SIMULATION PROJECT

PRESENTED AT
US-India Coal Working Group
8th Annual Meeting
New Delhi, India March 24, 2011

COMPUTER SIMULATION TO EVALUATE THE BENEFITS OF CLEAN COAL FOR THERMAL POWER GENERATION

PREPARED BY MARK A. SHARPE
SHARPE INTERNATIONAL LLC., USA

ANALYZING THE VALUE OF WASHED COAL

<u>OBJECTIVE:</u>

MODEL THE PARAMETERS i.e.

1. *RAW COAL QUALITY AND WASHABILITY CHARATERISTICS,*
2. *SIMULATION OF COAL PREPARATION PROCESSES,*
3. *EVALUATE ECONOMIC ASPECTS OF WASHING COSTS, YIELD IMPACT, TRANSPORTATION, EFFICIENCY,*
4. *TO COMPARE THE COSTS AND BENEFITS OVER A RANGE OF CONDITIONS.*

ANALYZING THE VALUE OF WASHED COAL

STEPS IN THE ANALYSIS:

- DATA COLLECTION
- DATA ANALYSIS AND EVALUATION
- PROCESS SELECTION
- DERIVING THE COST/BENEFITS OF CLEAN COAL
- WORKING WITH THE RESULTS
- SUMMARY

Clean Coal Process Simulator Project Schedule

- Project Development Plan - Completed
- Coal Sample Data Collection – Completed
- Software Development-Presented to CMPDI
- Draft GUI & Logic Ladder-Meeting with CMPDI for Acceptance March 25th
- Development of Software – JAVA : Underway
- Working Prototype – August 2011
- Final Simulator Developed Using JAVA/SWING – October 2011

Clean Coal Process Simulator

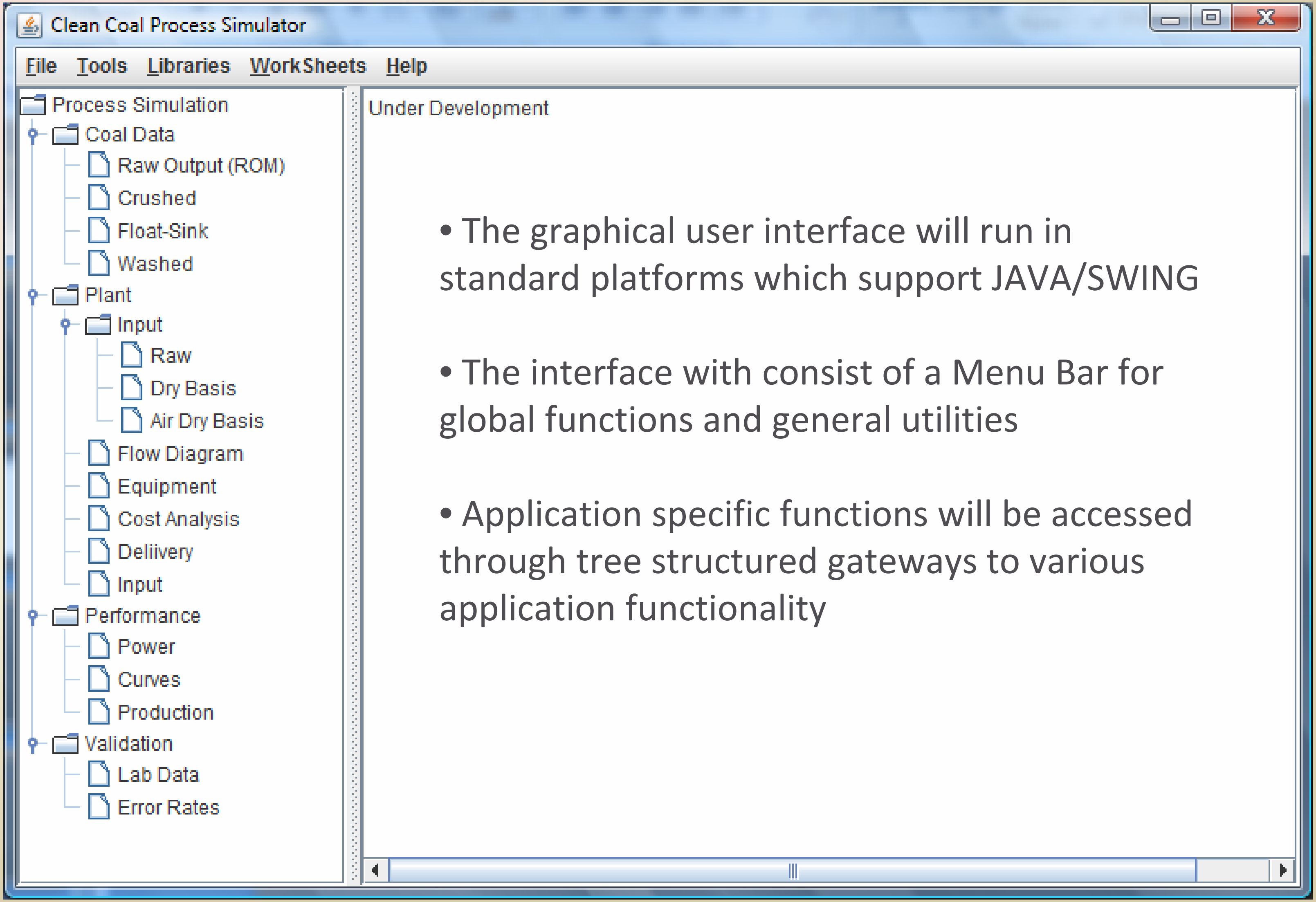
Graphical User Interface

Working JAVA Prototype

Clean Coal Process Simulator GUI Prototype

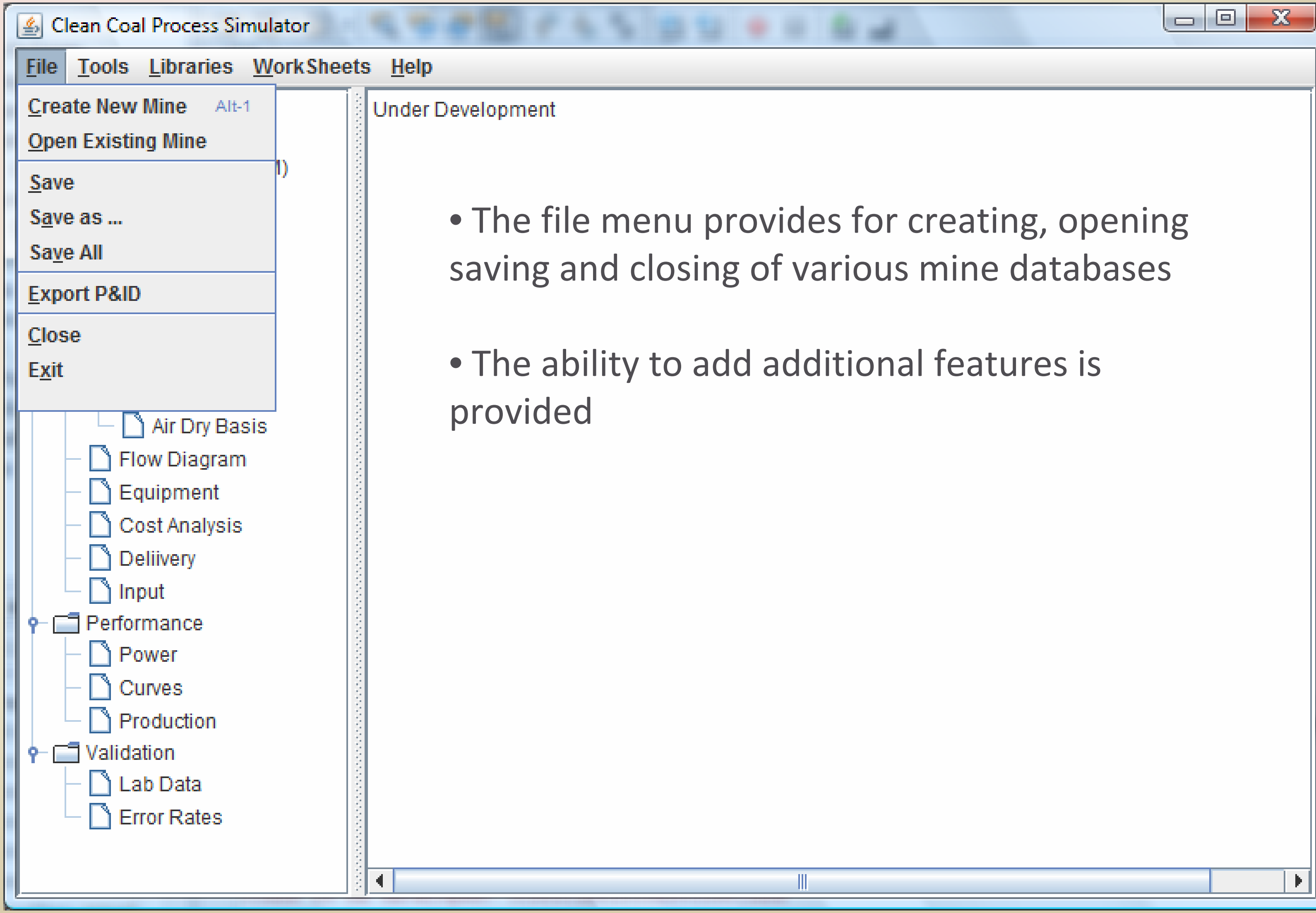
- Presented to CMPDI for acceptance
- Software Development Program & Draft Logic Ladder and GUI Models
- DYNAMIC LOGIC MODEL-GR2.xlsx
- Working Prototype
- Final Simulator Developed Using JAVA/SWING

Clean Coal Process Simulator GUI



- The graphical user interface will run in standard platforms which support JAVA/SWING
- The interface with consist of a Menu Bar for global functions and general utilities
- Application specific functions will be accessed through tree structured gateways to various application functionality

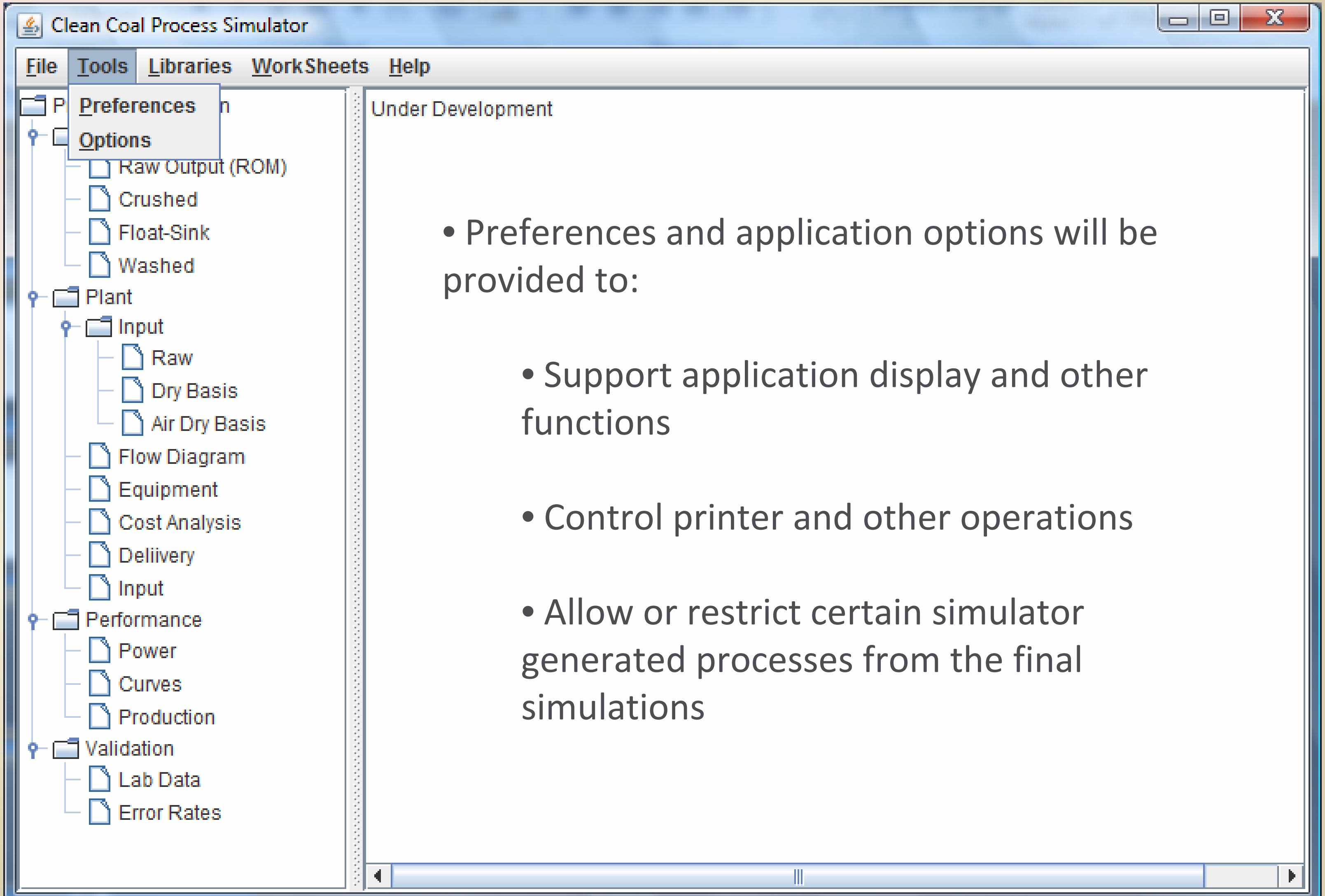
Clean Coal Process SimulatorGUI



- The file menu provides for creating, opening saving and closing of various mine databases

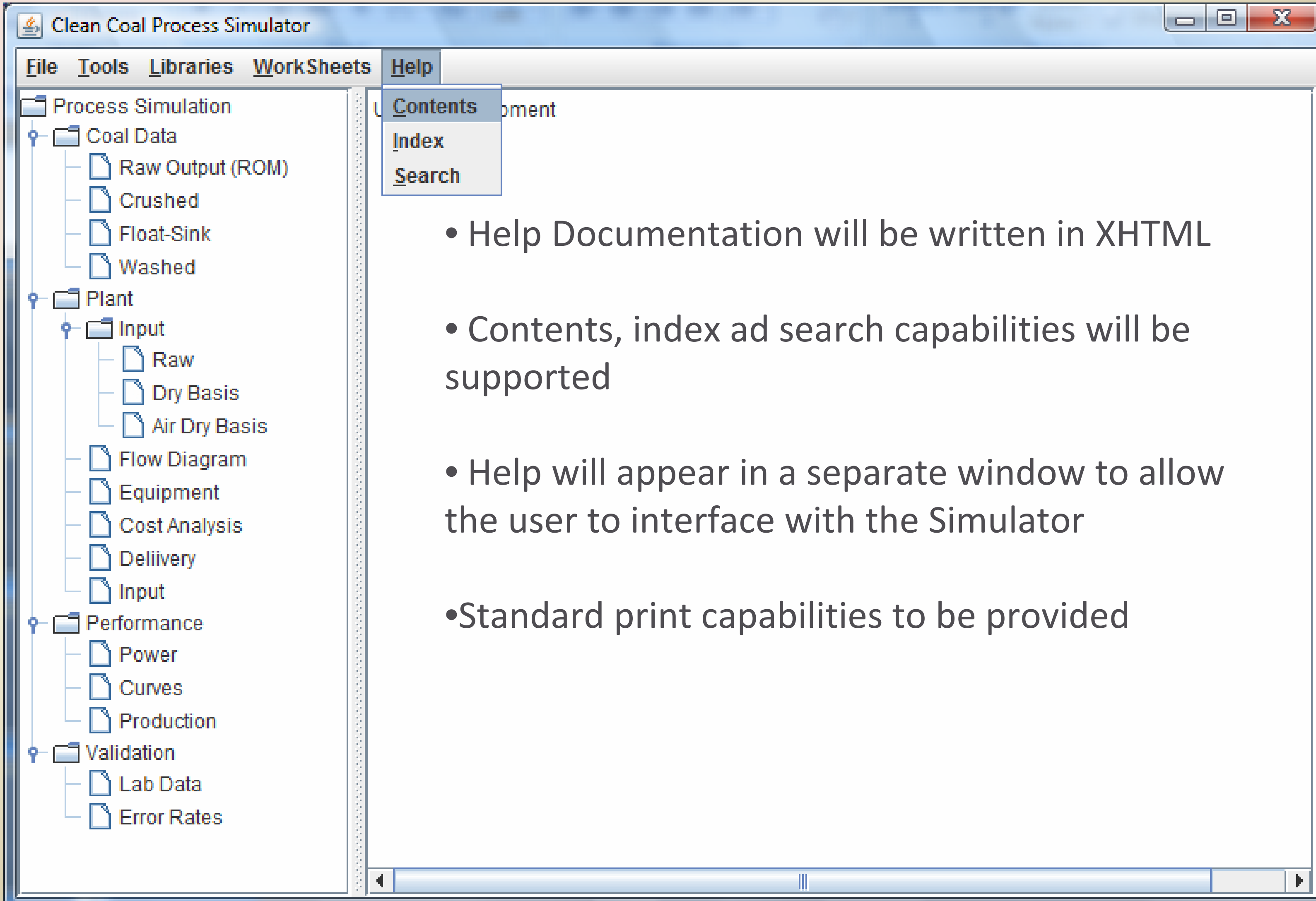
- The ability to add additional features is provided

Clean Coal Process Simulator GUI



- Preferences and application options will be provided to:
  - Support application display and other functions
  - Control printer and other operations
  - Allow or restrict certain simulator generated processes from the final simulations

Clean Coal Process Simulator GUI



- Help Documentation will be written in XHTML
- Contents, index ad search capabilities will be supported
- Help will appear in a separate window to allow the user to interface with the Simulator
- Standard print capabilities to be provided

Clean Coal Process Simulator GUI

Clean Coal Process Simulator

File Tools Libraries WorkSheets Help

- Process Simulation
  - Coal Data
    - Raw Output (ROM)
    - Crushed
    - Float-Sink
    - Washed
  - Plant
    - Input
      - Raw
      - Dry Basis
      - Air Dry Basis
    - Flow Diagram
    - Equipment
    - Cost Analysis
    - Deliivery
    - Input
  - Performance
    - Power
    - Curves
    - Production
  - Validation
    - Lab Data
    - Error Rates

Under Development

Baroud OCP 100 ROM COAL DATA

Size Fraction mm		Wt%	Ash %	Moist %	Over Size (mm) plus	Overs Cum Wt%	Overs Cum Ash%	Overs Cum M%	Under Size (mm) minus	Under Cum Wt%	Under Cum Ash%	Under Cum M%
plus	200	4.20	52.20	7.40	200	4.20	52.20	7.40	200	95.80	47.35	5.54
200	150	16.10	49.80	7.00	150	20.30	50.30	7.08	150	79.70	46.86	5.24
150	100	16.60	48.90	5.80	100	36.90	49.67	6.51	100	63.10	46.32	5.09
100	50	13.90	48.20	5.50	50	50.80	49.27	6.23	50	49.20	45.79	4.98
50	25	22.10	49.60	5.10	25	72.90	49.37	5.89	25	27.10	42.68	4.88
25	13	13.00	45.60	5.00	13	85.90	48.80	5.75	13	14.10	39.99	4.77
13	6	3.50	41.50	5.30	6	89.40	48.51	5.74	6	10.60	39.49	4.59
6	3	3.90	40.10	4.50	3	93.30	48.16	5.68	3	6.70	39.14	4.64
3	0.5	3.40	38.20	4.20	0.5	96.70	47.81	5.63	0.5	3.30	40.10	5.10
0.5	0	3.30	40.10	5.10	0	100.00	47.56	5.61	0	0.00		
	Total	100.00	47.56	5.61								

- Simulated input/output typical for many tree interfaces

- All application capabilities to be written in JAVA and stored in XML format

GUI - PROXIMATE DATA

Table 3 – TYPICAL PROXIMATE ANALYSIS INPUT DATA FIELDS		
Test	Air dried basis	60%RH & 40deg.C
Moisture %	M_{ADB}	M_{EQ}
Ash %	A_{ADB}	A_{EQ}
VM%	VM_{ADB}	VM_{EQ}
FC%	FC_{ADB}	FC_{EQ}
GCV (Kcal/Kg.)	GCV_{ADB}	------
HGI	HGI_{ADB}	------
Color & Text Style Coding **Headings ›› Size, mm**	***Data Input ›› M_{ADB}***	

M = Moisture
VM = Volatile Matter
GCV = Gross Calorific Value

A = Ash
FC = Fixed Carbon
HGI = Hard Grove Index

GUI FOR ROM SIZE CUM ASH

Table 1 – ROM (UNCRUSHED) TYPICAL SIZE CUM ASH INPUT DATA FIELDS			
Size, mm	Wt%	Ash%	Moisture%
+200	W_{+200}	A_{+200}	M_{+200}
200 -100	$W_{200-100}$	$A_{200-100}$	$M_{200-100}$
150-100	$W_{150-100}$	$A_{150-100}$	$M_{150-100}$
100-50	W_{100-50}	A_{100-50}	M_{100-50}
50-25	W_{50-25}	A_{50-25}	M_{50-25}
25-13	W_{25-13}	A_{25-13}	M_{25-13}
13-6	W_{13-6}	A_{13-6}	M_{13-6}
6-3	W_{6-3}	A_{6-3}	M_{6-3}
3-0.5	$W_{3-0.5}$	$A_{3-0.5}$	$M_{3-0.5}$
-0.5	$W_{-0.5}$	$A_{-0.5}$	$M_{-0.5}$
Totals	W_T	A_T	M_T

Color & Text Style Coding

Headings ›› Size, mm ***Data Input ›› W_x*** **Calculated Values ››W_T, A_T, M_T**

GUI - CRUSHED SAMPLE SIZE CUM ASH

Table 2 – (CRUSHED) TYPICAL SIZE CUM ASH INPUT DATA FIELDS

Size, mm	Wt%	Ash%	Moisture%
50-25	W_{50-25}	A_{50-25}	M_{50-25}
25-13	W_{25-13}	A_{25-13}	M_{25-13}
13-6	W_{13-6}	A_{13-6}	M_{13-6}
6-3	W_{6-3}	A_{6-3}	M_{6-3}
3-0.5	$W_{3-0.5}$	$A_{3-0.5}$	$M_{3-0.5}$
-0.5	$W_{-0.5}$	$A_{-0.5}$	$M_{-0.5}$
Totals	W_T	A_T	M_T

Color & Text Style Coding

Headings >> Size, mm   *Data Input >> W_x*   Calculated Values >> W_T, A_T, M_T

GUI - FLOAT – SINK RESULTS

Table 4 – TYPICAL FLOAT – SINK INPUT

Size (mm)		50 – 25		25 – 10		10-6		6-3		3- 0.5		50 – 0.5	
Sample Wt		56.0		16.6		11.2		5.2		6.2		95.2	
Wt %		58.8		17.4		11.8		5.5		6.5		100.0	
		Wt %	Ash %	Wt %	Ash %	Wt %	Ash %	Wt %	Ash %	Wt %	Ash %	Wt %	Ash %
<	1.4	0.5	14.2	3.3	13.7	3.6	9.2	9.2	7.7	20.4	6.0	3.1	8.9
1.4	1.5	6.4	21.8	12.6	21.9	10.5	17.7	11.6	17.6	13.7	17.0	8.7	20.4
1.5	1.6	19.4	30.1	20.0	30.7	16.3	26.4	15.8	26.7	15.6	25.9	18.7	29.4
1.6	1.7	18.7	38.7	17.9	39.2	17.1	34.6	15.1	34.8	14.3	34.3	17.9	37.9
1.7	1.8	8.8	44.1	5.5	44.8	15.2	42.2	12.8	42.0	12.8	42.3	9.5	43.5
1.8	1.9	10.3	49.8	11.0	49.9	10.8	49.9	11.0	49.5	8.9	49.8	10.4	49.8
+	1.9	35.9	69.8	29.7	68.8	26.5	68.6	24.5	68.4	14.3	68.5	31.7	69.4
		100.0	48.6	100.0	44.8	100.0	42.4	100.0	39.8	100.0	32.1	100.0	45.7

Color & Text Style Coding

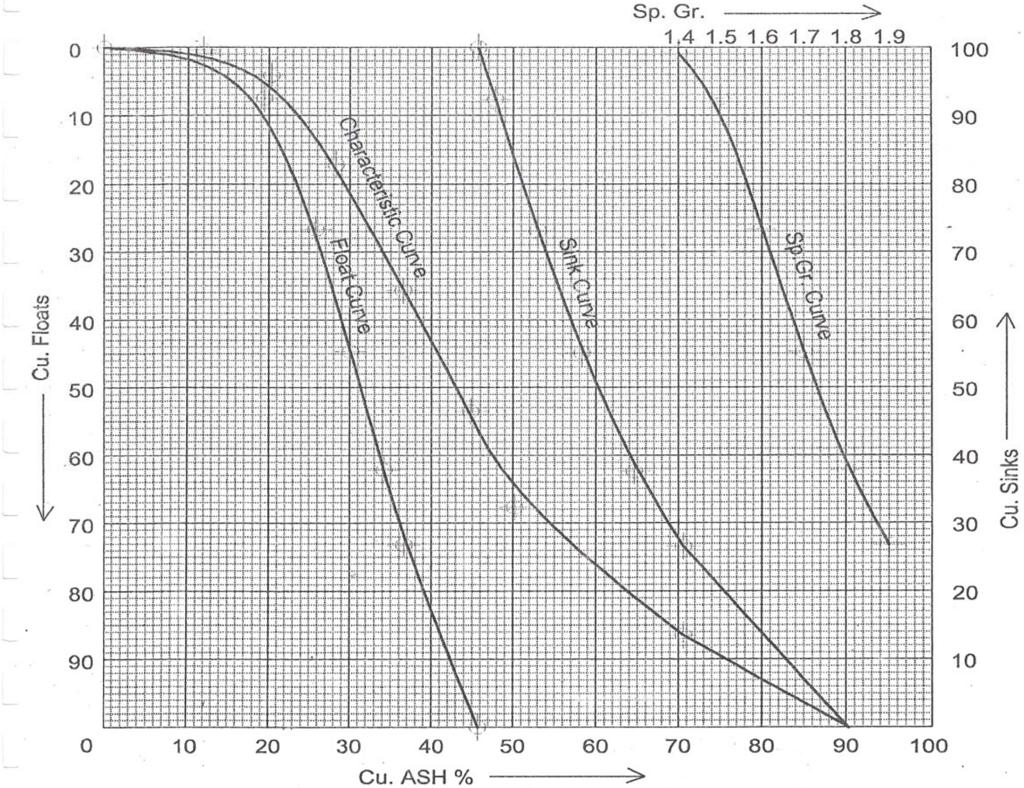
Headings ›› Size, mm Data Input ›› Wt% Calculated Value ›› Totals & Ash

RAW COAL QUALITY AND WASHABILITY

GUI - WASHABILITY DATA ANALYSIS

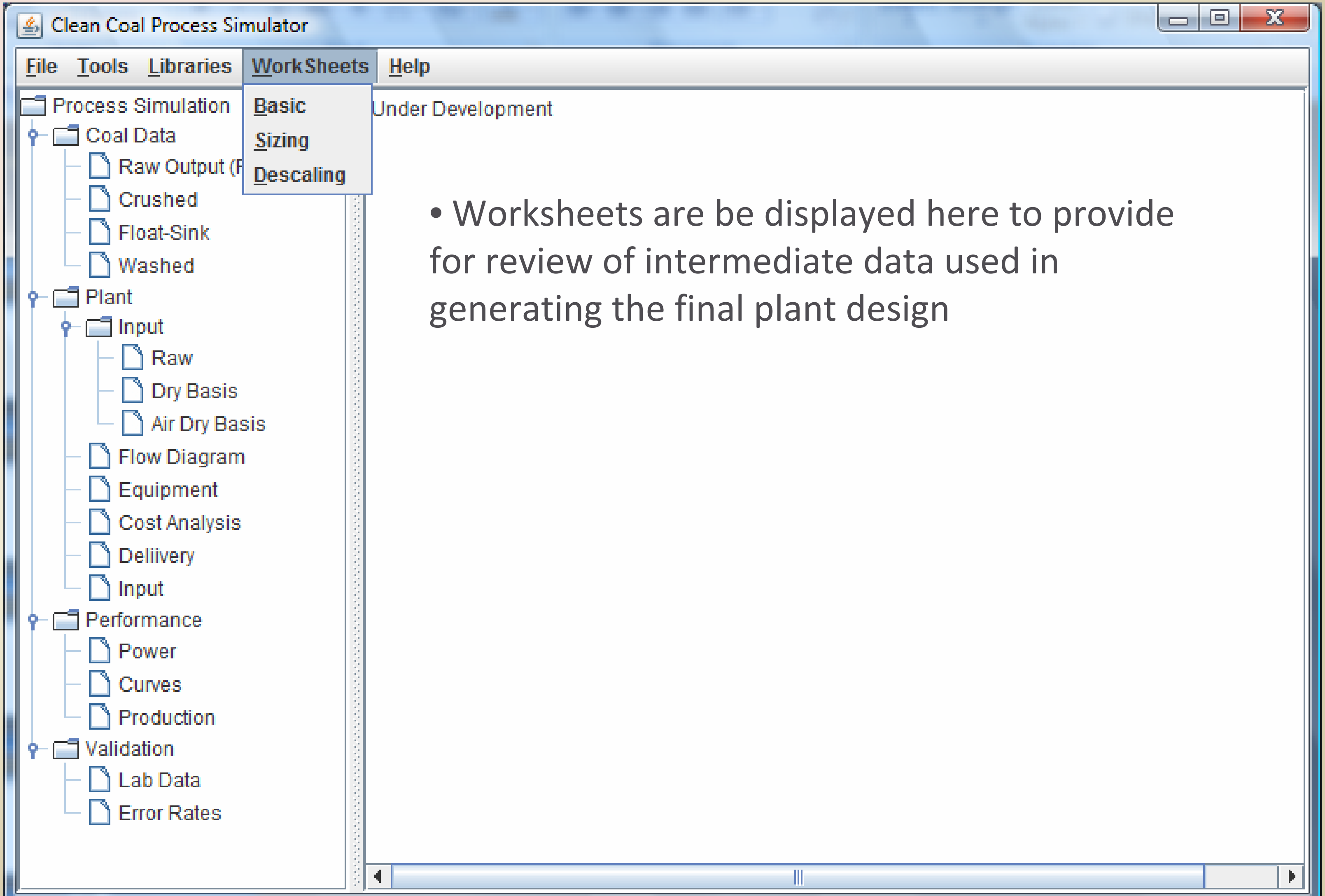
Table 5 – TYPICAL WASHABILITY DATA DEVELOPED FROM FLOAT-SINK TESTS														
Col 1		Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12	Col 11	Col 12
		Direct, 50-0.5mm			Cumulative float, 50–0.5mm			Cumulative sink, 50-0.5mm					+/-0.1 r-d (NGM)	
Relative density - r-d fraction		Wt %	Ash %	Wt% of Ash of Total	Cum Wt% of Ash %	Wt %	Ash %	Sink Wt% of Ash %	Wt %	Ash %	Ch. Wt%	Mayer's Pt. Value	r-d	Wt%
<	1.4	*3.1*	*8.9*	0.3	0.3	3.1	8.9	45.4	96.9	46.8	1.6	0.3	1.4	11.8
1.4	1.5	*8.7*	*20.4*	1.8	2.1	11.8	17.4	43.6	88.2	49.4	7.5	2.1	1.5	27.4
1.5	1.6	*18.7*	*29.4*	5.5	7.6	30.5	24.8	38.1	69.5	54.8	21.2	7.6	1.6	36.6
1.6	1.7	*17.9*	*37.9*	6.8	14.4	48.4	29.6	31.3	51.6	60.7	39.5	14.4	1.7	27.3
1.7	1.8	*9.5*	*43.5*	4.1	18.5	57.9	31.9	27.2	42.1	64.6	53.2	18.5	1.8	19.9
1.8	1.9	*10.4*	*49.8*	5.2	23.7	68.3	34.6	22.0	31.7	69.4	63.1	23.7	1.9	42.1
>	1.9	*31.7*	*69.4*	22.0	45.7	100.0	45.7				84.2	45.7		
		100.0	46.2	45.7										
Color & Text Style Coding Headings >> Size, mm *Data Input >> Wt%* Calculated Value >> A_x														

TYPICAL WASHABILITY CURVES



Customer	BHARAT COKING COAL LIMITED	
Job Title	Nichitpur OCP Seam III	Job No. 314208064
Subject	Washability Curve Part III Size : 50 - 0.5 mm	

Clean Coal Process Simulator GUI



- Worksheets are be displayed here to provide for review of intermediate data used in generating the final plant design

DESHALING

- THE SAMPLE ANALYSES DATA IS EVALUATED FOR DESHALING POTENTIAL BY TWO METHODS
  1. REMOVAL OF TOP SIZE BY DRY SCALPING SCREEN AND/OR,
  2. WET HIGH GRAVITY (FLOAT AT SPECIFIC GRAVITY GREATER THAN 1.9) SEPARATION

DRY BYPASSING OF FINES

- THE SAMPLE ANALYSES DATA IS EVALUATED FOR FINE COAL BYPASS POTENTIAL USING THEORETICAL YIELDS OF WASHABILITY TESTS
  1. BYPASS SIZE FOR DRY SCREENING AT 13, 6 OR 3 mm CAN BE SELECTED

PROCESS SIMULATION

THE COMPUTER MODEL WILL SIMULATE CLEAN AND REJECT PERFORMANCE OF GENERIC FLOWSHEETS AT FIVE LEVELS

- LEVEL 1
  - ROUGH SCALPING AND CRUSHING
- LEVEL 2
  - COARSE COAL (+13 MM) CLEANING ONLY
- LEVEL 3
  - COARSE AND FINE COAL CLEANING
- LEVEL 4
  - COARSE, FINE, AND ULTRA FINE COAL CLEANING
- LEVEL 5
  - LEVEL 4 CLEANING PLUS MIDDLINGS CRUSHING AND REWASH

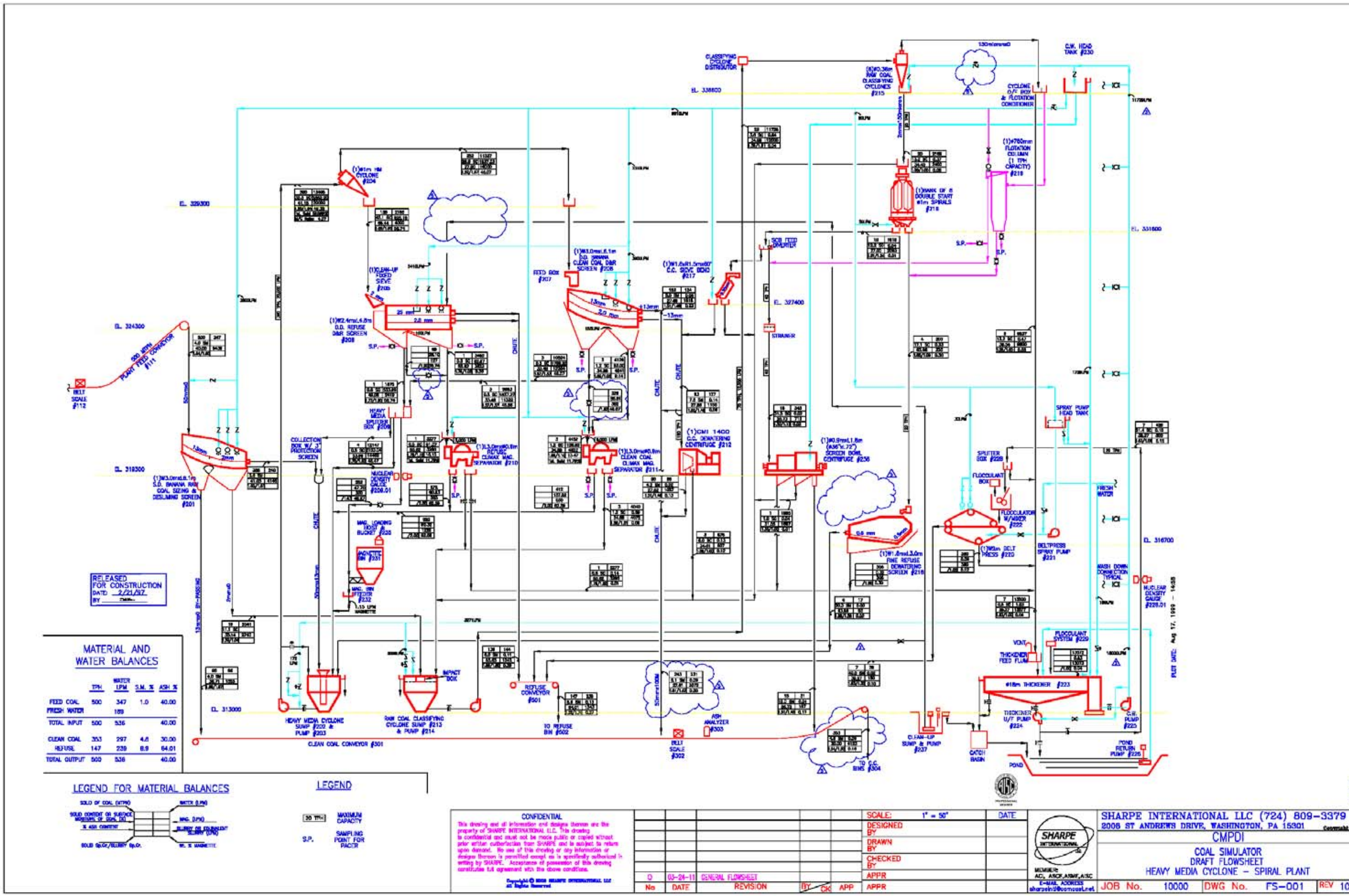
PROCESS SIMULATION

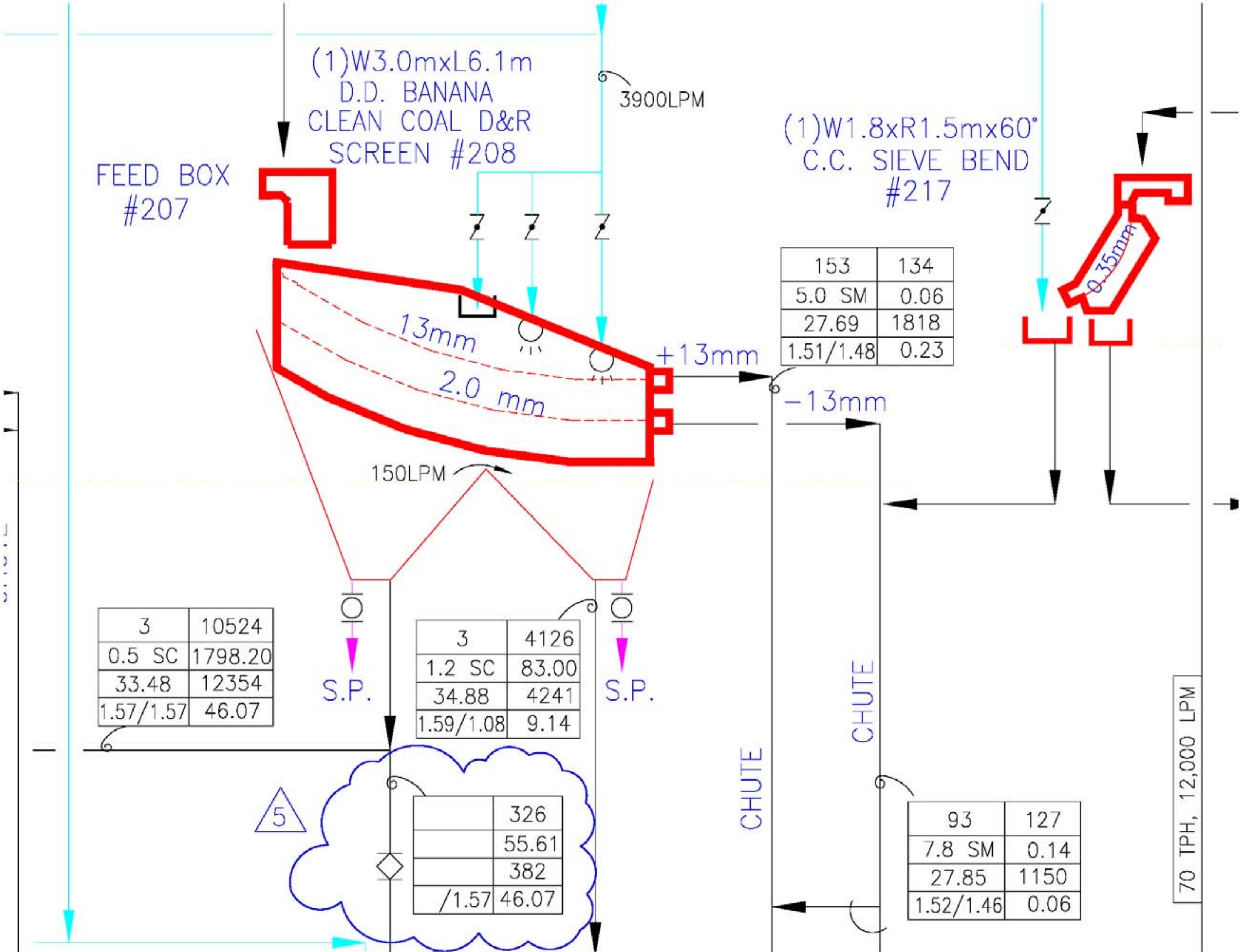
PROCESS SELECTION

BASED ON INPUT FROM THE USER SUCH AS:

- REQUIRED CLEAN COAL ASH
- MINIMUM YIELD
- MINIMUM ASH IN REJECT
- MAXIMUM WASHING COST

THE PROGRAM WILL SELECT A RECOMMENDED LEVEL OF WASHING AND REPRESENTAIVE FLOWSHEET. USERS CAN THEN MANUALLY MODIFY THE FINAL FLOWSHEET.


MATERIAL AND WATER BALANCES
TPH | WATER LPM | S.M. % | ASH %
FEED COAL 500 347 1.0 40.00
FRESH WATER 189
TOTAL INPUT 500 536 40.00
CLEAN COAL 353 297 4.6 30.00
REFUSE 147 239 8.9 64.01
TOTAL OUTPUT 500 536 40.00
LEGEND FOR MATERIAL BALANCES
LEGEND
MAXIMUM CAPACITY
S.P. SAMPLING POINT FOR PACER
RELEASED FOR CONSTRUCTION
HEAVY MEDIA CYCLONE SUMP #202 & PUMP #203
RAW COAL CLASSIFYING CYCLONE SUMP #213 & PUMP #214
CLEAN COAL CONVEYOR #301
CONFIDENTIAL
GENERAL FLOWSHEET
REVISION
SCALE: 1" = 50'
DESIGNED BY
DRAWN BY
CHECKED BY
APPR
SHARPE INTERNATIONAL
SHARPE INTERNATIONAL LLC (724) 809-3379
2006 ST ANDREWS DRIVE, WASHINGTON, PA 15301
CMPDI
COAL SIMULATOR
DRAFT FLOWSHEET
HEAVY MEDIA CYCLONE – SPIRAL PLANT
JOB No. 10000
DWG No. FS-001
REV 10


(1)W3.0mxL6.1m
D.D. BANANA
CLEAN COAL D&R
SCREEN #208
3900LPM
FEED BOX
#207
(1)W1.8xR1.5mx60°
C.C. SIEVE BEND
#217
0.35mm
13mm
2.0 mm
+13mm
-13mm
153 | 134
5.0 SM | 0.06
27.69 | 1818
1.51/1.48 | 0.23
150LPM
S.P.
S.P.
3 | 10524
0.5 SC | 1798.20
33.48 | 12354
1.57/1.57 | 46.07
3 | 4126
1.2 SC | 83.00
34.88 | 4241
1.59/1.08 | 9.14
5
326
55.61
382
/1.57 | 46.07
CHUTE
CHUTE
93 | 127
7.8 SM | 0.14
27.85 | 1150
1.52/1.46 | 0.06
70 TPH, 12,000 LPM

PROCESS SIMULATION

<u>FOR DETAILED SIMULATION, FINITE CURVE MODELING IS BEING USED</u>

USE POLYNOMIAL CURVE GENERATORS SUCH AS MATLAB® OR KALEIDAGRAPH®. ($Y=M+M^1+M^2 + \ldots+M^X$) TO REPRESENT THE CHARACTERISTICS OF THE SIZE RANGE TYPICAL OF THE FEED DISTRIBUTION TO A SPECIFIC CLEANING DEVICE.

PROCESS SIMULATION

THE CURVES ARE APPROXIMATED FOR THE TOTAL RANGE OF COAL SIZES AND ALSO FOR THE COARSE, FINE AND SMALL COAL RANGES.

PROCESS SIMULATION

- <u>EXAMPLE</u>
  - FOR THE 100 X 13mm SIZE RANGE, THE THEORETICAL SPECIFIC GRAVITY DETERMINED BY THE CLEAN PRODUCT CUMULATIVE ASH CAN BE REPRESENTED BY THE FORMULA

$SG = M_0 + M_1 + M_2 + M_3$

$SG = 1.2975 + 0.0006493*A^1 + 0.00019622*A^2 +$

$-0.0000009393*A^3$

EXAMPLE: USING ASH (A) = 34; $SG_{A=34} = 1.5095$

PROCESS SIMULATION

- PROCESS EQUIPMENT PARTITION CURVES

THE PERFORMANCE AND EFFICIENCY OF THE CLEANING DEVICES ARE REPRESENTED BY PARTITION CURVES.

(TYPICAL EXAMPLE IS WHITEN FORMULA)

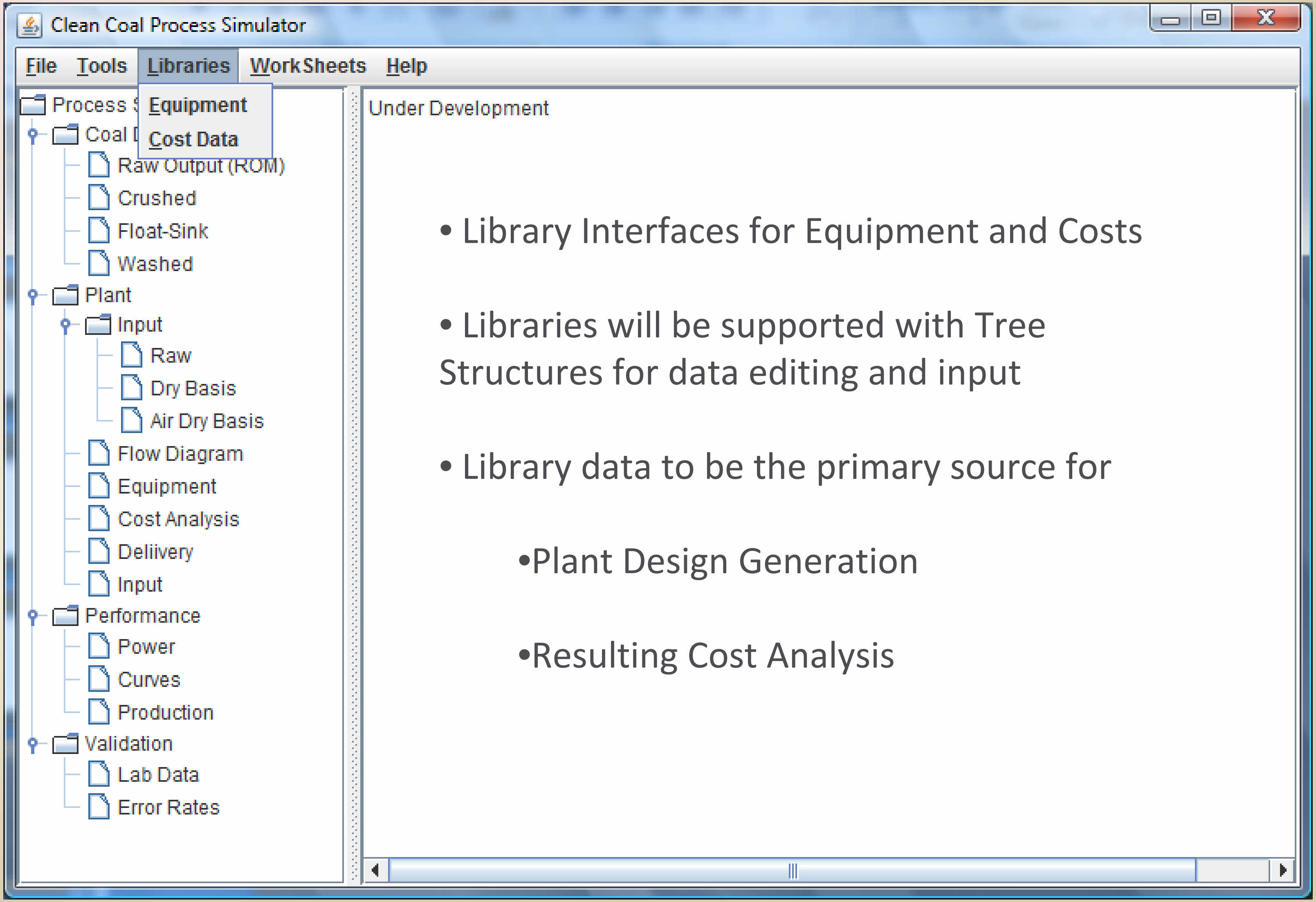
$$P = \frac{1}{1 + \exp\left\{\frac{(SG_{50} - SG)}{0.91}\right\}}$$

P = PROBABILITY OF REPORTING TO REFUSE

SG_{50}= CUTPOINT SG AT P = 0.5

Ep = PROBABLE ERROR BEING STEEPNESS OF CURVE

Clean Coal Process Simulator GUI



- Library Interfaces for Equipment and Costs
- Libraries will be supported with Tree Structures for data editing and input
- Library data to be the primary source for
  - Plant Design Generation
  - Resulting Cost Analysis

DERIVING THE COST AND BENEFITS

ECONOMICS

CAPITAL COSTS – PLANT CAPITAL COST IS ESTIMATED USING ROUTINELY UPDATED COST DATA FOR PLANT PHYSICAL SIZE AND CAPACITY AND EQUIPMENT COSTS. EQUITY AND LOAN VALUES CAN BE INPUT AND ANALYSIS FOR ROI PERFORMED

ECONOMIC ANALYSES OF WASHED COAL

DERIVING THE COST AND BENEFITS

ECONOMICS (CONT.)

OPERATING COSTS - HISTORIC AND CURRENT LABOR AND SUPPLY DATA, ADJUSTED FOR INFLATION OR UPDATED IS USED TO ESTIMATE THE OPERATING COST PER TON.

DERIVING THE COST AND BENEFITS

ECONOMICS (CONT.)

YIELD/ENERGY RECOVERY – THE YIELD OF CLEAN PRODUCT IS CALCULATED FOR THE SELECTED PROCESS FLOWSHEET WITH ADJUSTMENTS FOR EFFICIENCY. EFFICIENCY OF THE DEVICES IS THE FUNCTION OF THE PARTITION CURVES MENTIONED EARLIER. COAL CHARACTERISTICS INCLUDING NEAR GRAVITY CONTENT ARE ACCOUNTED FOR IN THE GENERATION OF THE PARTITION CURVE FOR THE SPECIFIC COALS.

ECONOMIC ANALYSES OF WASHED COAL

VALUES ADDED FROM USING WASHED COAL

- TRANSPORTATION SAVINGS – MAXIMUM HEAT CONTENT SHOULD BE TRANSPORTED PER TON/KM
- POWER PLANT BENEFITS - LOWER O&M COSTS PER KWH AND IMPROVED EFFICIENCIES.
- REDUCED CARBON EMISSIONS -
- INTEGRATED GENERATION - MICRO POWER PLANT AT THE WASHERY SITE
- RECLAMATION – RETURN TO MINE AREA OF WASHERY REJECTS AND FLY ASH

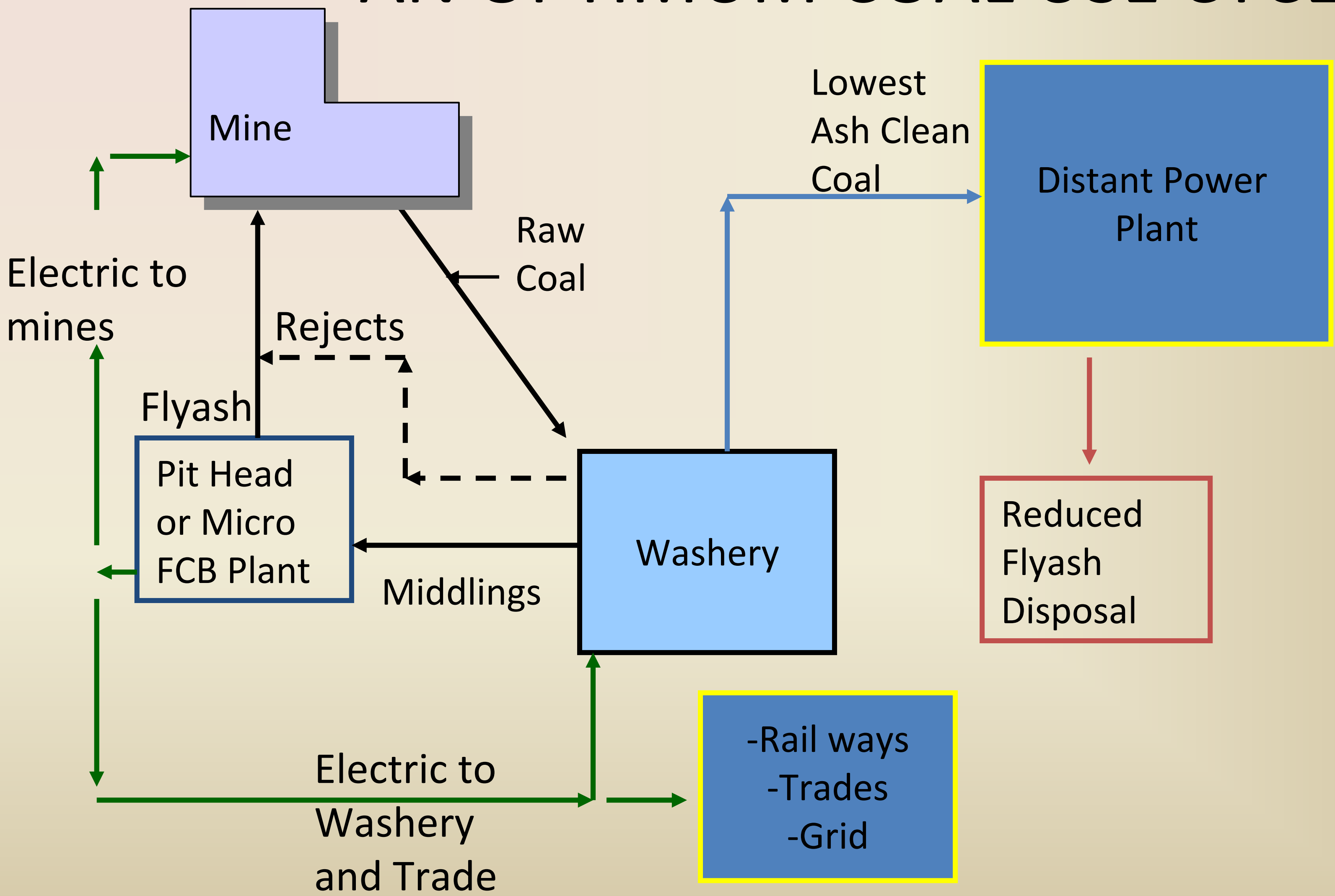
ECONOMIC ANALYSES OF WASHED COAL

OPTIMIZING THE COAL CYCLE

- HIGH CAPACITY, LOW PER TON COST MINES
- EFFICIENT LEVEL 3 WASHERIES (HEAVY MEDIA AND FINE CLEANING CIRCUITS) FOR MAKING TERTIARY PRODUCTS (LOW ASH, MIDDLING, REJECTS)
- ASH CONTENT OF WASHED COAL SHOULD BE AS LOW AS POSSIBLE WHILE MAINTAINING 95% ORGANIC EFFICIENCY (MARKET DRIVEN ELSEWHERE)
- MIDDLINGS FOR CONSISTENT QUALITY TO PIT HEAD AND MICRO GENERATION POWER STATIONS
- PLACEMENT OF REJECTS AND ASH FROM PROCESS BACK IN THE MINE PIT

ECONOMIC ANALYSES OF WASHED COAL

AN OPTIMUM COAL USE CYCLE



ECONOMIC ANALYSES OF WASHED COAL

COMPARING DELIVERED COST IN HEAT UNITS INDIAN COAL

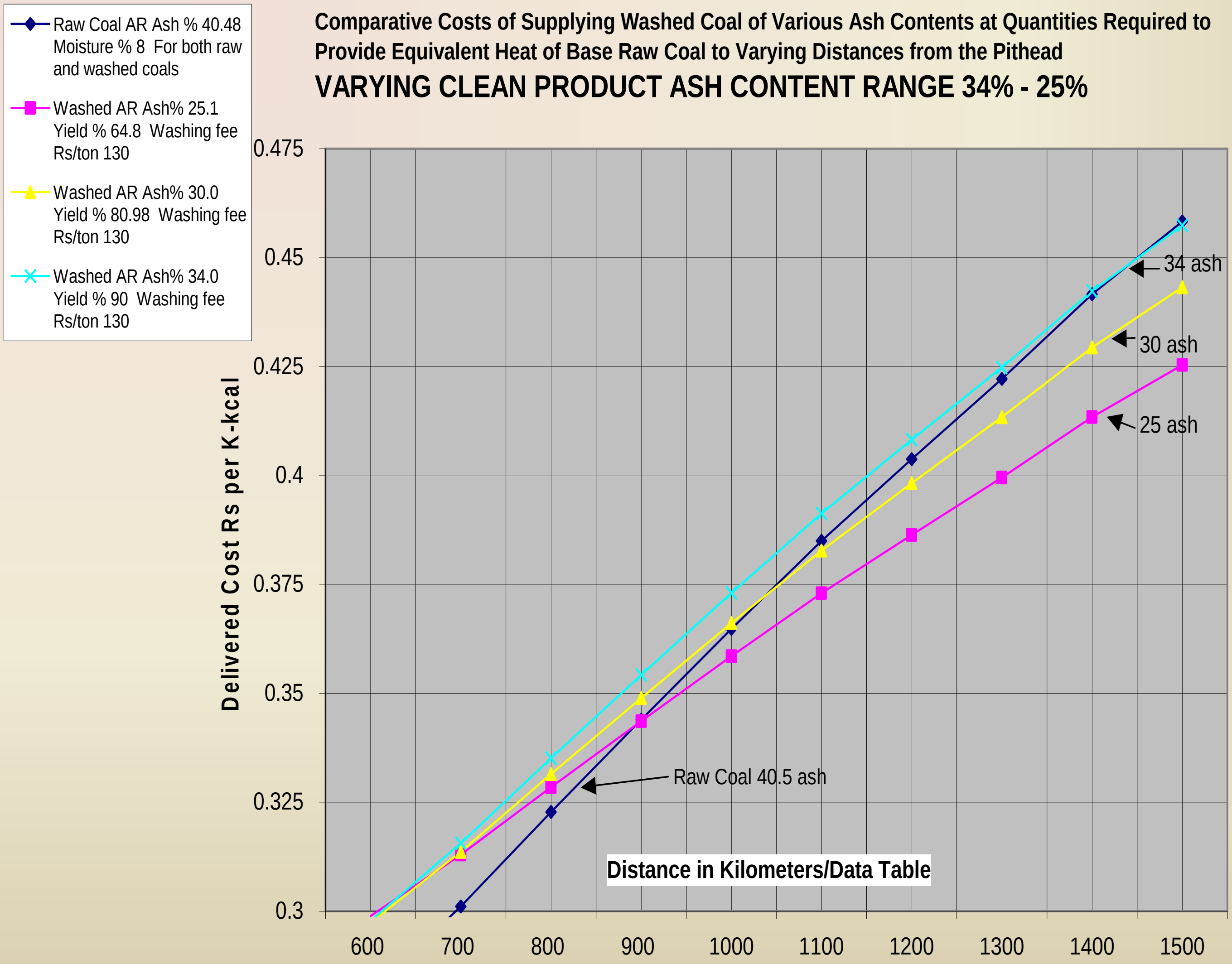
- ASSUMPTIONS USED FOR COMPARISON:
  - AVERAGE ASH CONTENT ROM IS 40.5% AT AIR-DRIED MOISTURE OF 8%
  - GCV ROM COAL IS 3540 KCAL/KG
  - RAIL TRANSPORT COST IS RS 0.90/TON/KM
  - COST OF ROM FOBT IS RS 550
  - YIELDS SHOWN ARE BASED ON TYPICAL RESULTS FROM WASHING DIPKA COAL AT BILASPUR WASHERY

ECONOMIC ANALYSES OF WASHED COAL

BENEFITS OF WASHED COAL

TRANSPORTATION

ECONOMIC ANALYSES OF WASHED COAL

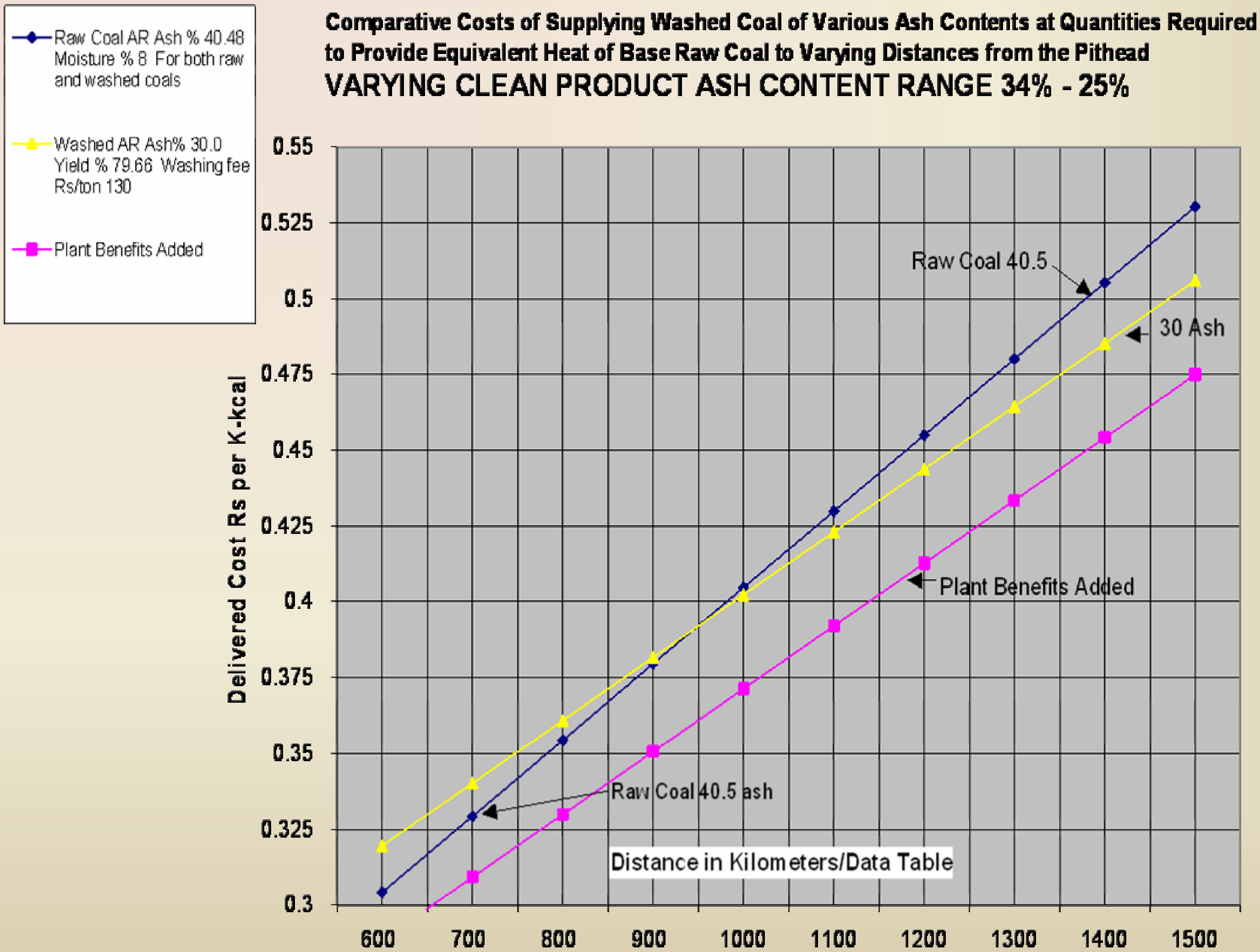


ECONOMIC ANALYSES OF WASHED COAL

BENEFITS OF WASHED COAL

COST REDUCTIONS AND IMPROVEMENTS AT POWER STATION

ECONOMIC ANALYSES OF WASHED COAL



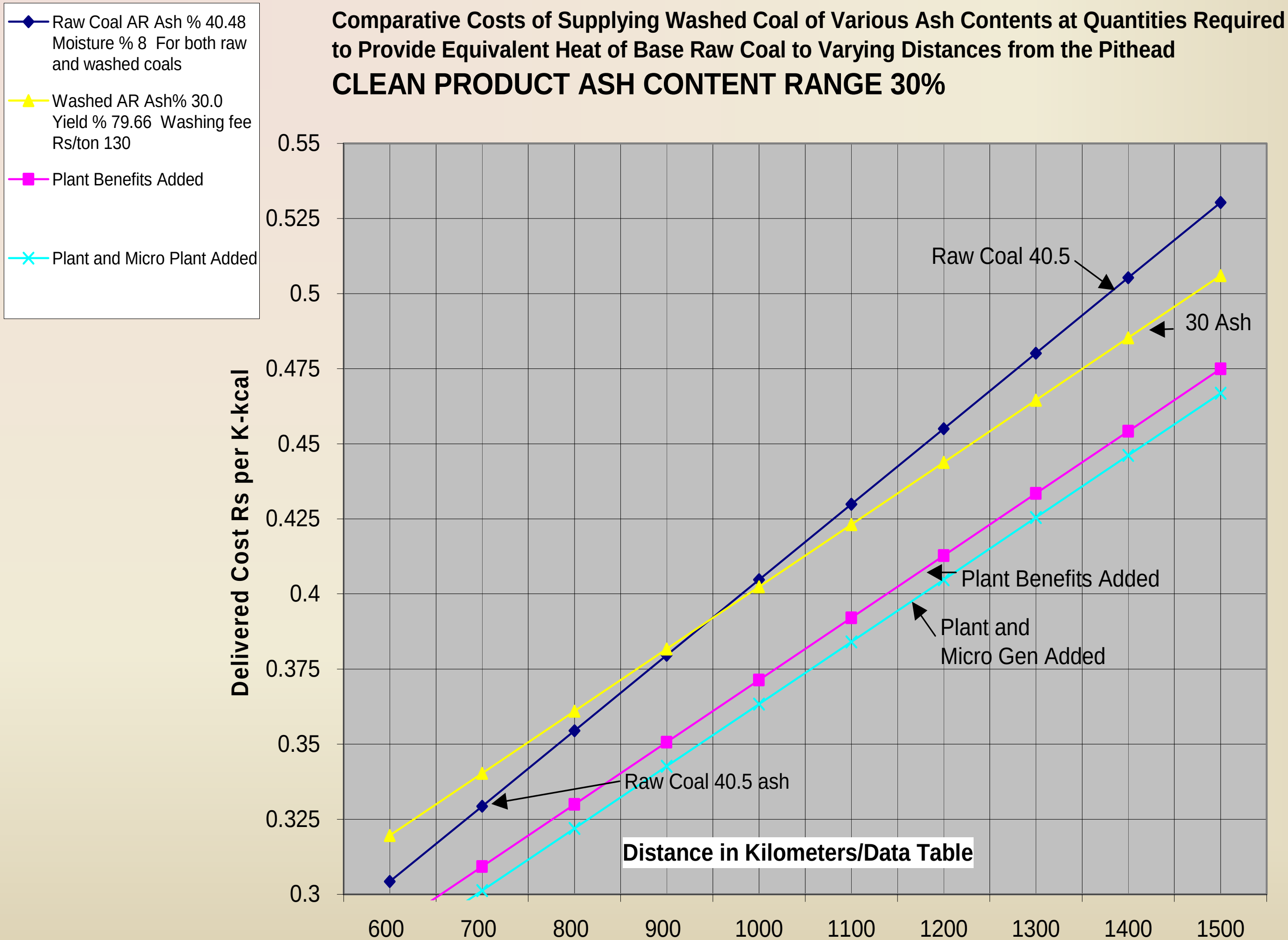
30 ASH WITH POWER PLANT SAVINGS

ECONOMIC ANALYSES OF WASHED COAL

BENEFITS OF WASHED COAL

MICRO GENERATION OF POWER FROM WASHERY REJECTS

ECONOMIC ANALYSES OF WASHED COAL



30 ASH WITH PLANT SAVINGS AND MICRO GEN

Combined Benefits

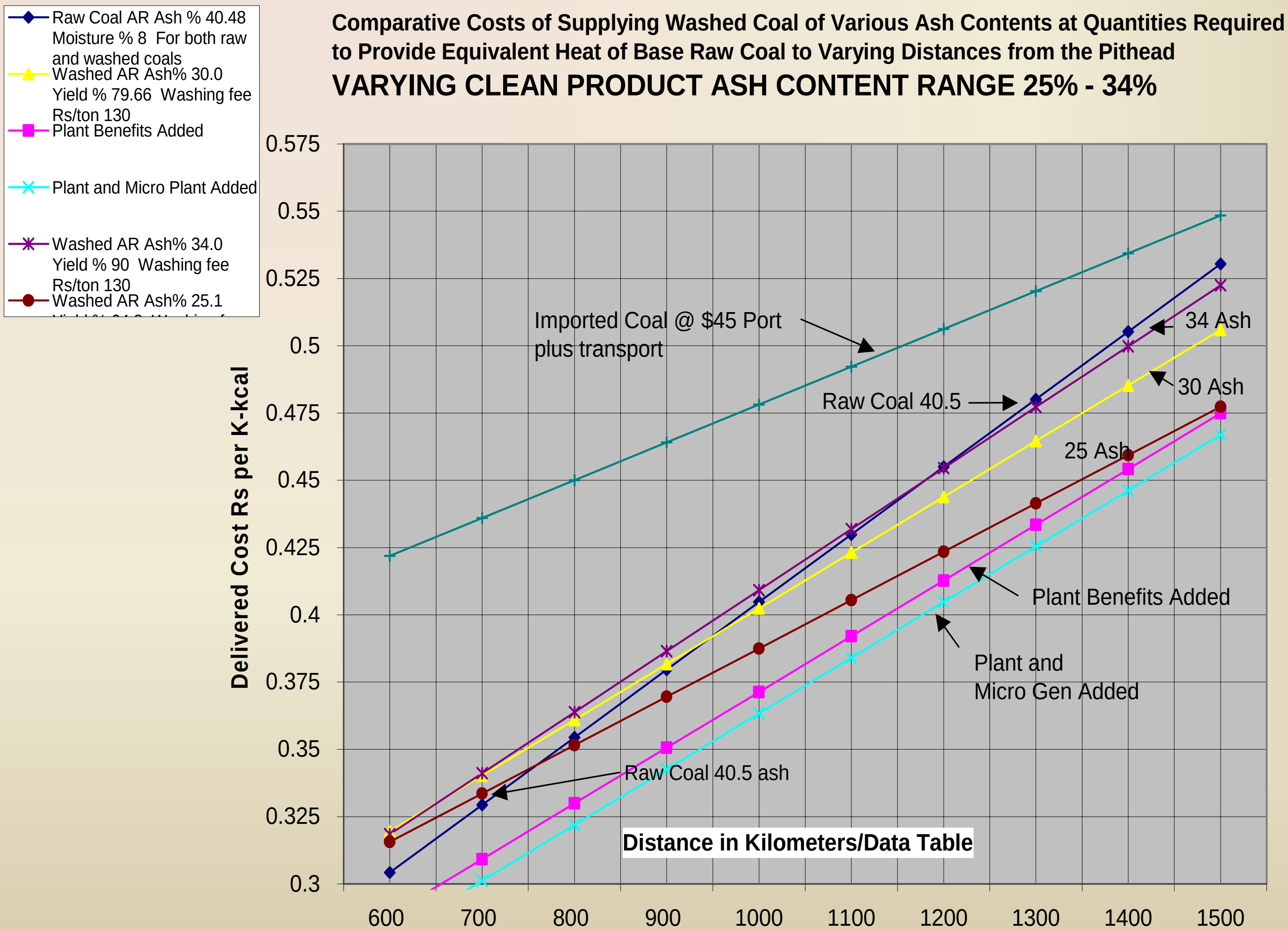
- USING A 500 MW POWER PLANT AT 1400 KM DISTANCE AS A MODEL, THE COMBINED BENEFIT FOR USING BENEFICIATED 30% ASH OVER A 40.5% RAW COAL WILL BE:
  - RS 0.020 FOR TRANSPORTATION
  - RS 0.031 FOR PLANT IMPROVEMENT
  - RS 0.008 FOR REJECT BASED GENERATION

  TOTAL RS 0.059 PER K-KCAL BURNED

  ANNUAL BENEFIT IS OVER 50 CRORES SAVINGS

ECONOMIC ANALYSES OF WASHED COAL

WASHED VS IMPORTS



Imported coal 15% ash – 6400 Kcal/kg

Clean Coal Process Simulator GUI

- Expect approval of the draft Logic and GUI design by April 1, 2011 which will support the current delivery schedules

- Minor changes in the content of the current interfaces and lower level interfaces are expected during the development cycle

- Any major changes to the overall look and feel of the user interface will be submitted for approval during the development cycle

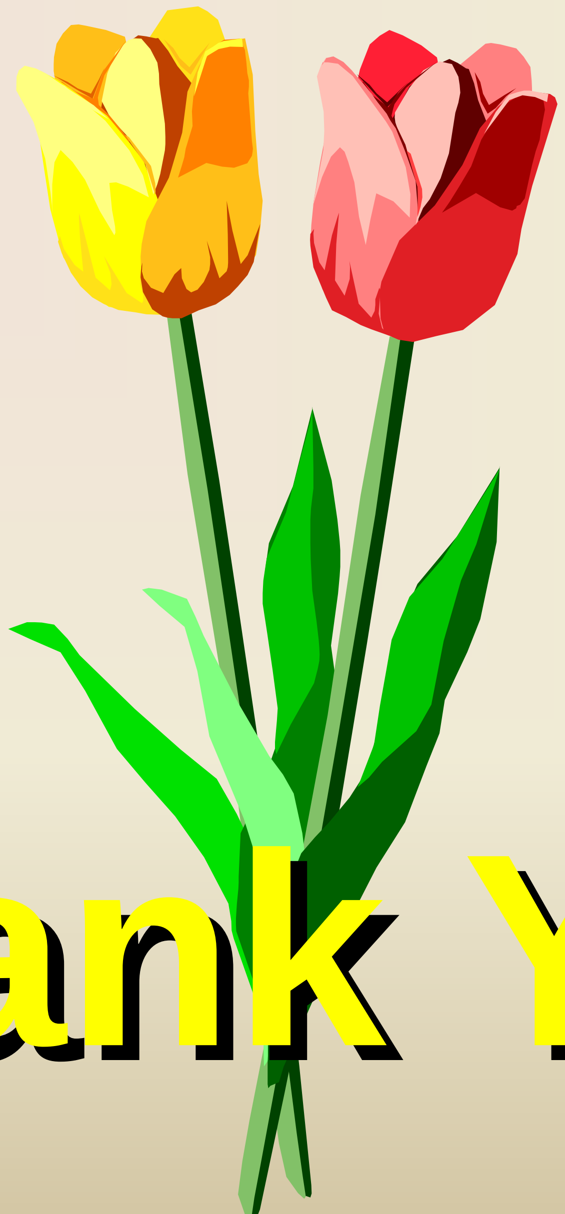
CLOSING COMMENTS

- USING WASHED COAL MUST BE CONSIDERED IN AN INTEGRATED SCHEME, TRANSPORT ALONE IS SIGNIFICANT BUT OTHER BENEFITS ARE GREATER,
- CURRENT DISTANT POWER PLANT OPERATORS SHOULD CONSIDER OPTIMUM SCHEME FOR DELIVERY OF LOWEST ASH TO THEIR PLANT WHILE SHARING IN THE BENEFITS OF MICRO POWER GENERATION,
- COMPETITION BY IMPORTED COALS
  - Cont.

ANALYZING THE VALUE OF WASHED COAL

CLOSING COMMENTS CONT.

- WASHED COAL HAS PROVEN TO BE COMPETITIVE WITH IMPORTED COALS FOR COASTAL PLANTS WITH GREATER THAN 1000 KM TRANSPORT DISTANCES,
- COMPUTER MODELING OF THE COAL-USE CYCLE WILL IMPROVE THE UNDERSTANDING OF THE BENEFITS OF USING WASHED INDIAN COALS,
- INDIA HAS AN ABUNDANT NATURAL SOURCE OF ENERGY IN ITS COAL RESERVES, PLAN ITS USE-USE IT WISELY.



Thank You