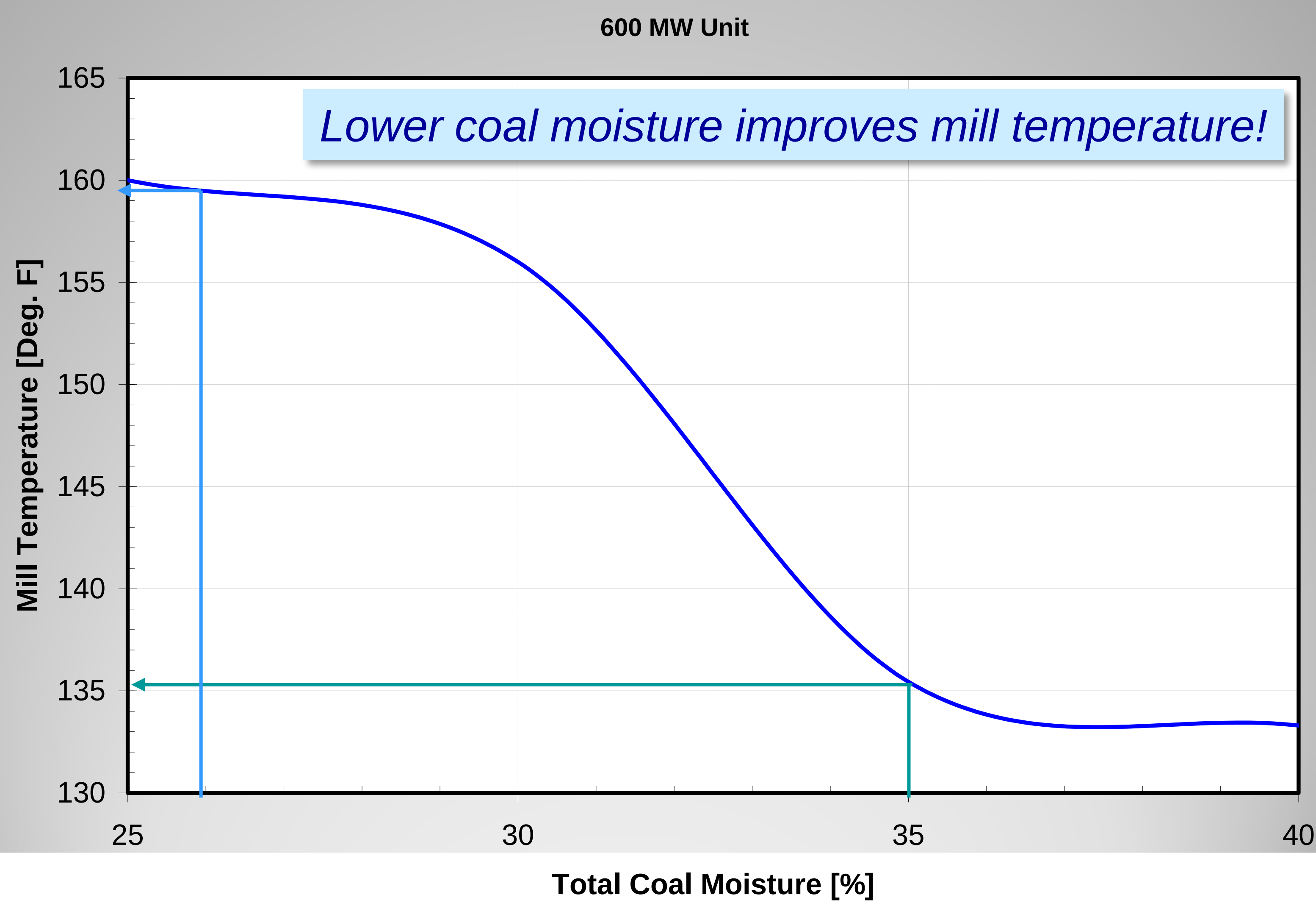
Reduction in coal moisture improves NHRT



Coal Drying effects on Mills

- Reduces total coal flow, and number mills
- Reduces primary air flow requirements
- Reduces mill wear
- Reduces total mill power
- Increases mill capacity
- Coal cleaning further reduces mill wear and power
    - Pyrites, stones, rocks, etc. are removed in coal dryer

Effect of Coal Moisture on Mill Temperature

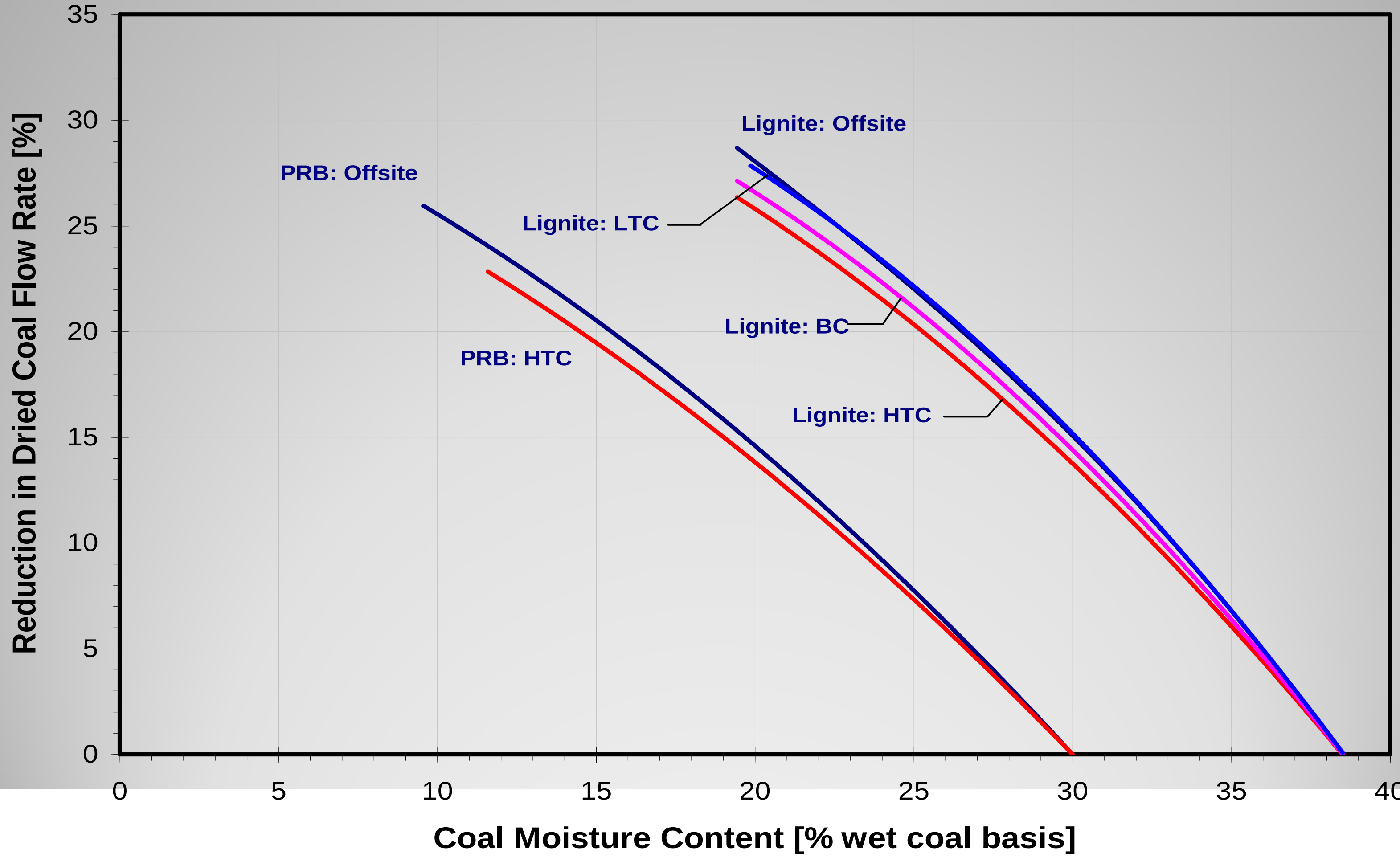


Coal Moisture effects Coal Handling

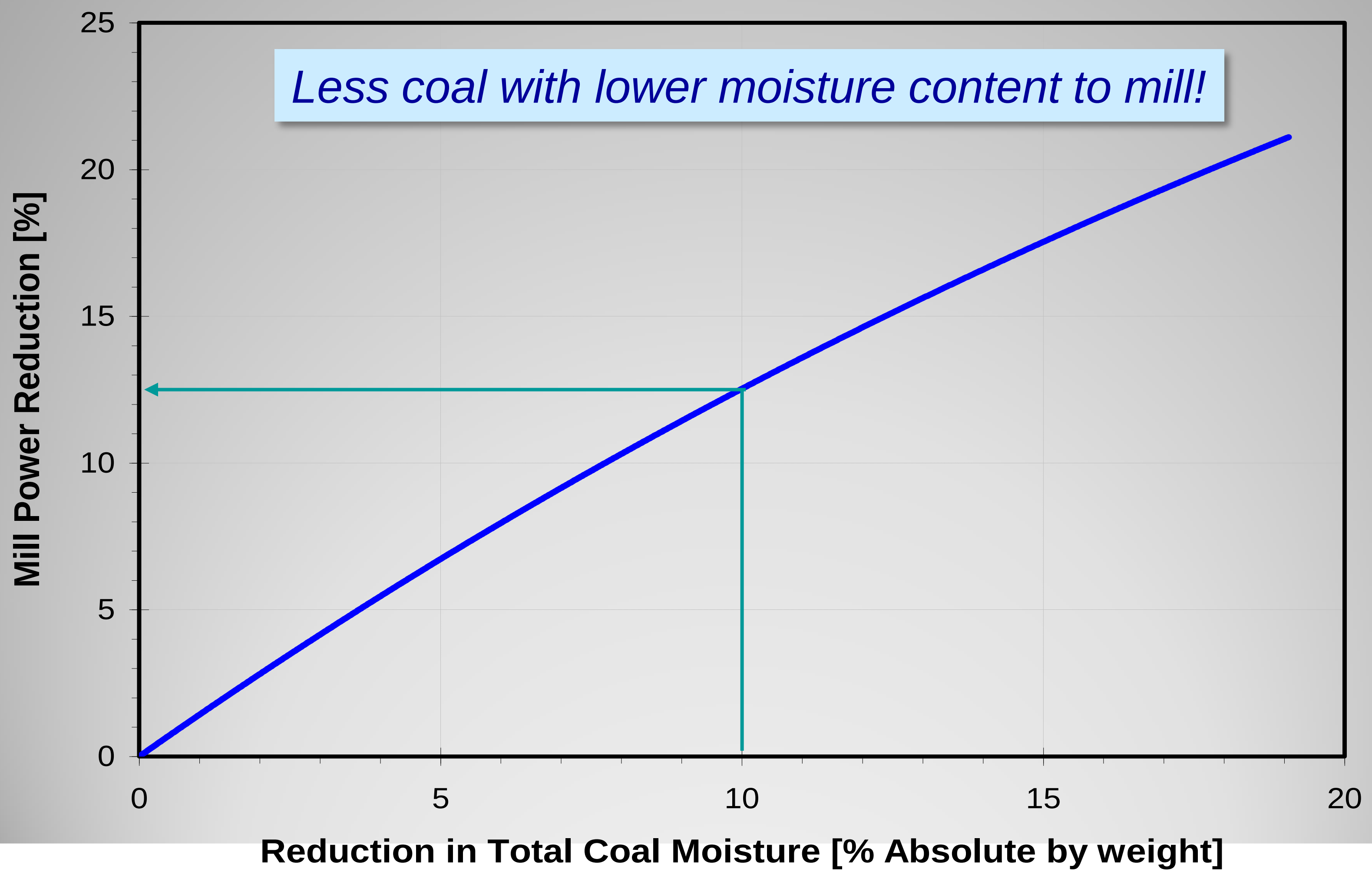
- Reduced coal flow into plant
- Fewer feeder stalls
- Improves coal energy stored in a bunker
- Spontaneous combustion (auto-ignition)?
  - Air leakage into the coal bunker (silo) must be eliminated.
  - Equilibrium coal moisture important
- Increased dust
- Improved coal flow through chutes

Coal Moisture effects Coal Flow Rate

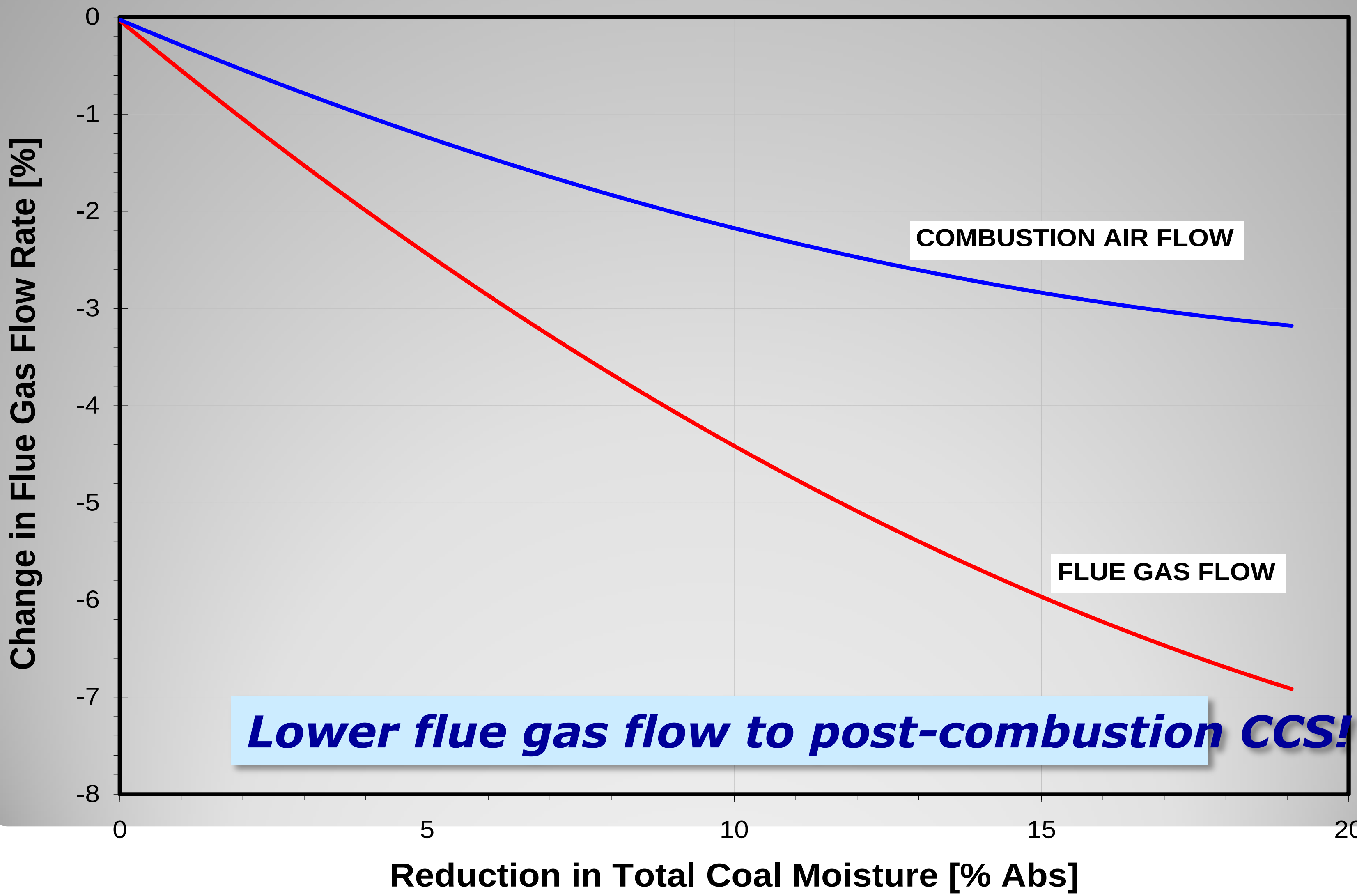
Less coal to handle and mill!



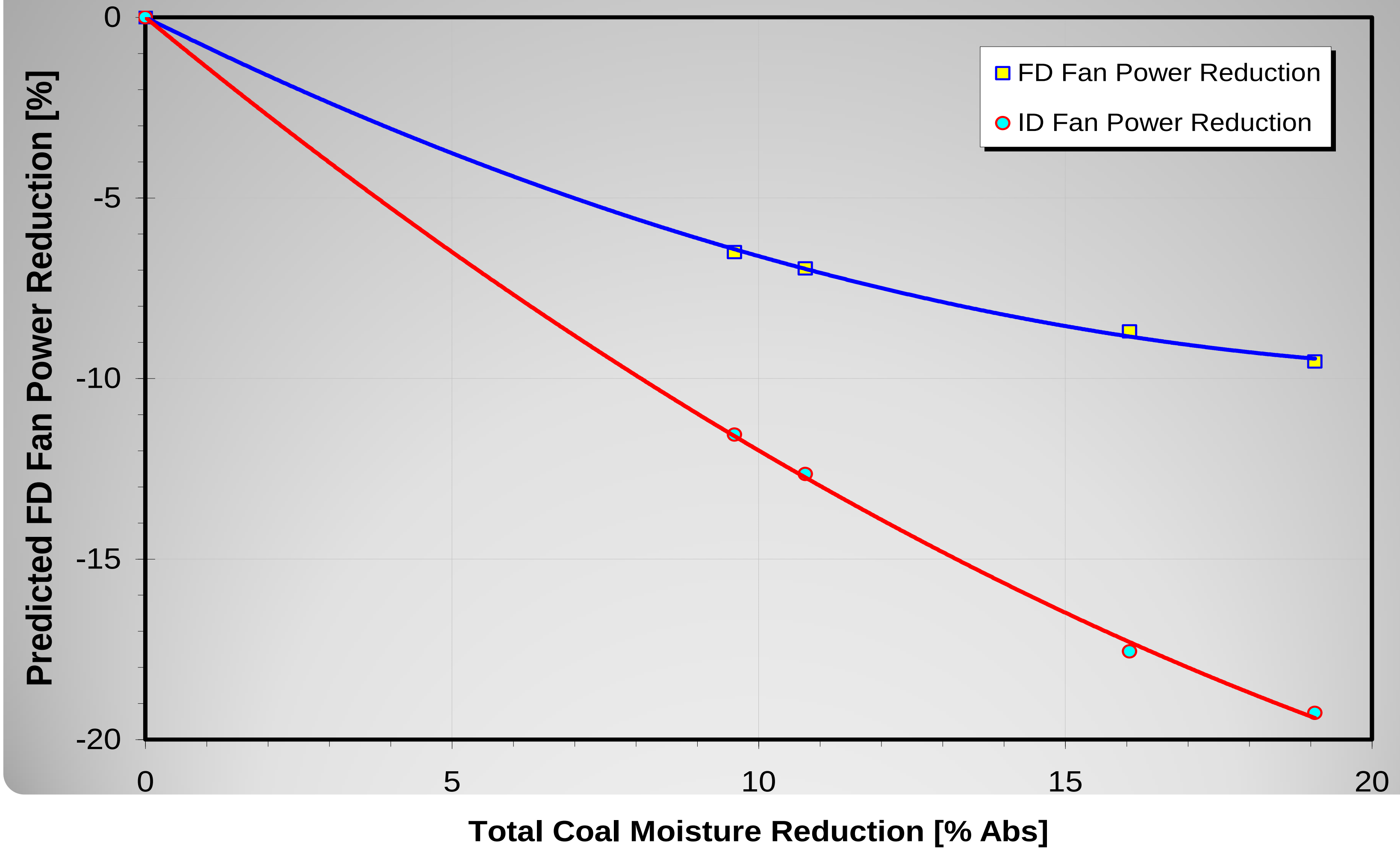
Effect of Coal Moisture on Mill Power



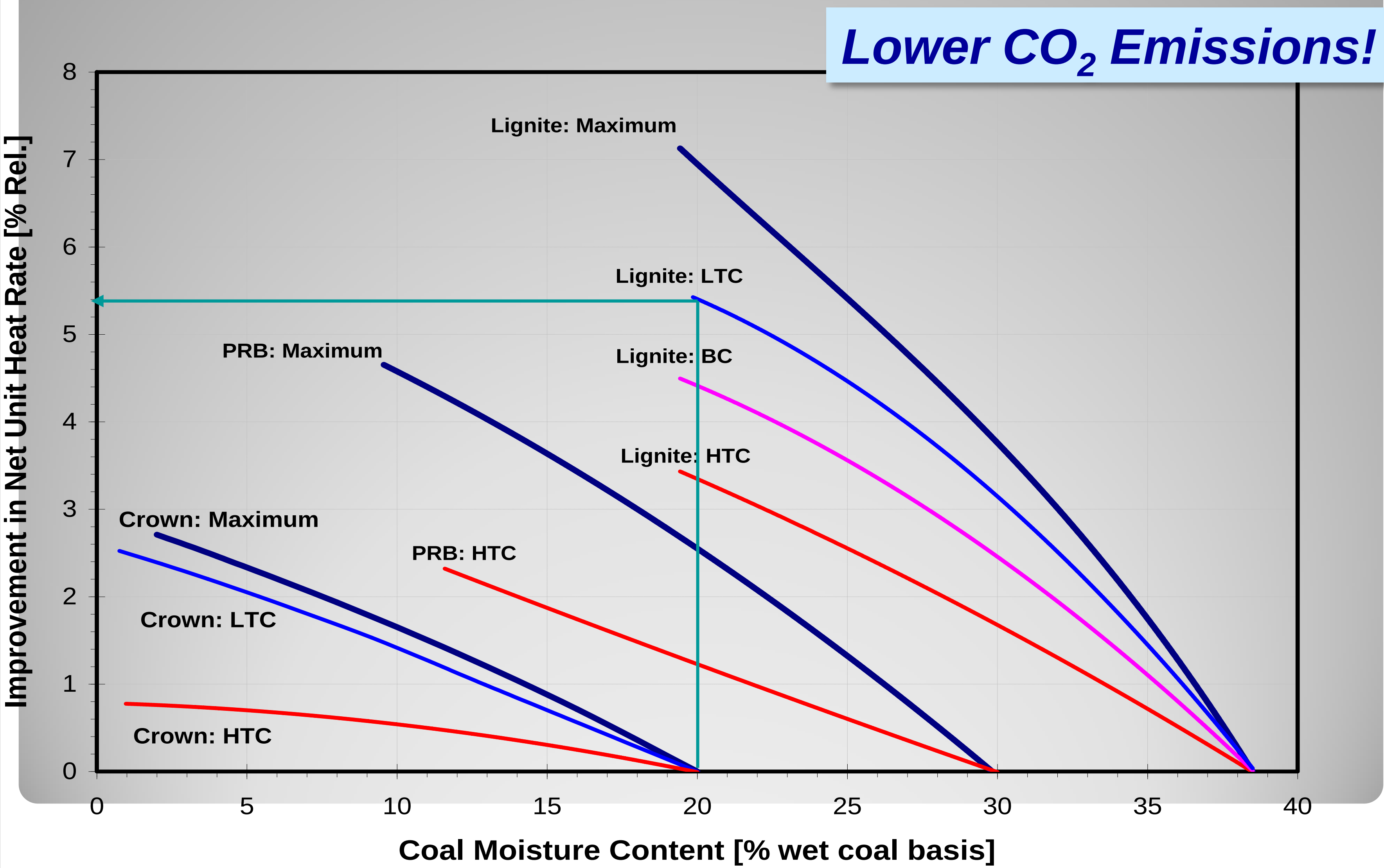
Effect of Coal Moisture on Flow Rates of Combustion Air and Flue Gas



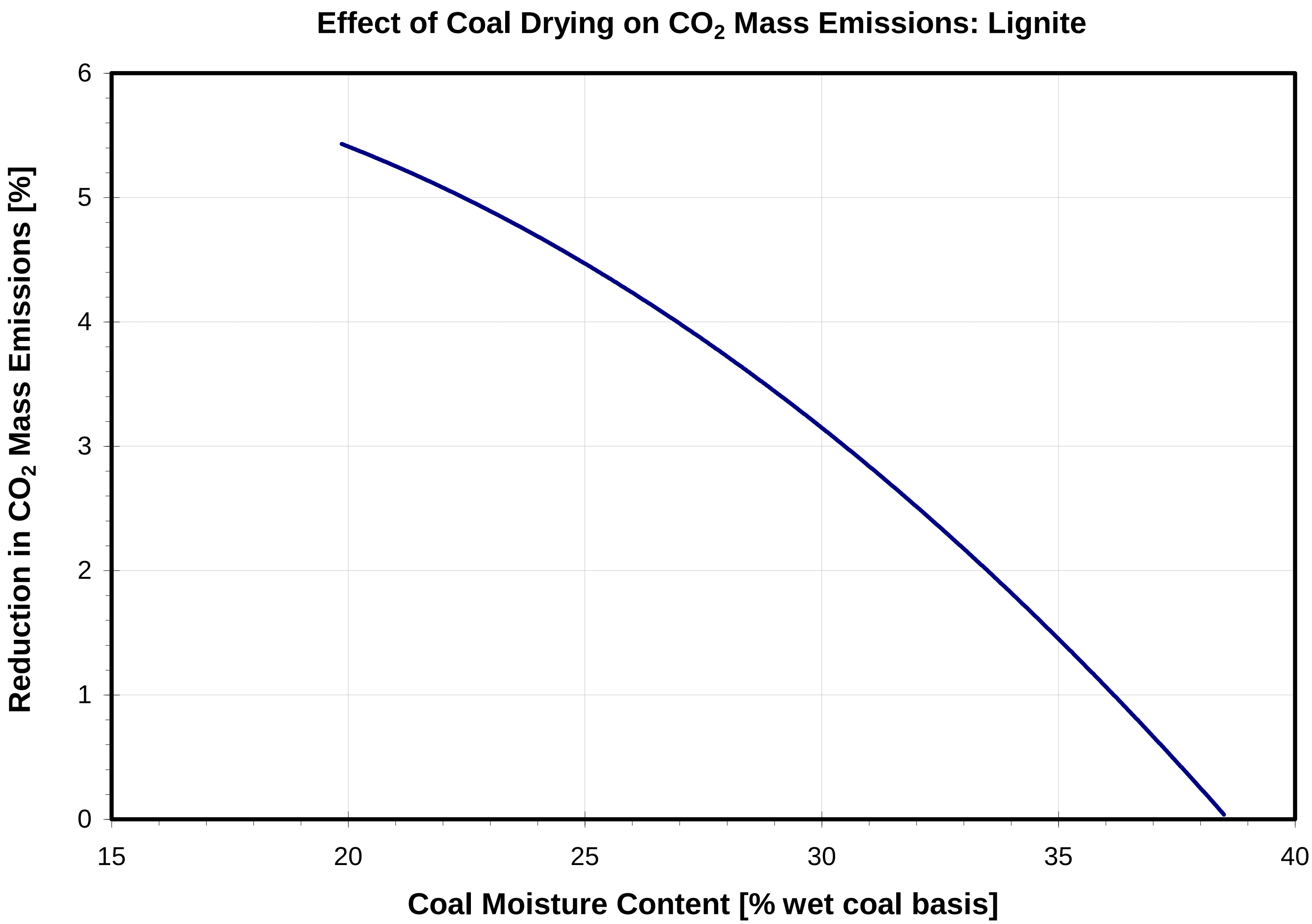
Lower coal moisture reduces fan power



Effect of Coal Moisture and Thermal Integration of a Coal Drying System on Unit Heat Rate



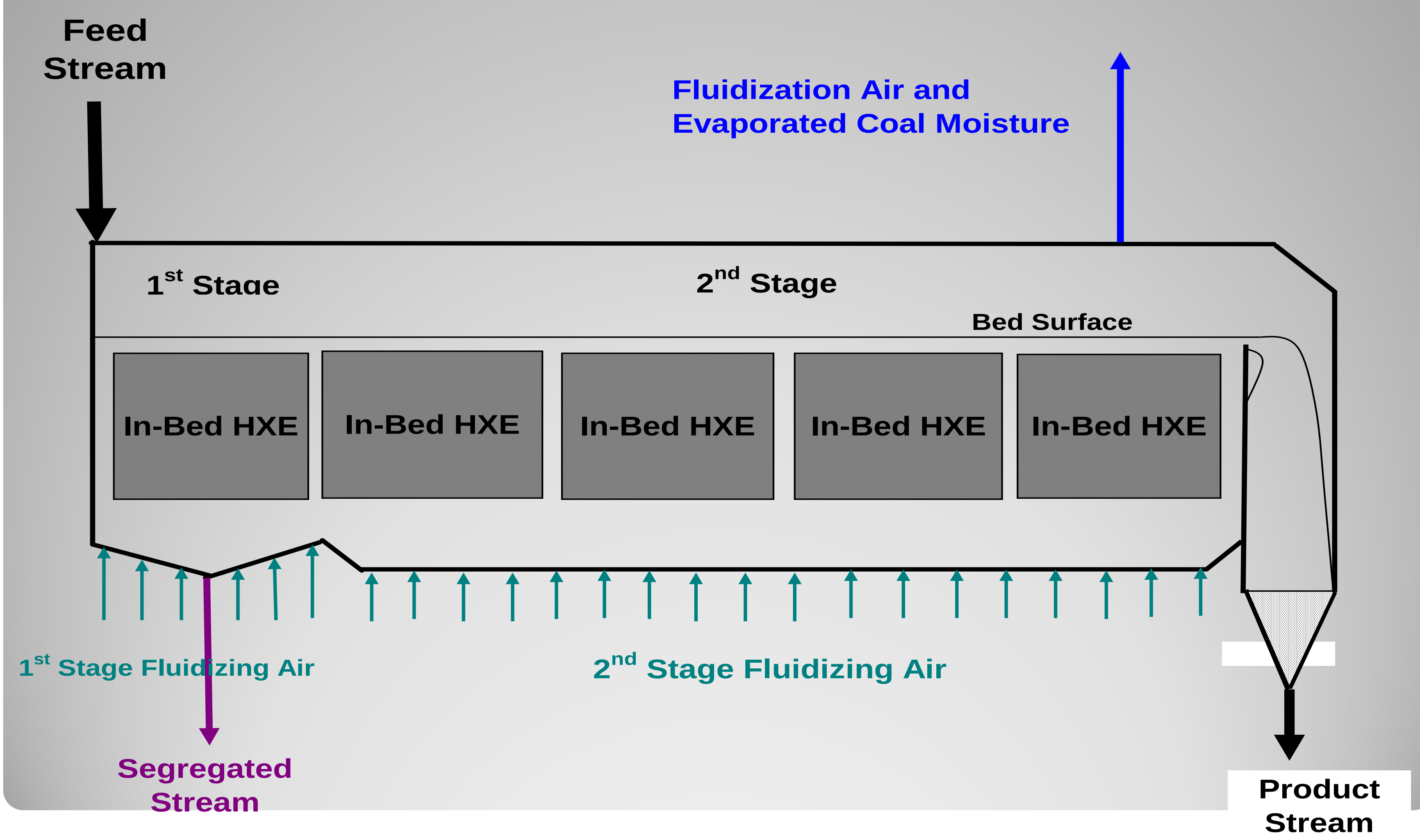
Lower coal moisture reduces CO_2 emissions



28

Thermal Drying of High-Moisture Coals

DryFining™: Fluidized Bed Dryer

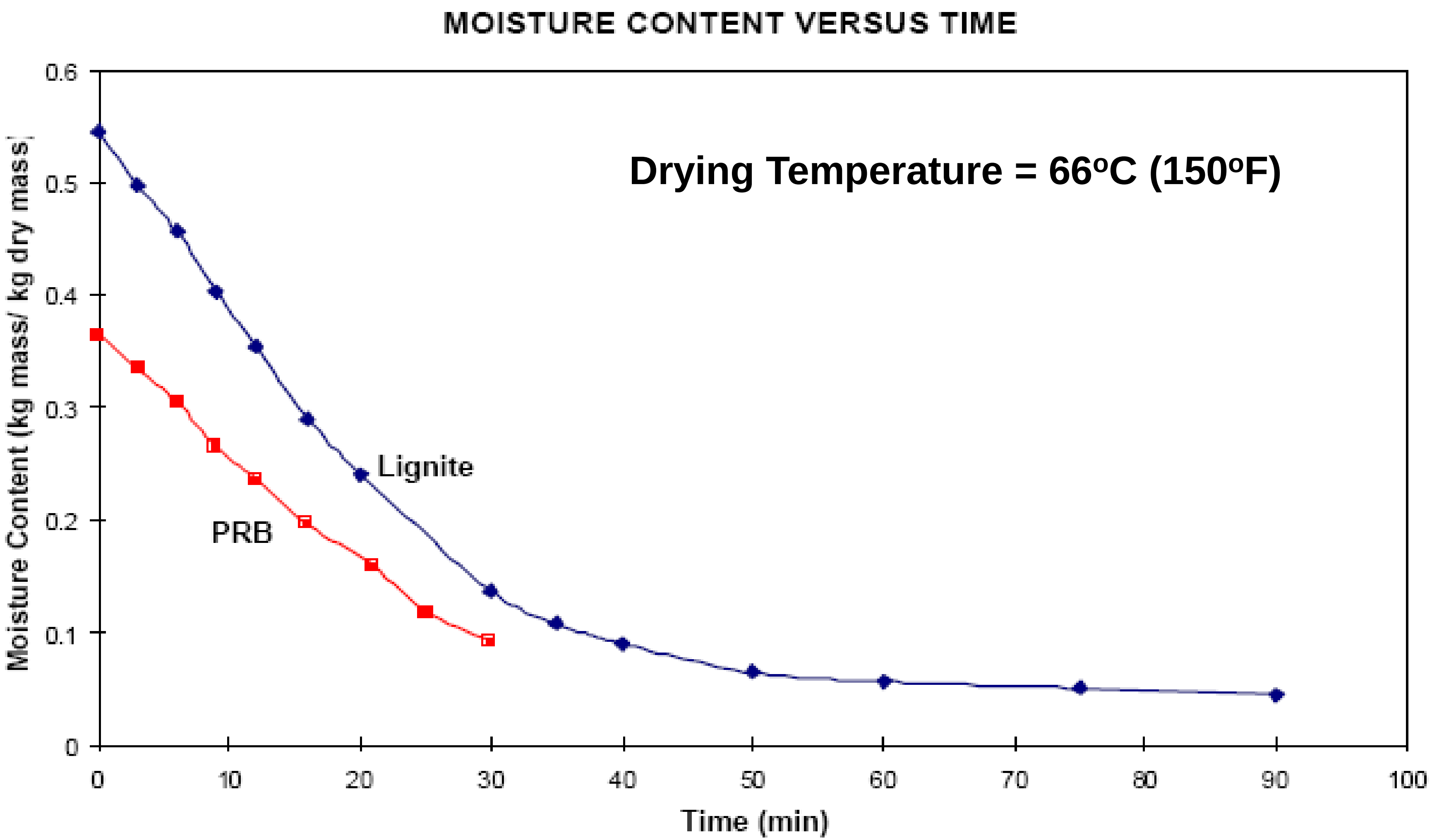


Factors Affecting Coal Drying Rate and Product Moisture

- Coal composition
  - Amount of free and inherent moisture
- Dryer residence time
- Dryer heat flux
- Temperature of fluidizing air
- Flow rate of fluidizing air
- Humidity of fluidizing air

31

Moisture Content vs. Residence Time



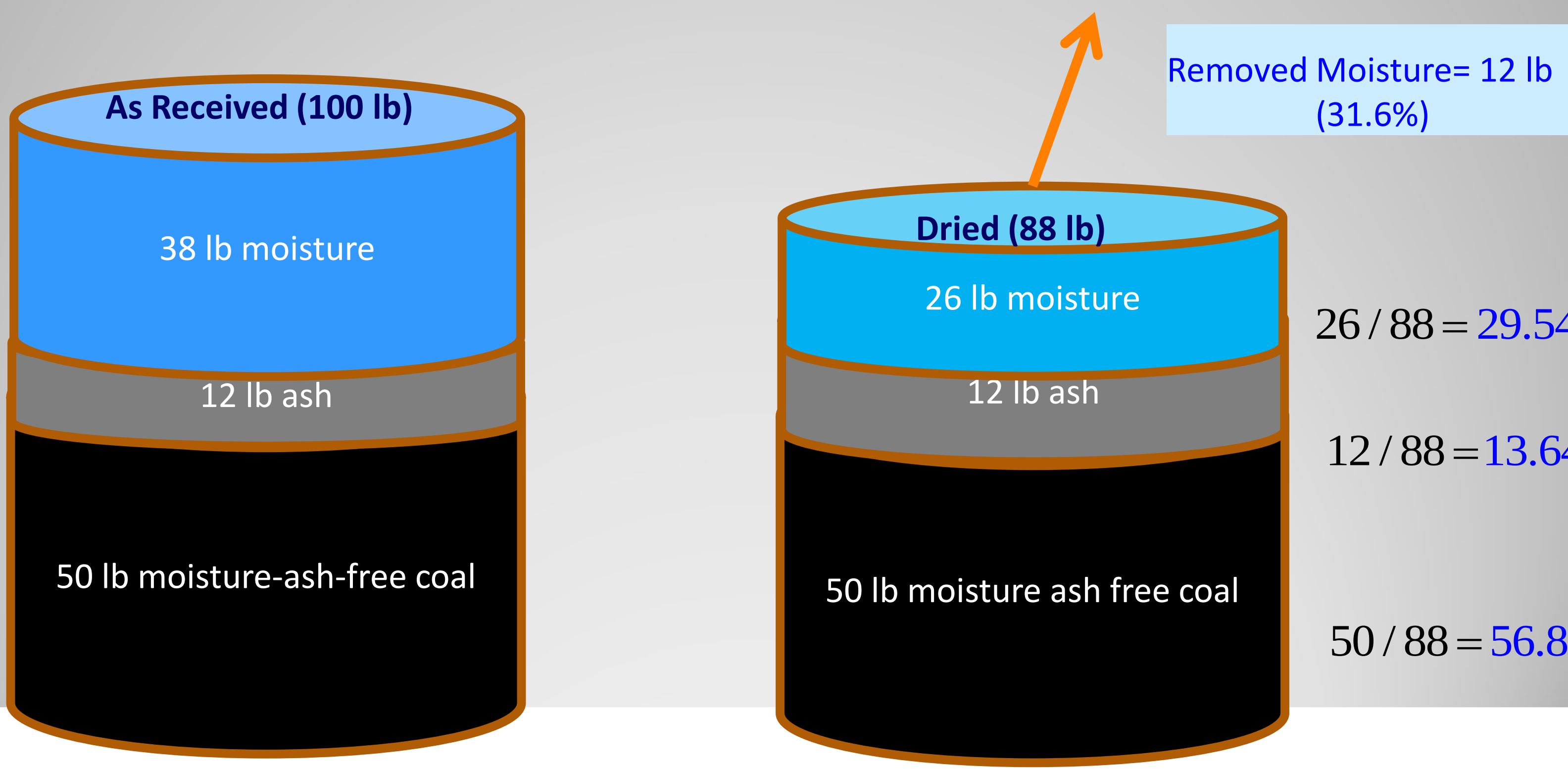
32

Calculating Coal Properties

$$TM = \frac{lb\, coal\, moisture}{lb\, wet\, coal}$$

$$HHV_{Dried} = \frac{HHV_{AR}}{1 - \Delta TM_{Removed}}$$

Parameter	Units	AR	Dried
TM	%	38.0	**29.5**
Coal Moisture	lb/lb wet coal	0.38	**0.26**
Removed Moisture	lb/lb wet coal		**0.12**
HHV	BTU/lb	6,200	**7,045**
Ash	%	12	**13.64**



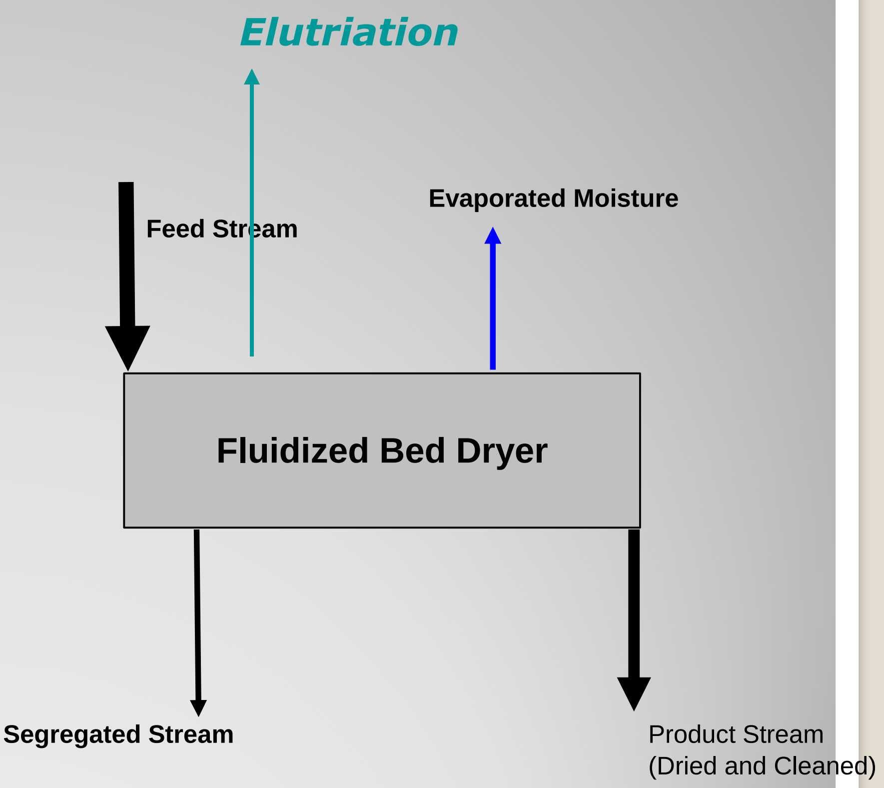
$$26/88 = 29.54\%$$

$$12/88 = 13.64\%$$

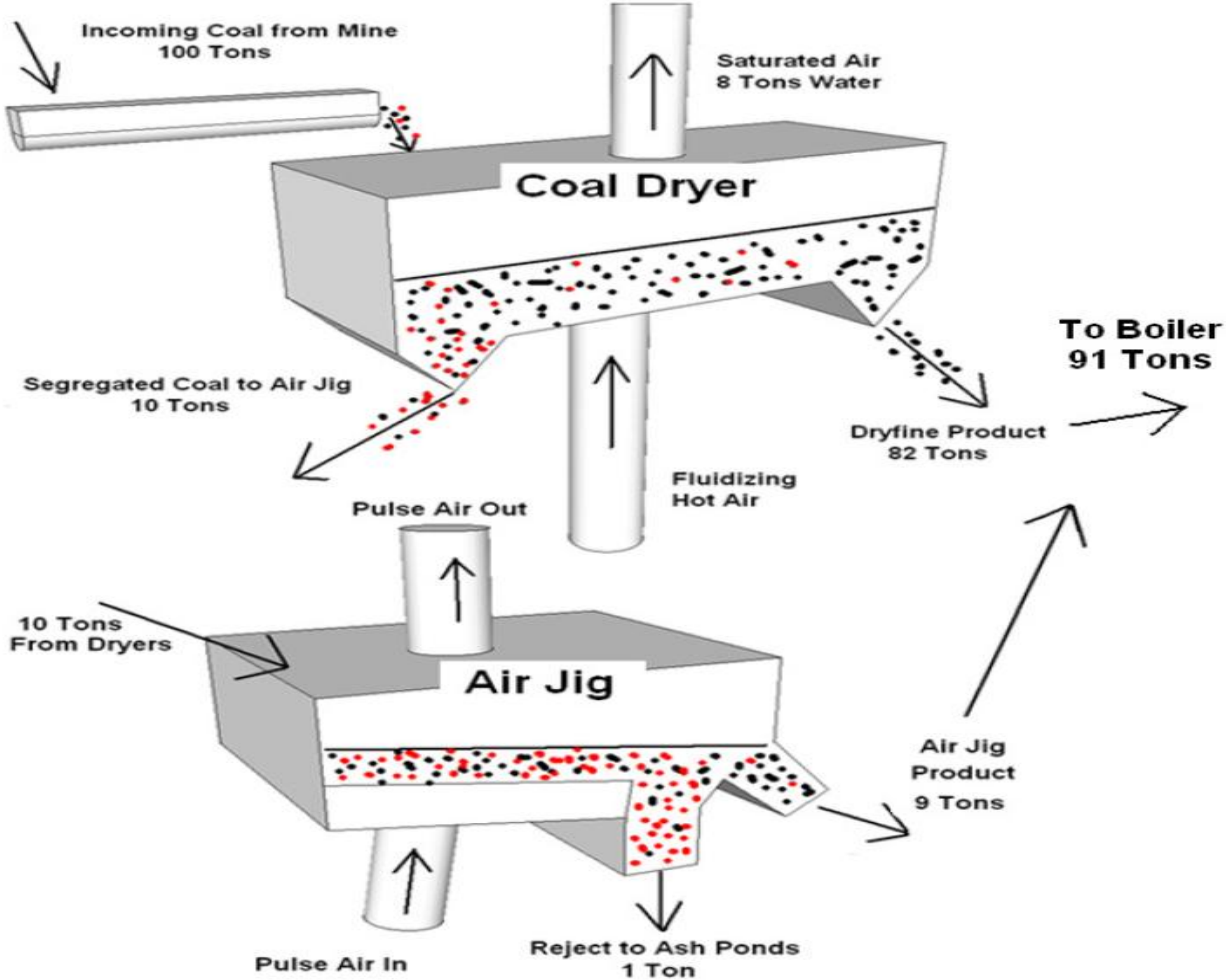
$$50/88 = 56.82\%$$

Dryer Inlet and Outlet Streams

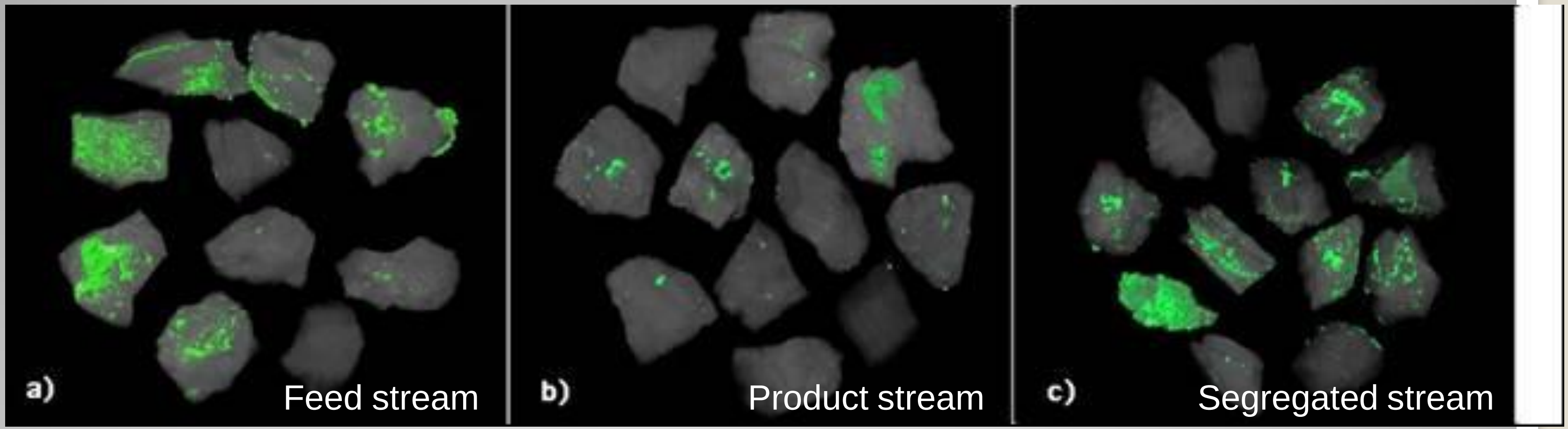
- ***Raw coal feed stream***
  - *High moisture*
- ***Elutriated fines (dust) stream***
  - *Fine material*
  - *High ash and sulfur content*
  - *Low heat content*
- ***Segregated Stream – rejects***
  - *A mixture of non-fluidizable and fluidizable materials*
  - *High in sulfur and mercury*
  - *With a properly designed discharge device it is possible to concentrate non-fluidizable material in the segregated stream.*
    - ***Major reduction in sulfur and mercury***
- ***DryFine Product Stream***
  - *Low moisture*
  - *High HHV*
  - *Reduced sulfur and mercury contents*



DryFine System Overview



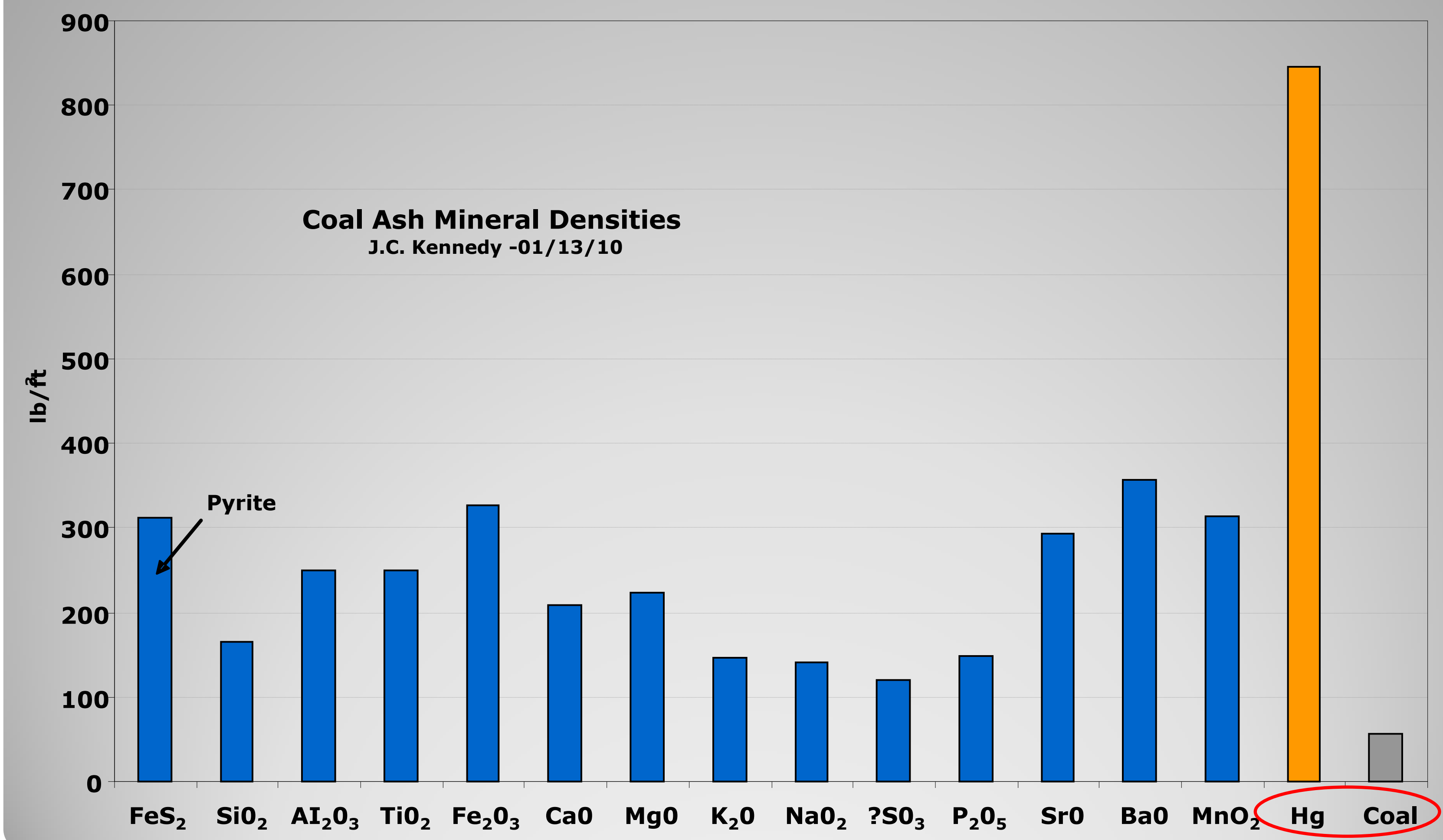
Coal morphology changes caused by drying



- Coal is shown as transparent grey, silicates and other minerals in green color.
- Based on visual observation feed and segregated streams are both relatively richer in silicates compared to the partially dried (product) stream.
- Quantitatively, feed stream contains **4.8%** of silicates (by volume), while product and segregated streams contain **2.8** and **2.7**% of silicates, respectively.
- As coal shrinks and cracks during drying the particle size distribution changes generating more surface area and exposing more of the minerals allowing for increasing mineral separation.

X-ray CT image of layers of coal from (a) feed, (b) partially dried (product), and (c) segregated streams. colored objects are higher CT absorbing material (iron and silicate containing minerals). Analysis performed at the Center for Quantitative Imaging at the Pennsylvania State University's Energy Institute.

Patented Segregation



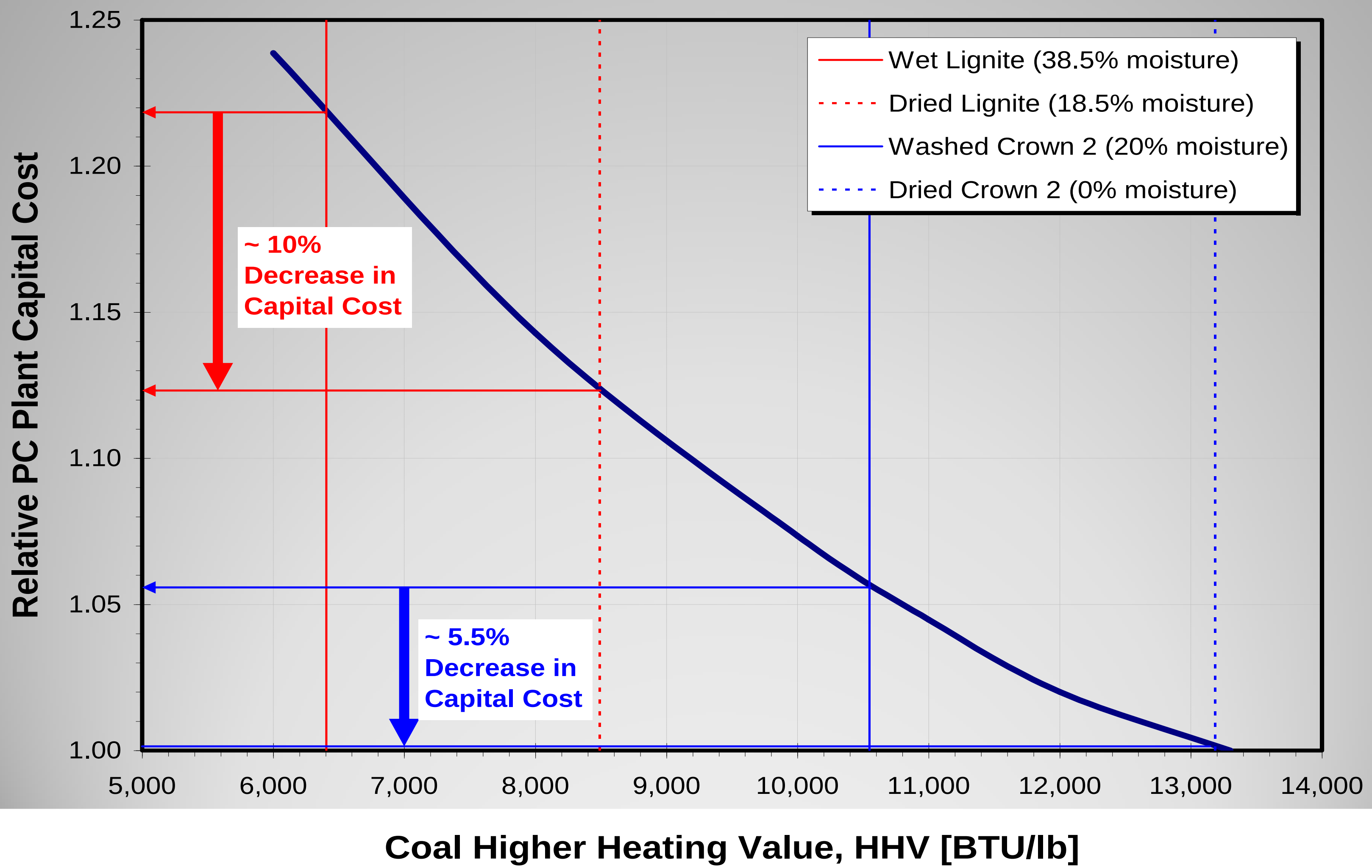
Basic characteristics of DryFining™

- Low-temperature, atmospheric pressure process
  - No high-temperature or high-pressure parts
  - No exotic materials
- Uses waste heat to remove coal moisture
  - **No external heat sources are needed**
- Simple, no moving parts
  - Equipment is simple and inexpensive to manufacture.
- Improves performance
  - Positive effect on auxiliaries
  - **Performance improvement strongly depends on system integration**
- Reduces emissions by removing **moisture**, **sulfur** and **mercury** from coal
  - Positive effect on pollution control equipment, and environmental compliance cost.

DryFining Applications

- **Retrofit** coal drying system to existing power plants firing low-rank high-moisture fuels to:
  - Improve efficiency (and recover efficiency loss due to CCS)
  - Reduce emissions & environmental compliance cost
  - Improve unit availability
  - (Alternate equipment arrangements)
- **New Design Integration** coal drying system into a new power plant design (supercritical, ultra-supercritical, gasifier-based systems, etc.) to:
  - Maximize efficiency and reduce impact of Carbon Capture
  - Reduce emissions
  - Reduce capital investment cost
  - Reduce environmental compliance cost
  - Improve unit availability
- **Coal Preparation** beneficiated coal for the market use
  - Reduce transportation costs

Lower coal moisture reduction capital cost of new power plants

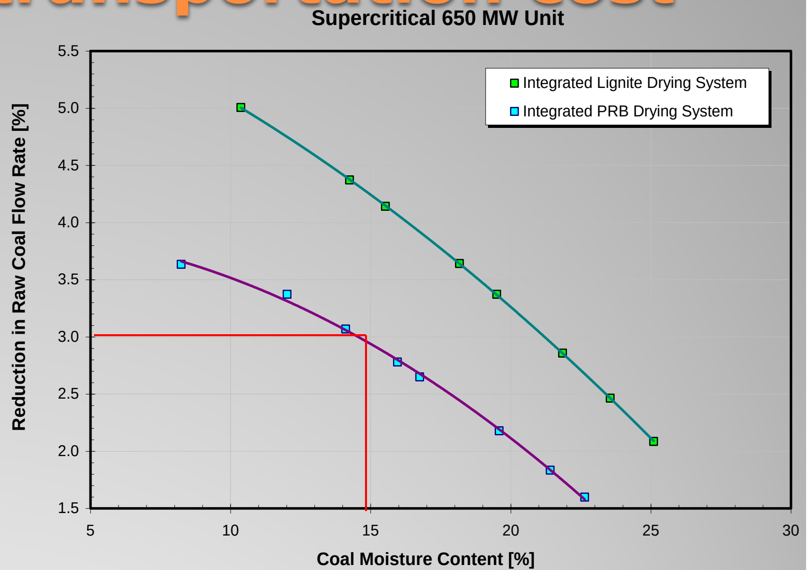


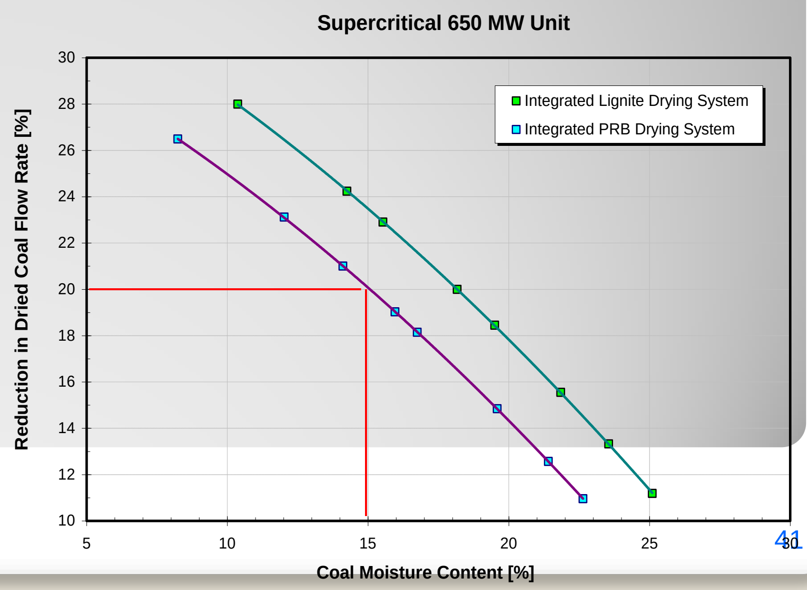
Source: EPRI

Drying at the Mine reduces transportation cost

- Coal drying at the plant results in fuel saving equivalent to heat rate improvement.
- Drying at the mine results in savings equivalent to heat rate improvement plus the transportation cost of the water removed
- **Example**: Buy lignite at the mine \$10/ton and ship to Plant for \$40/ton → **Total =\$50/ton**
  - Drying on site from **30%** to **15%** results in raw coal and freight saving of **3%**
  - Drying at the mine results in a **3%** reduction in raw coal and a **20%** reduction in freight, or
  - Need waste heat source at mine.

$$\frac{20\% \times \$40 + 3\% \times \$10}{\$50} = 16.7\%$$





41

Commercial Coal Drying System: Construction

Dryer area before & after

Rigging Dust Collectors

44

Summer 2009 Installation

45

DryFining™ conveying system

Project did not impact availability!

January 2010

Coal Drying System: Emissions Test Results

(September 2009, March/April 2010, and October 2011)

DryFining system performance & emissions

Test	$O_{2,APH,in}$ %	Stack flow kscfm	SO_x lb/MBtu	NO_x lb/MBtu	Hg^T $\mu g/Nm^3$	Fuel klbs/hr
Pre	2.54	1,536	0.577	0.283	14	946
Post*	2.76	1,467	0.3055	0.194	8.75	852.5
%Diff	**+8.6**	**-4.5**	**-47**	**-30**	**-37.5**	**-9.9**

Test	Mill Power kW	HR_{net} BTU/kWh	η_B %-point	$O_{2,APH,in}$ %	APH Leakage %	TM** %	HHV** Btu/lb
Pre	3916	10465	78.67	2.54	8.2	37.8	6,251
Post*	3544	10046	80.8	2.76	4.1	30.2	7,037
%Diff	**-10.5**	**-4**	**-2.7**	**+8.6**	**-50**	**-20**	**+12.6**

* Post March/April 2010 and October 2011
** Dryer functionality tests , January 2010

50

DryFining system performance & emissions

Test	Stack Flow klb/hr	$CO_{2,Stack}$ % vol	$CO_{2,Stack}$ % wt	CO_2 Mass Emissions klb/hr	Q_{CEM} MBTU/hr	FEGT ºF
Pre	6,135	13.14	19.92	1,240	5,773	2,000
Post*	5,861	13.65	20.68	1,212	5,646	2,053
%Diff	**-5.1**	**+3.85**	**+3.0**	**-2.3**	**-2.2**	

Test	HHV MAF BTU/lb	ID Fan Power kW	Opacity %	Burner Tilt Degrees	WFGD Inlet Temp. ºF	Stack Temp. ºF
Pre	12,146	8,767	6.6	19.2	345	188
Post*	12,046	7,251	5.8	11.5	309	156
%Diff	**-o.8**	**-17.3**	**-0.8**	**-40.1**	**-36**	**-32**

* Post March/April 2010 and October 2011
** Dryer functionality tests , January 2010

Mercury in Flue Gas

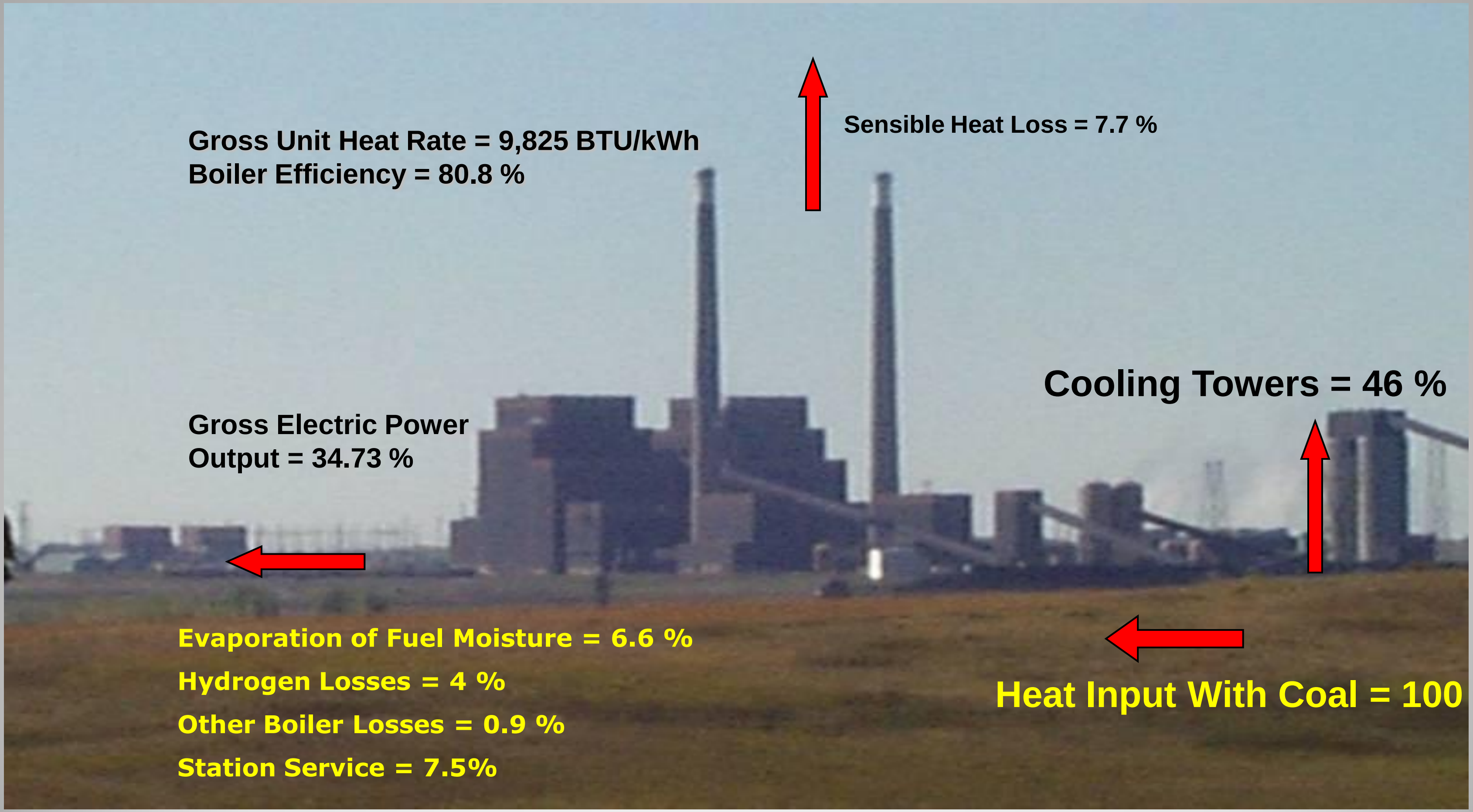
sCEM Measurements				
Measurement Location	**Measured Quantity (sCEM)**	**Units**	**Wet Coal Baseline Average**	**Dried Coal Average**
APH Inlet	Total Hg	$\mu g/dNm^3$ at 3% O_2	**19.2**	**15.3**
	Elemental Hg	$\mu g/dNm^3$ at 3% O_2	18.0	15.3
	Oxidized Hg	% of Hg^T	**11**	**1**
FGD Inlet	Total Hg	$\mu g/dNm^3$ at 3% O_2	**16.0**	**13.7**
	Elemental Hg	$\mu g/dNm^3$ at 3% O_2	11.6	8.0
	Oxidized Hg	% of Hg^T	27	42
FGD Outlet	Total Hg	$\mu g/dNm^3$ at 3% O_2	**13.1**	**9.5**
	Elemental Hg	$\mu g/dNm^3$ at 3% O_2	12.3	8.9
	Oxidized Hg	%	**7**	**6**
FGD Bypass	Total Hg	$\mu g/dNm^3$ at 3% O_2	**14.82**	**14.40**
	Elemental Hg	$\mu g/dNm^3$ at 3% O_2	11.57	9.70
	Oxidized Hg	% of Hg^T	22	33
Stack	Total Hg	$\mu g/dNm^3$ at 3% O_2		**8.7**
	Elemental Hg	$\mu g/dNm^3$ at 3% O_2		8.3
	Oxidized Hg	% of Hg^T		**5**

Hg^T reduction = 43%

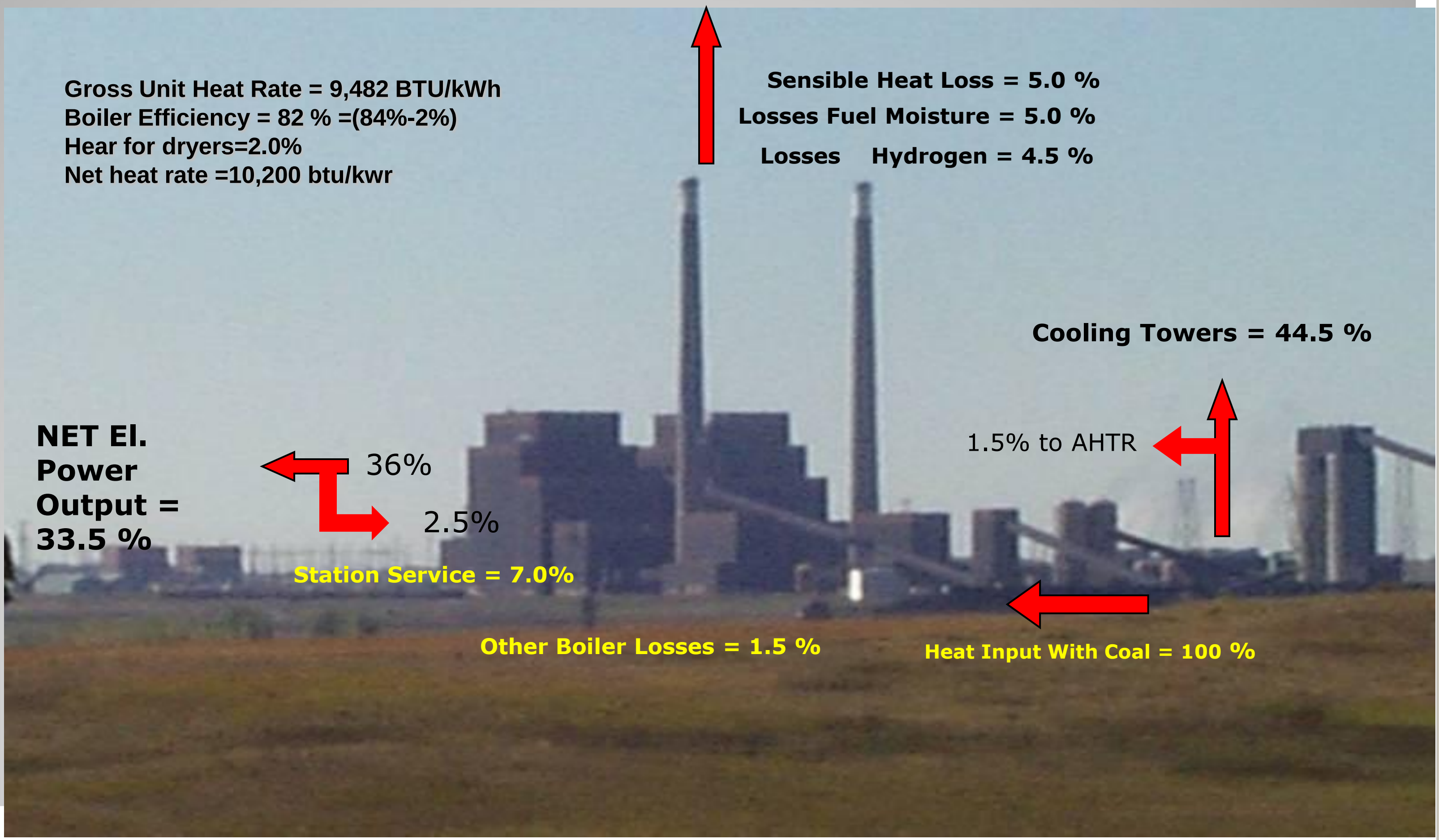
Native Mercury Removal	Wet Coal Baseline Average	Dried Coal Average
	%	%
Native Hg^T Removal Across APH/ESP	**16**	**10**
Native Hg^T Removal Across FGD	**15**	**35**
Native Hg^T Removal Across APH/ESP/FGD	**31**	**38**
Native Hg^{2+} Removal Across FGD	**74**	**86**
Hg^{2+} Re-emitted as Hg^0	**33**	**17**

52

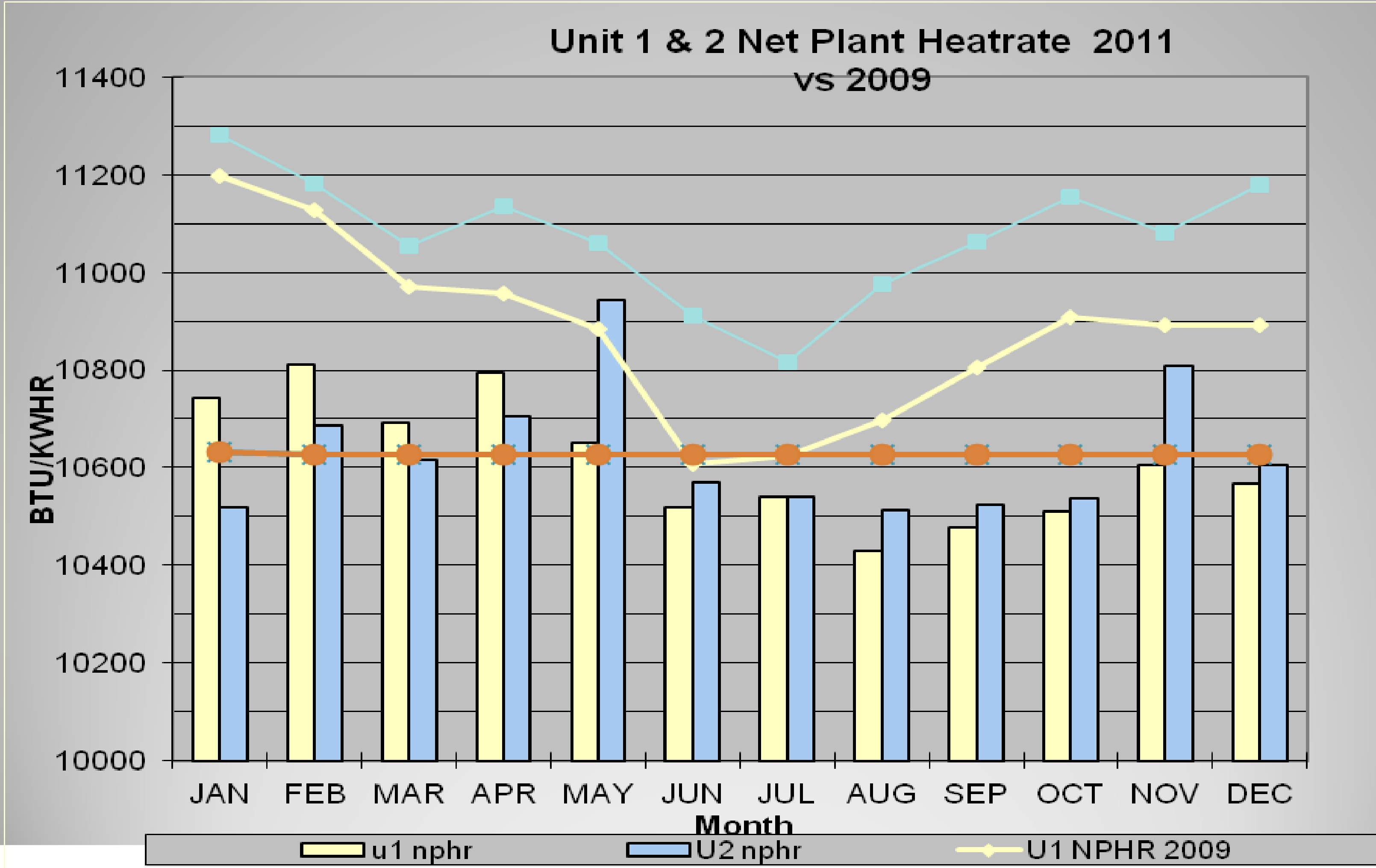
Energy Flows: Coal Creek Station 2006



Heat Flows: Coal Creek Station 2013

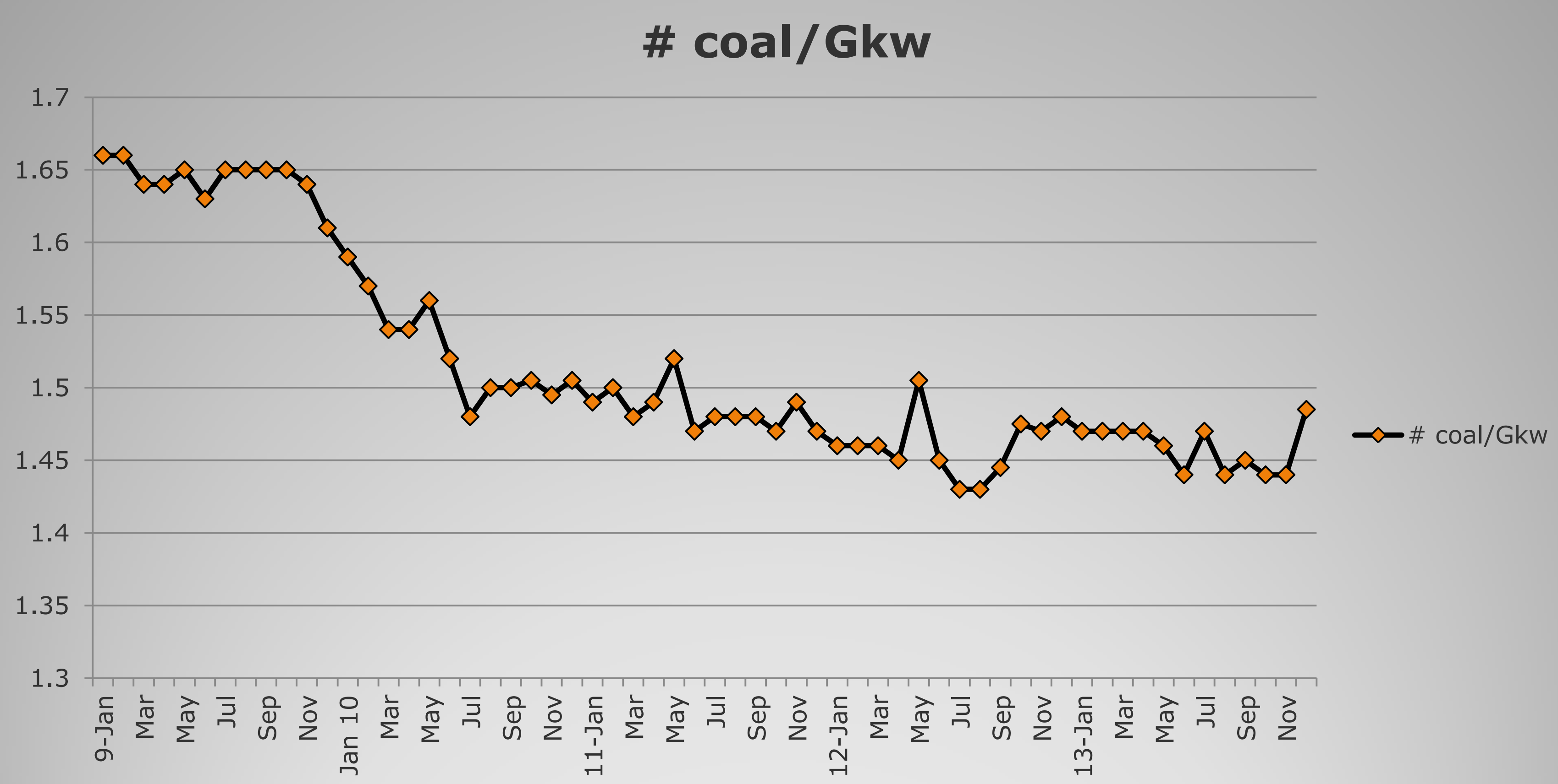


Seasonal heat rate improvement



DryFining results at Coal Creek

- **$20+ million in annual O&M savings**
- **10% less fuel** – reduces O&M on fuel handling
- **54% less SO_2** - Segregation of ash minerals, plus improved collection efficiency, less coal flow
- **40% less Hg**- Segregation of ash minerals, plus improved collection efficiency, less coal flow
- **32% less NO_x**- Reduced volumetric release rate, improved air & fuel distribution to furnace
- **4% less CO_2**- 4% improved cycle efficiency
- Did qualify for a Section 45 coal production tax credit



Less coal per MW

2010 Coal-fired Project of the Year