Conference :-
Heat Rate
Efficiency Summit 2023

Topic :
Heat Rate & Flexibility
Coal fired Generation Units

Council of Enviro Excellence

3RD HEAT RATE EFFICIENCY SUMMIT 2023

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HEAT RATE AND FLEXIBILITY

Coal-fired generation units

Anjan Kumar Sinha
November 30th, 2023

PRESENTATION OUTLINE

1. The Indian Transition
2. Metrics of Heat Rate during changed mode of Operation
3. Coal Quality and efficiency
4. Interrelationships of FLEXIBILITY and Heat Rate
5. Implemented Solutions
6. Combustion Optimization
7. Coal Flow Balancing
8. Case Studies

INTERTEK IS Uniquely positioned to deliver ATIC solutions

Systemic approach to Quality and Safety

44,000+ EMPLOYEES

GLOBAL MARKET LEADER IN ASSURANCE

12,000+ AUDITORS, INSPECTORS, TECHNICAL PERSONNEL

340,000+ INSPECTIONS AND OTHER TECHNICAL VISITS / YEAR

100+ COUNTRIES

GLOBAL MARKET LEADER IN TIC

1,000+ LABS &OFFICES

80+ LANGUAGES

Our Sectors

Products | Trade | Resources

Intertek Engineering Consulting
Engineering | Failure Analysis | Technology

POWER PLANT FLEXIBILITY
INTERTEK EXPERIENCE

INTERTEK IS A WORLD LEADER IN THE FIELD OF IDENTIFYING AND ESTIMATING THE COSTS OF FOSSIL PLANT CYCLING.

WE ARE ONE OF THE FIRST TO IDENTIFY CYCLING AS A MAJOR COST ISSUE.

- Our staff is highly experienced and well versed with:
- Power plant component damage mechanisms and failure
- Component/unit reliability modelling
    - Component aging and impact of fatigue cycling on aging components
- Capital and O&M accounting and how to associate costs to cycling damage and unit reliability
- Relevant industry databases
- Statistical modelling, unit commitment and production cost analysis
- We have extensive experience working on utility projects
- We know how to take sparse data and utilize it effectively
- We advise on design improvements, equipment upgrades/replacement and operating process improvements to ensure your plant operates more efficiently and reliably.
- Asset Life Optimization and assessment of future capital and maintenance costs, stranded costs and dispatch

Strong Commitment to Research & Developmen t

Numerous Patents/ Proprietary Technologies

In-House Metallurgical & Mechanical Test Laboratory

Electric Power Research Institute

Department of Energy

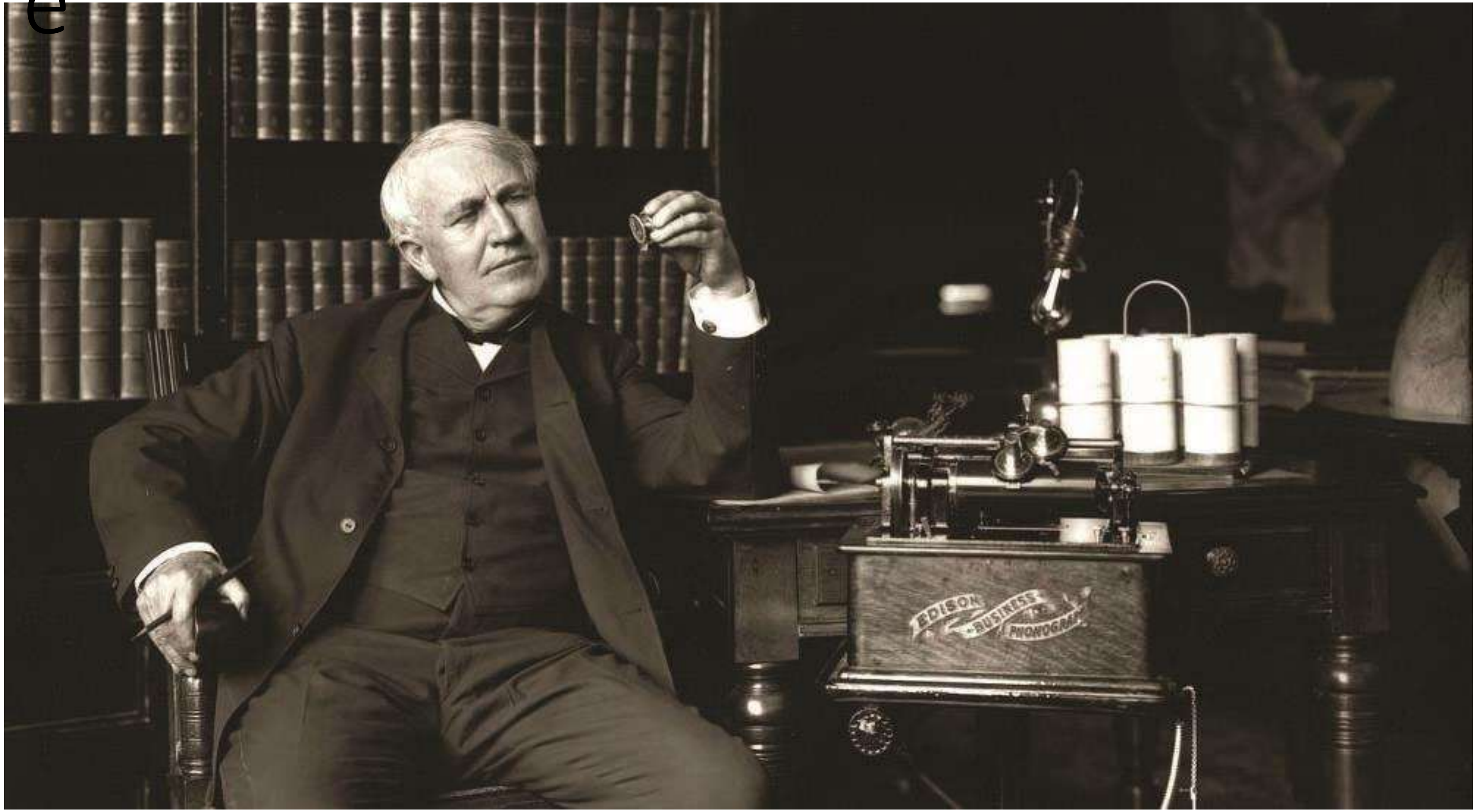
Gas Research Institute

Oil & Gas Companies

Utilities

More than 10,000 Completed Projects

Heritage



ETL Testing Laboratories founded by Thomas Edison in 1896.

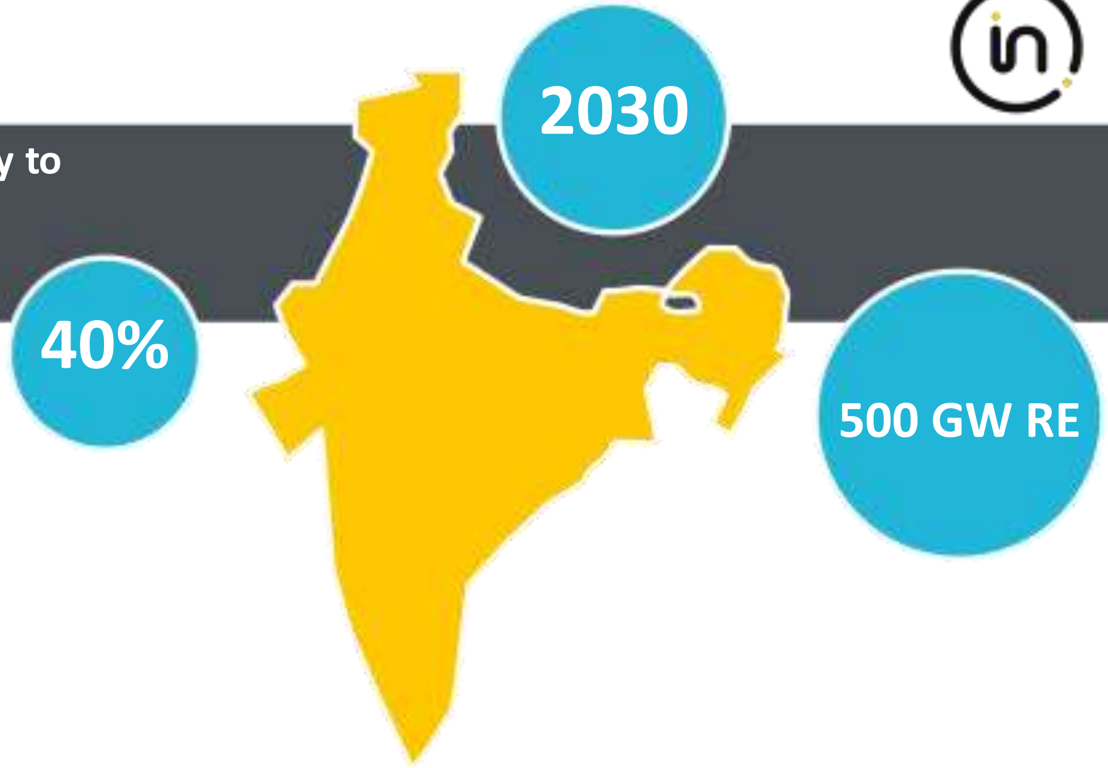
Edison Once Said:

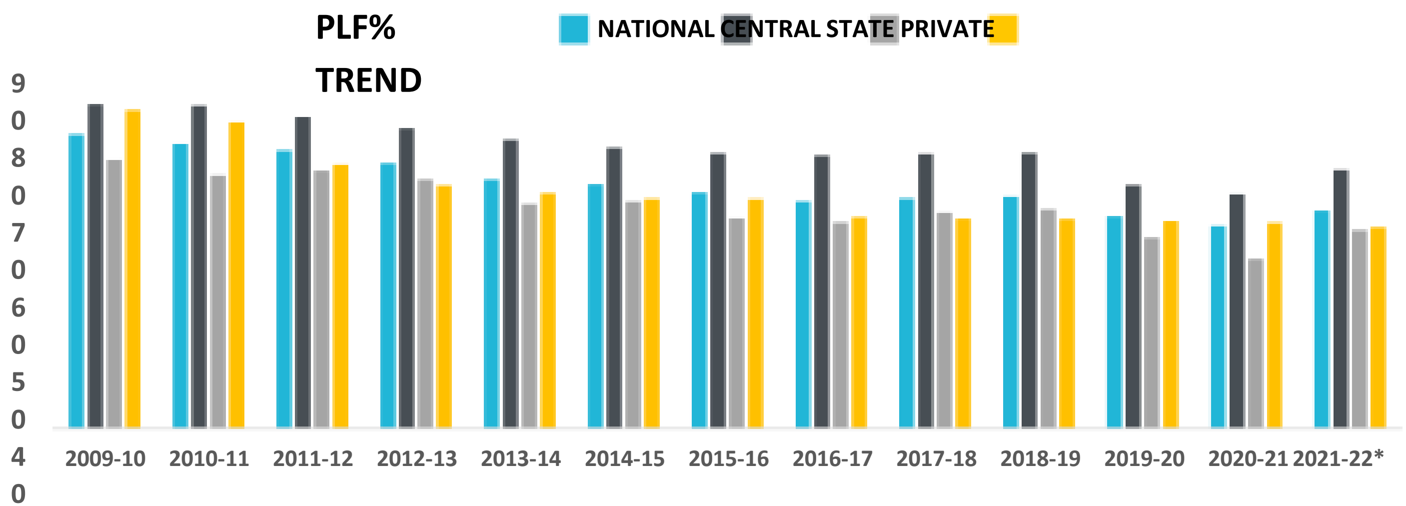
"We are like tenant farmers chopping down the fence around our house for fuel when we should be using natures inexhaustible sources of energy – sun, wind and tide."

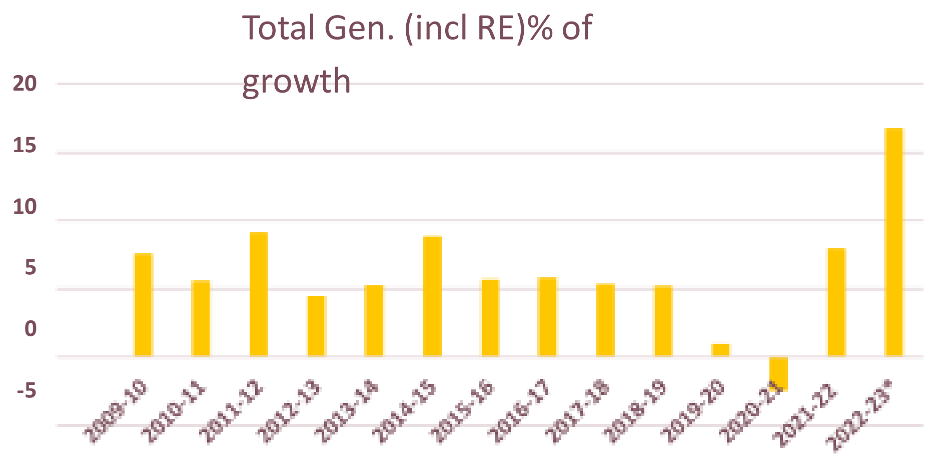
In conversation with Henry Ford and Harvey Firestone (1931); as quoted in Uncommon Friends: Life with Thomas Edison, Henry Ford, Harvey Firestone, Alexis Carrel & Charles Lindbergh (1987) by James Newton, p. 31

THE INDIAN TRANSITION

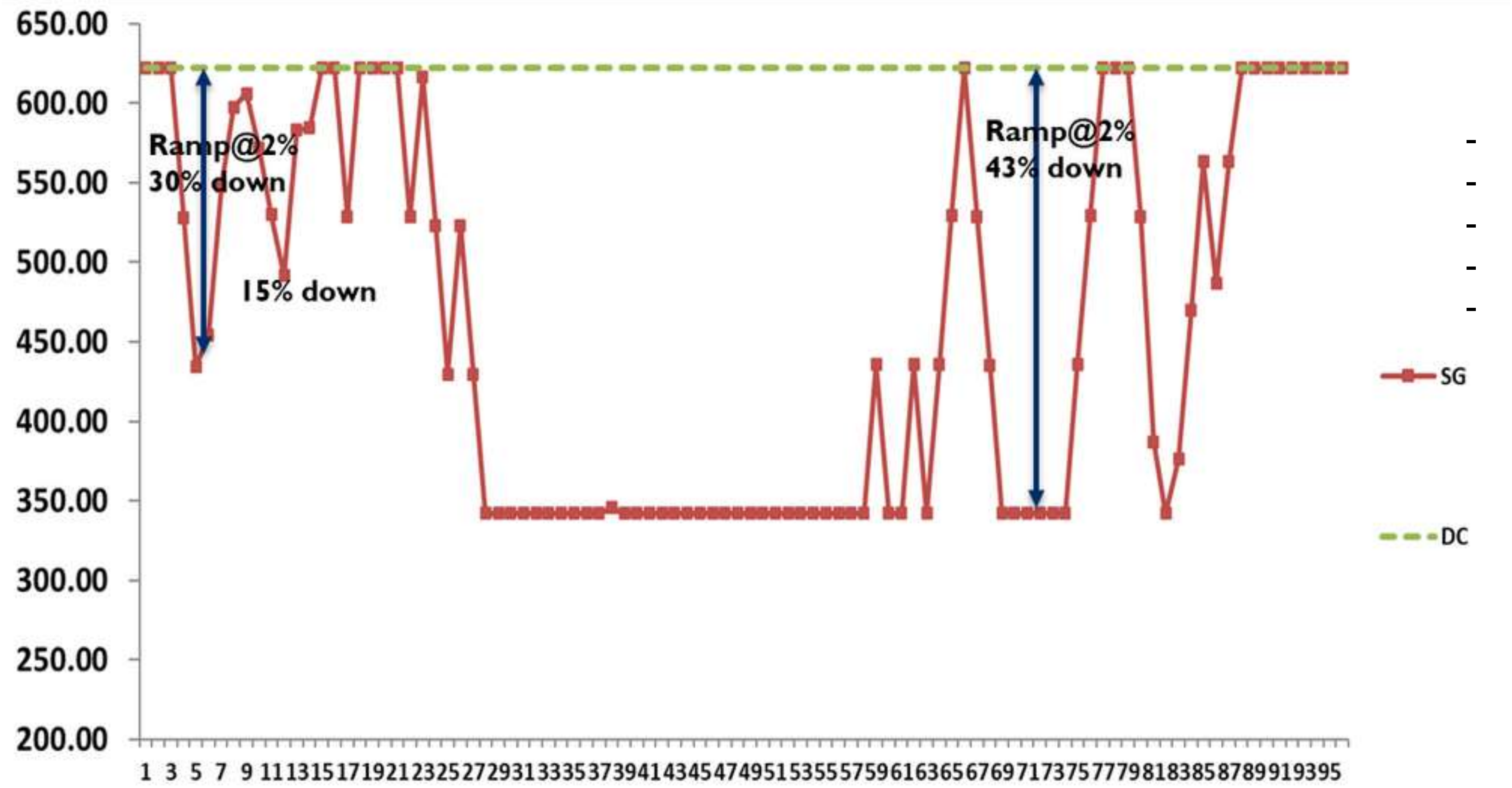
- India's pledge to increase the share of non-fossil fuels-based electricity to 40 percent by 2030
- 500 GW RE by 2030
- Coal in India is increasingly needed to flexible and play a greener role
- Inadequacy of other balancing resources
- Coal is the mainstay of power generation in India
- Fuel economics-Non-Pit head stations will have costlier fuel
- Tightening environmental legislation
- Transition to electricity market mechanisms –markets will force to operate more efficiently, even during flexible operation



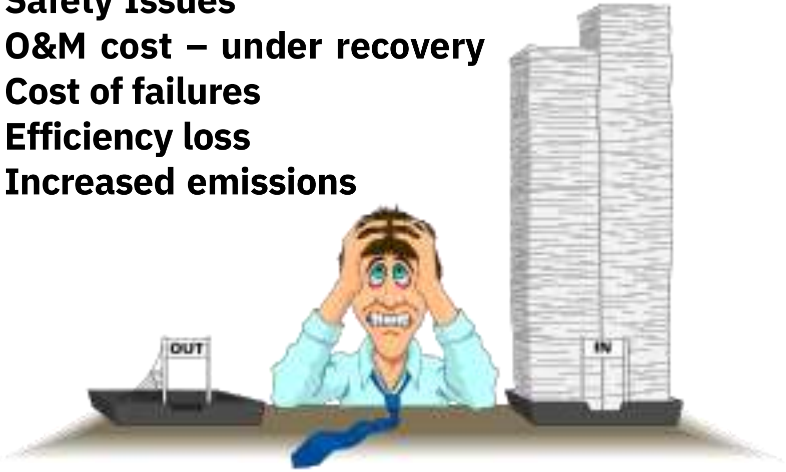




Real example of Scheduling of a unit and the effect



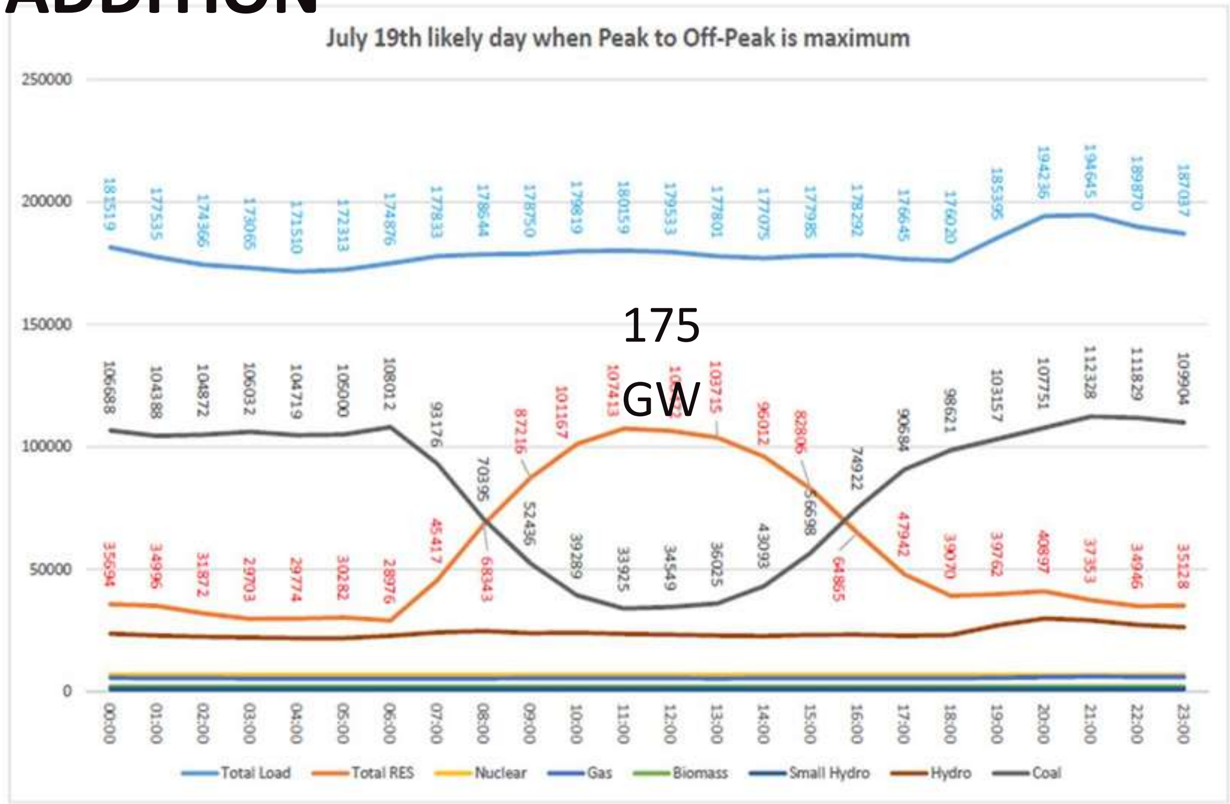
- Safety Issues
- O&M cost – under recovery
- Cost of failures
- Efficiency loss
- Increased emissions



Opportunities:
- Primary Response
- Secondary Response/AGC
- Ancillary Service Markets
- RTM

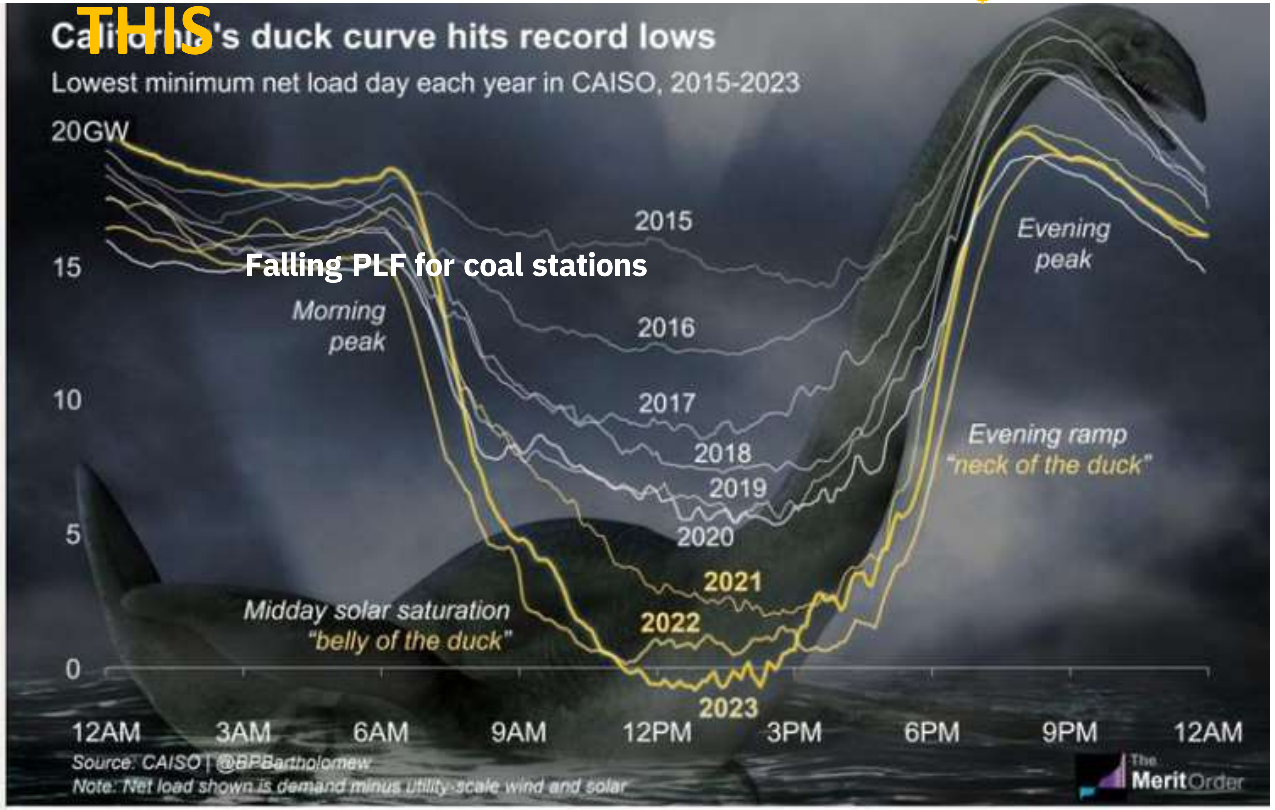
- **If we consider a significant load following of ramp size>15%,then we have at least 7 significant load followings**
- **Each of this event costing X $ for the generator, which the generator has to recover from the market/ need to have a regulatory mechanism.**

THE NEW PARADIGM WITH RE ADDITION



175 GW

ARE WE PREPARED FOR THIS

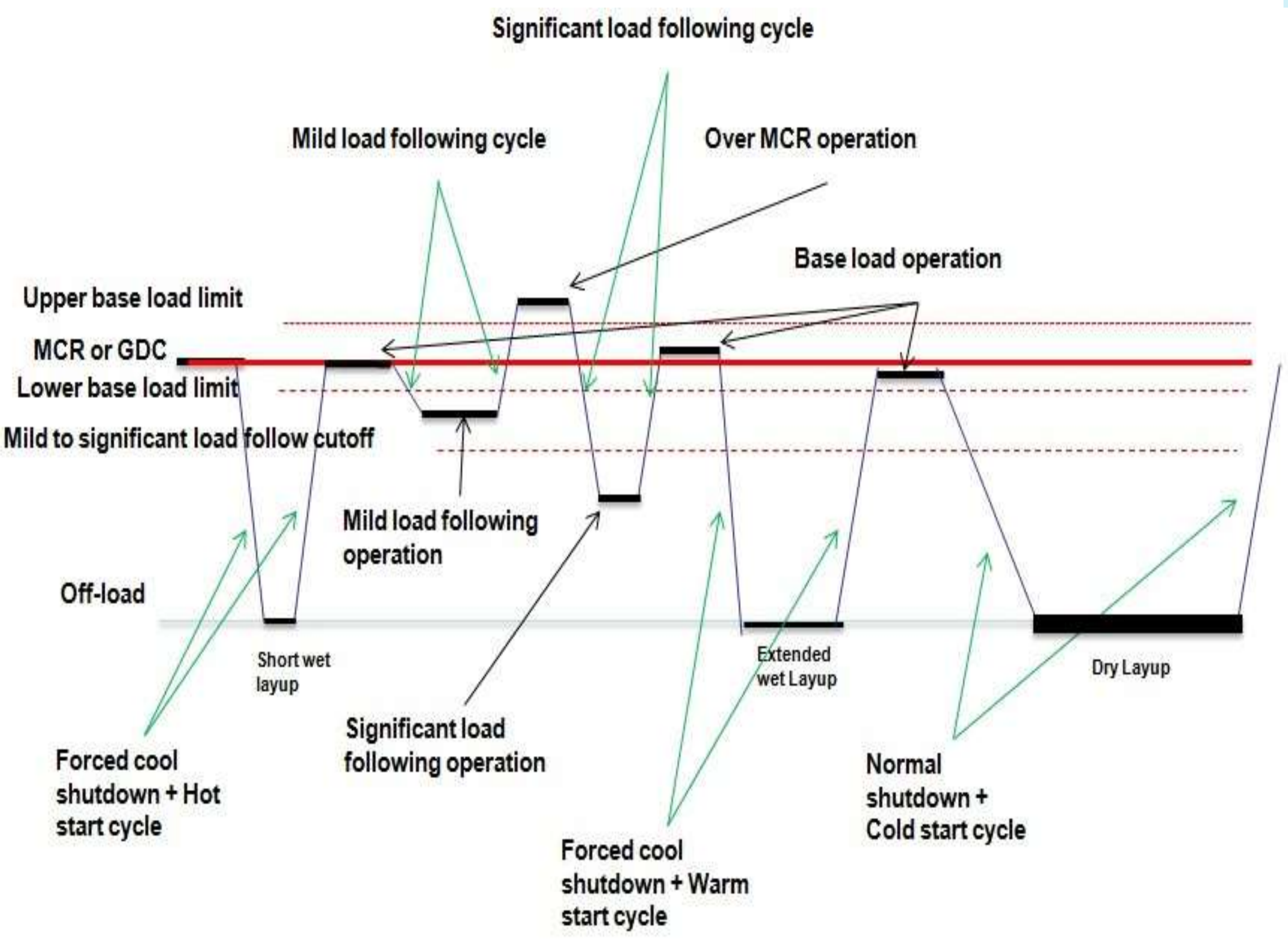


Falling PLF for coal stations

- The situation will be more extreme with more RE (as planned till 2030)

- Units were not designed to operate in fluctuating mode
- Compensation required for recovery of O&M costs incurred due to increased cycling on the units
- It is important for the station to know what will be the costs & risks

METRICS OF HEAT RATE TO BE REVISITED FOR ADDRESSING FLEXIBLE OPERATION

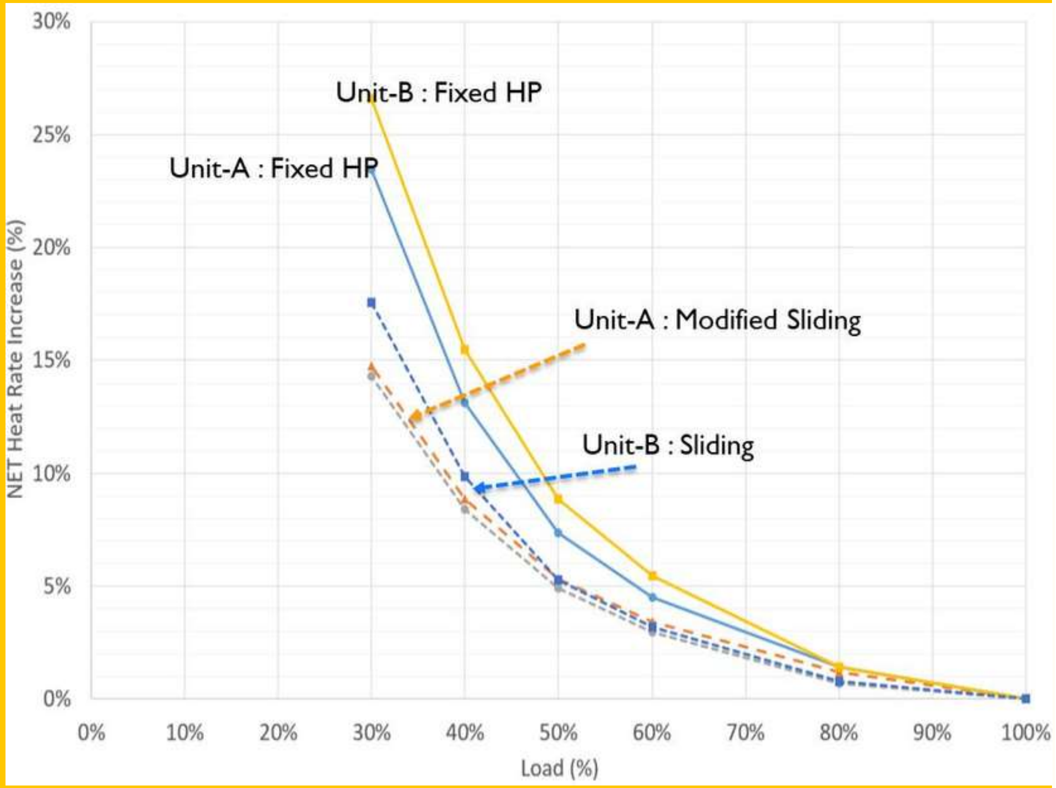


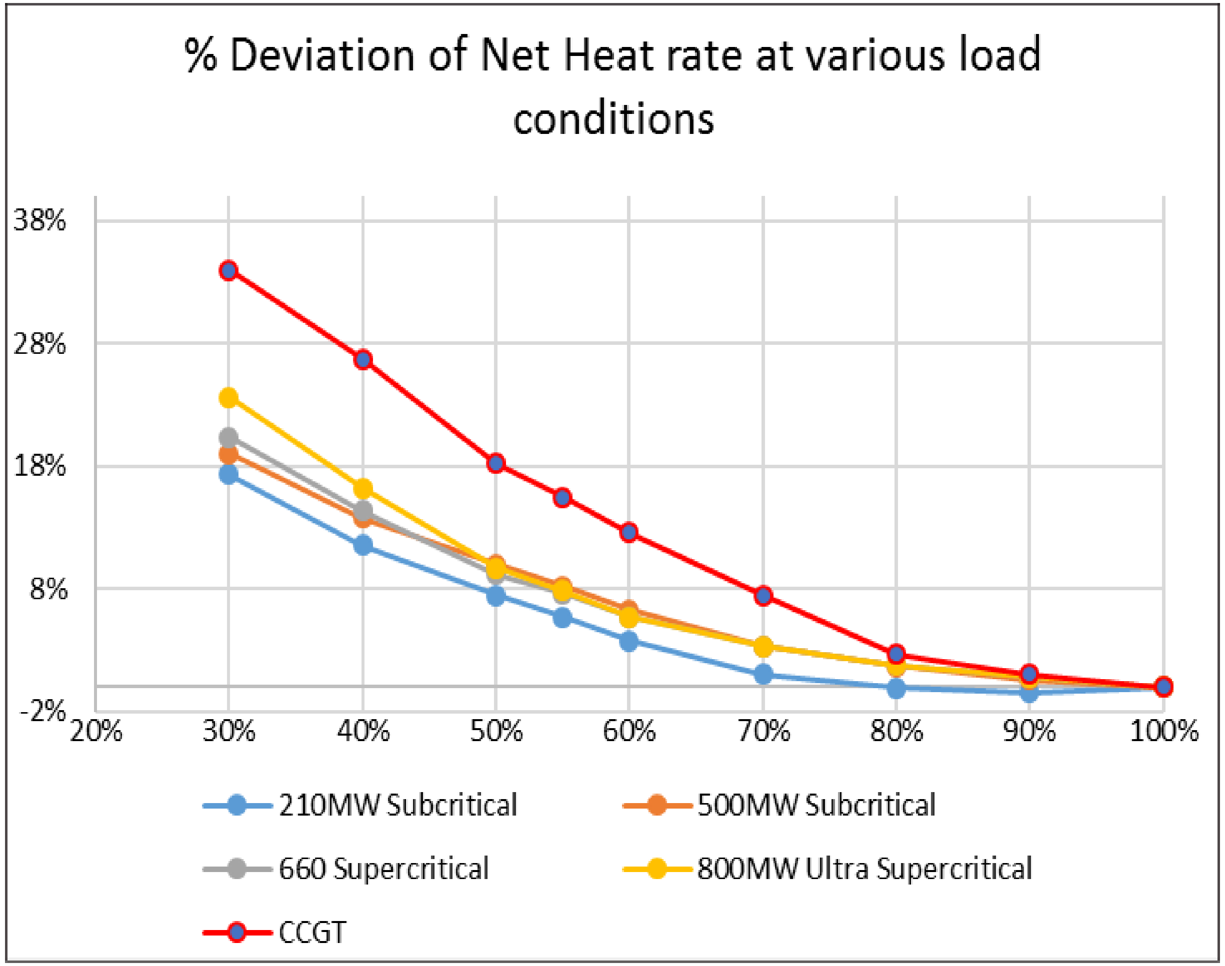
How do you managepart Loiadeffciency-Heat Rate/ APC

- O&M Procedures
- Automation
- Adequacy of Instrumentation
- Monitoring & Control
- Data & Analytics
- Organisational Structure/ Efficiency
- Testing- O2, CT performance, Boiler/Turbine efficiency, ~~Dirty air flow,~~ representative FG sampling
- OEM support
- Budgetary constraints
- Energy Audits
- Test runs

Source: EPRI

PART LOAD EFFICIENCY

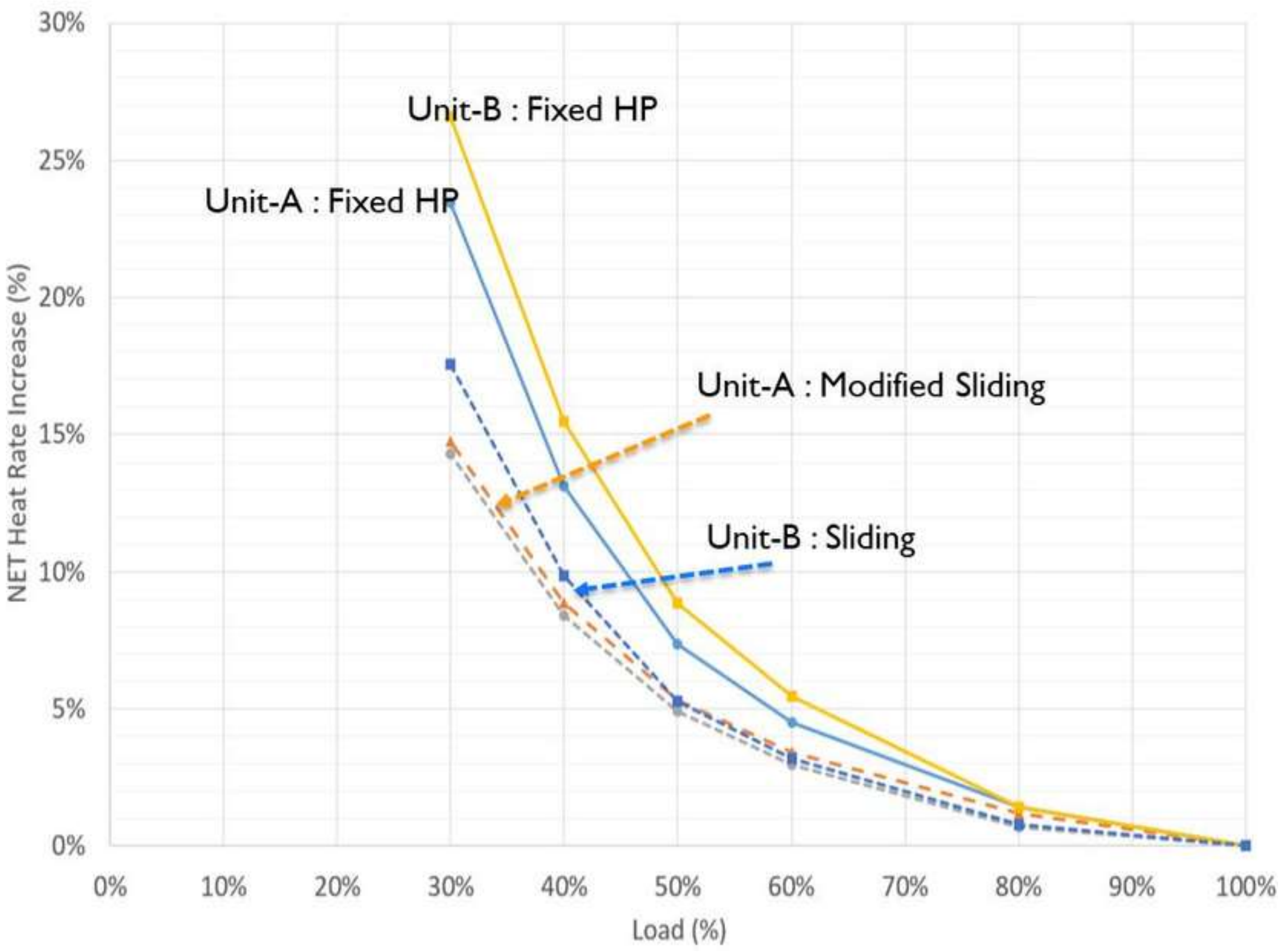




Sliding Pressure

Benefits

EFFICIENCY ISSUES



Burner Performanc e

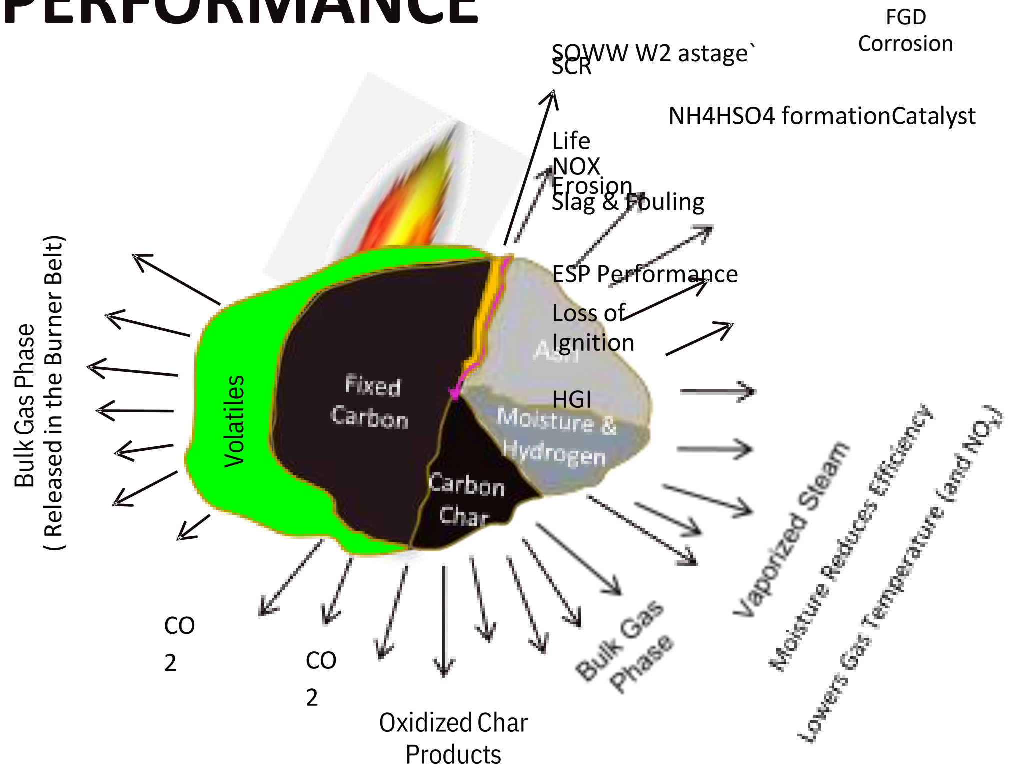
Combustion Issues

Fuel Issues

Furnace Heat V aterwall Refracto &
BalanceCleanli essCasing Issues

Expansion
Fan B urner
Joint &
IssuesDamper/

COAL QUALITY IMPACT ON PERFORMANCE



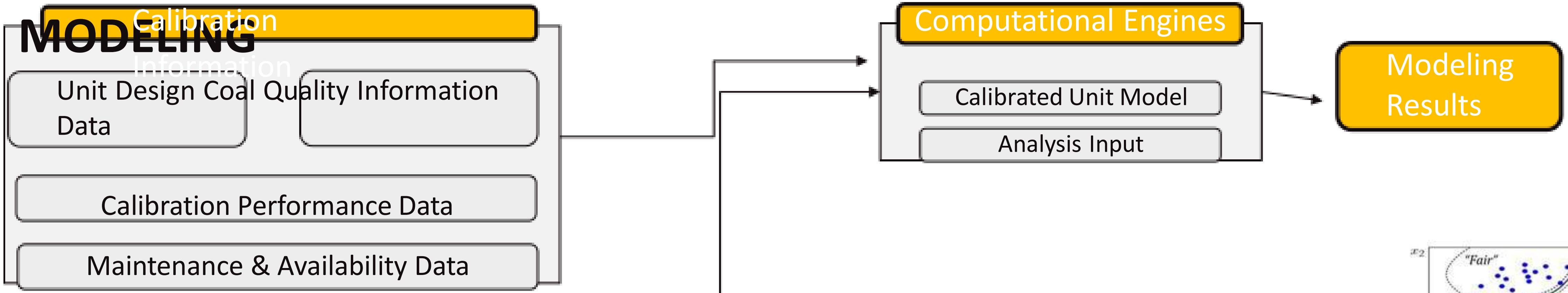
Source: EPRI

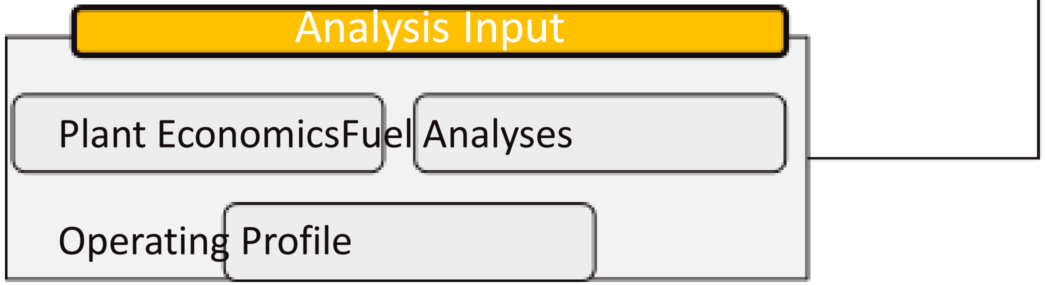
TableNo: SamplescollectedfromCoalStations Samp						
le Mois t(%)	(%)	(%)	(%)	VM Ash FC HGI GCV		
1 7.2 25.3 36.36 31.14 68.54 3795						
2 6.05 25.25 29.92 38.78 59.22 4058						
3 8.24 18.34 45.5 27.92 65.2 2869						
4 11.45 26.06 38.92 23.57 62.5 3264						
5 4.86 31.82 30.02 33.3 58.62 4623						
6 6.99 27.79 35.21 30.01 76.09 3871						
7 7.41 29.96 32.49 30.14 61.23 4821						
8 13.28 20.54 34.46 31.72 48.69 4014						
9 9.81 23.45 38.38 28.36 65.93 4268						
10 12.96 22.74 46.51 17.79 57.49 2636						
11 4.04 28.97 24.26 42.73 60.37 5003						
12 6.08 24.01 43.85 26.06 76.65 3692						
13 6.58 27.01 38.6 27.81 70.32 3962						
14 2.66 22.75 53.22 21.37 57.28 3645						
15 7.39 31.05 32.28 29.28 52.33 4538						
16 13.6 18.71 46.97 20.72 59.22 2683						
17 8.91 20.89 44.67 25.53 63.57 3066						
1	4.79	22.1	41.7	31.3	6	393
		1	7	3	2	7

- Stations get supplies from multiple sources
- Wide variations on daily basis
- Rarely the design coal is available
- Depletion of stocks
- High Ash content
- Seasonal variation
- Wet coal
- High GCV_Imported coal
- Coal blending
- Insufficient stock
- Coal yard management
- Logistics Issue
- Grade slippage
- Overheads
- Non-pithead – high cost – puts it low on merit order

Coal Variation during a test run

COAL MODELING

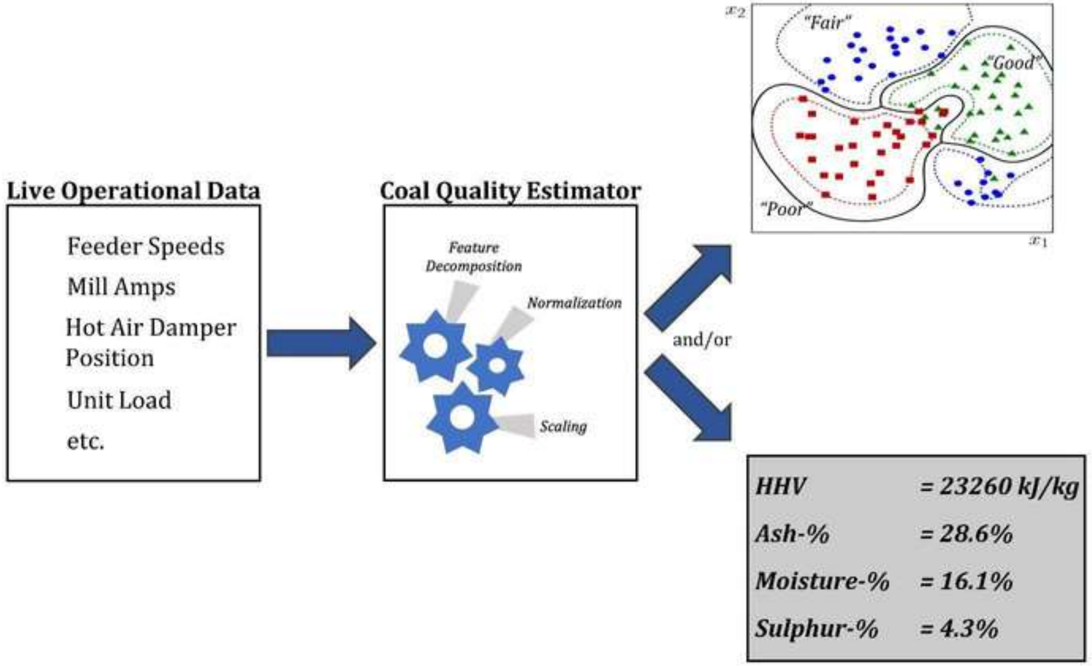




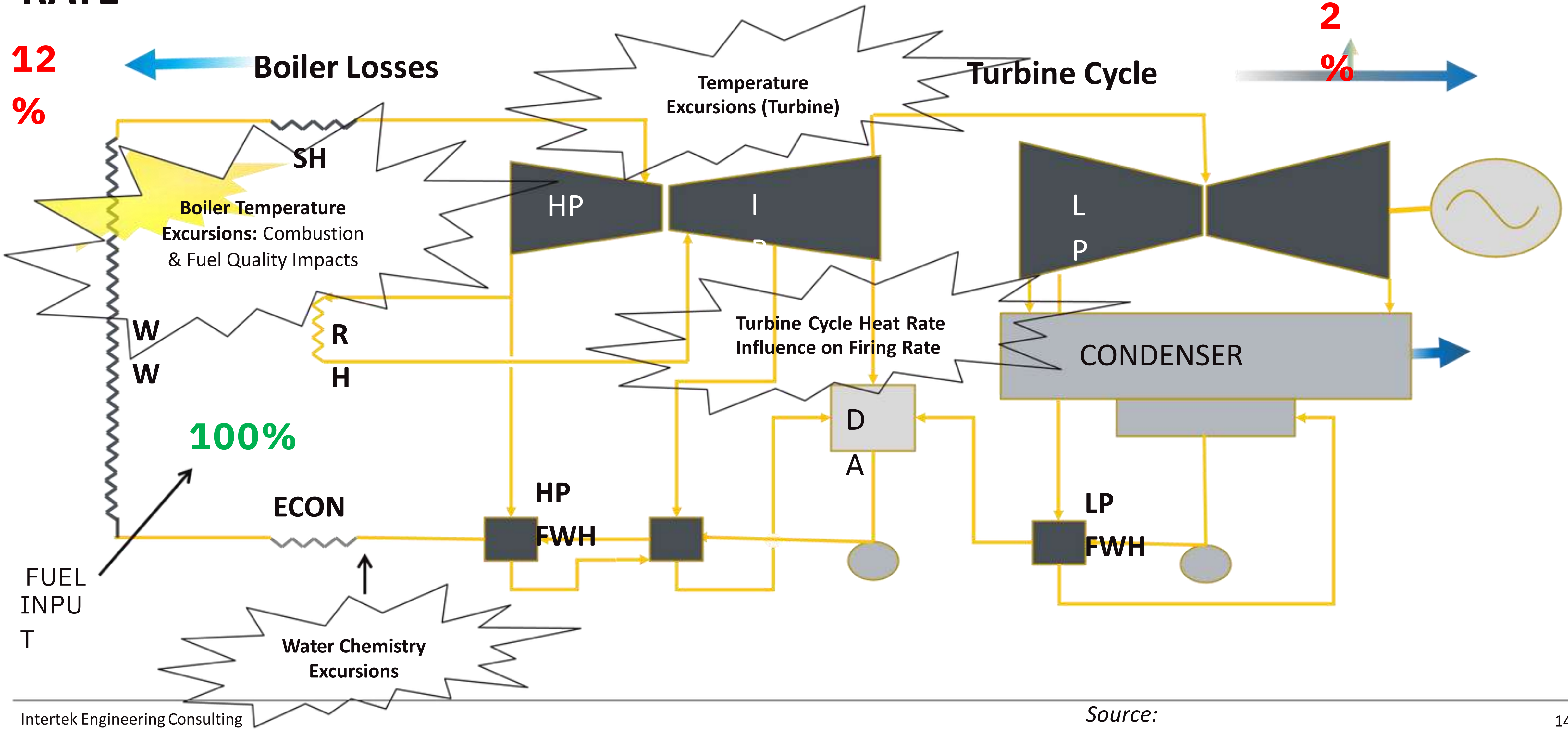
Real-Time Coal Quality Monitor

Our innovative approach to managing coal-fired boilers provides a reliable and efficient solution to the challenges inherent to coal fuel variability. By leveraging a finite set of historical coal analyses (proximate and ultimate) and linking them to real-time operating conditions, the application accurately predicts the specific characteristics of the fuel in real-time. This information is a proprietary enhancement for improving optimization of processes and promotes more efficient boiler performance.

The Coal Quality Monitor system provides primary outputs such as estimates of the fuel's heating value, moisture content, ash percentage, and sulfur percentage. These outputs provide a means of enabling site operators to anticipate changes in fuel characteristics and adjust their operations accordingly, leading to reduced maintenance costs and improved overall efficiency.



INTERRELATIONSHIPS OF FLEXIBILITY AND HEAT RATE



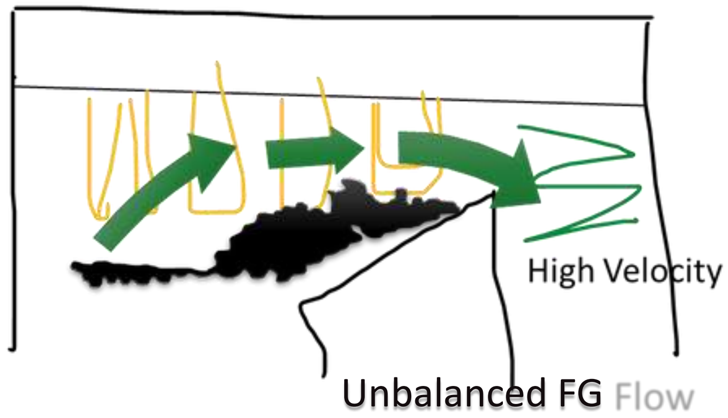
Source: EPRI

AVAILABLE SOLUTIONS….

Knowledge-based Soot blowing (KSB)

Every Unit is Unique

The Knowledge-based Soot blowing (KSB) application is an intelligent soot blowing program that effectively incorporates system knowledge from years of experience of site operators and engineers into a rule-based unit-wide soot blowing strategy.



Unbalanced FG
Flow

Slagging and Fouling Inference System

Understanding of real-time slagging and fouling conditions within a boiler are crucial for proper maintenance and management of the unit. When **sufficient instrumentation** (e.g., temperature measurement) is available, local conditions at individual walls and panel surfaces within the boiler can be inferred, and the relative amount of fouling and slag currently present can be indicated.

KEY FLYASHACCELERATED EROSION (FAE) INFLUENCERS

$$FAE = \frac{E_{ij}}{E_{avg}} = \left(\frac{V_{ij}}{V_{avg}}\right)^{n} x \left(\frac{M_{ij}}{M_{avg}}\right) x\ Cp$$

Where:

E_{ij} = Fly Ash Erosion Rate

E_{avg} – Plane Average FAE Rate

V_{ij} = Gas Velocity at Location (I,J)

V_{avg} = Plane Average Gas Velocity

M_{ij} = Fly Ash Loading at Location (I,j)

M_{avg} = Plane average Fly Ash Loading

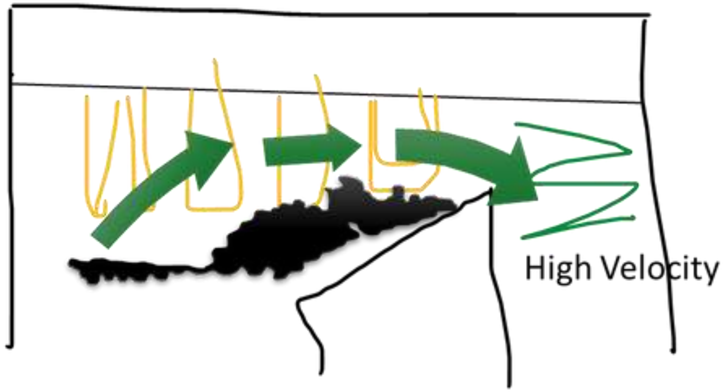
Cp = Particle Size Adjustment Factor

n = Velocity Exponent (Range: 2.5 at 260C to 3.5 at 816C)

Increased erosion caused by imbalances of gas temperatures and flow, velocity, resulting with localized erosion- being exponentially influenced as temperatures increase.

Ash deposits at the upper furnace, increase the FG velocity

The operational data reveal wide imbalances in temp (L & R sides).



Recommendation:

- CAVT
- HVT(Once- after every OH)
- FEGT
- ISB

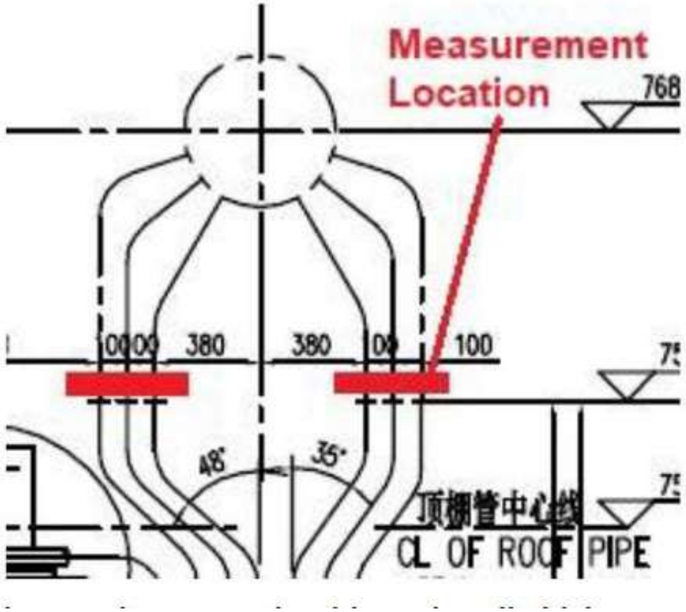
INSTRUMENTATIO
N

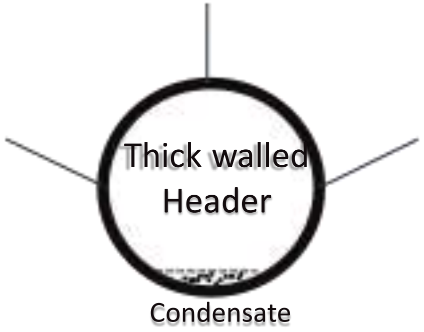
- FEGT
- Coal Pipe temp, velocity, mass flow •SA Flow(individual burner)
- Drain Flow, temperatures
- Coal Analyser

Correct Locations is important

Example- 1.How correct is the excess O2 measurement with air-in-leakages

2. Inadequate thermocouples at proper locations





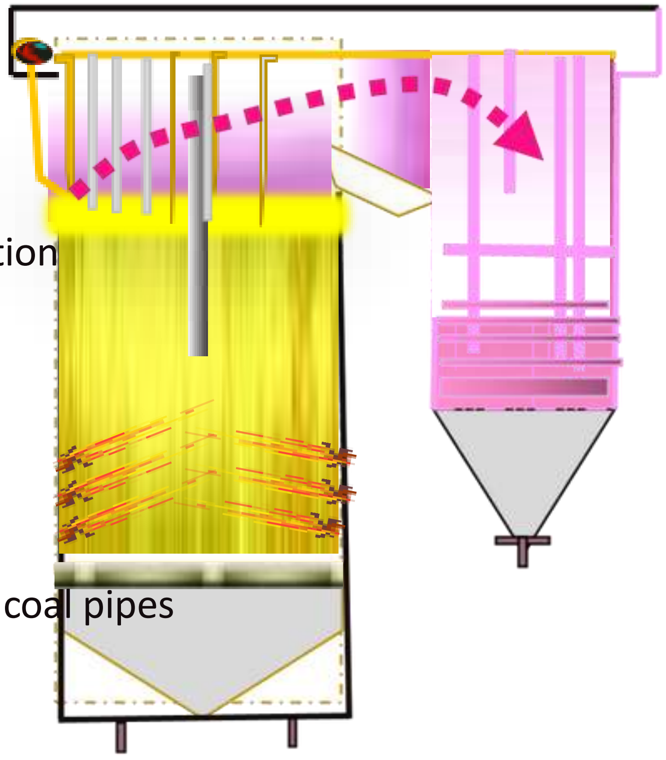
BOILER FLEXIBILITY INFLUENCE ON HEAT RATE

- Fuel Quality
- Firing Rate
- Operating Mode
- Adaptability to Load Changes without increasing thermal transients
- Combustion Performance
- Heat Transfer
- Air/Gas Management
- Environmental Performance
- Air in Leakages
- Unclean surface
- Circulation Issues and overheat (DNB)
- SH and RH Overheat
- High Spray Flow rates & Attemperator Damage
- Economizer Steaming
- Human error
- Deposits hindering heat transfer due to improper Chemistry
- Expansion joint failures

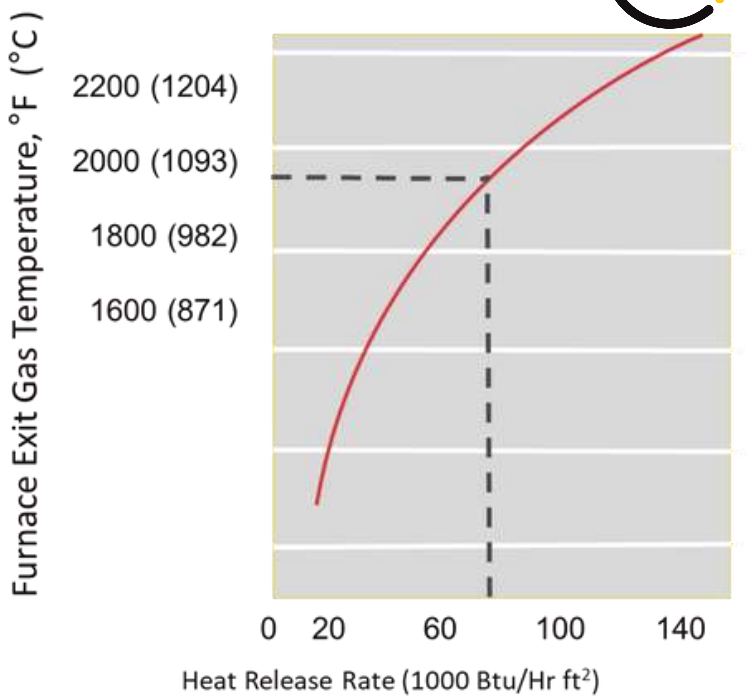
- Water wall circulation
- Sliding Pressure
- Lay-up requirement
- Aux Power consumption during lay-up
- Nox
- Overfiring
- Stagnant steam flow
- APH performance loss
- High FG temp

IMPROVING COMBUSTION EFFICIENCY

- Coal fineness
- **Balancing of Coal flow across the coal pipes**
- **Fuel/Air ratio, Combustion air**
- Air in Leakage
- Furnace exit gas temperature
- Bottom Ash & Fly Ash Unburnt
- Flue gas temperature and excess air stratification
- Flue gas oxygen /Excess air level
- Coal mill inlet/outlet temperature
- Primary Air header pressure
- Mill outlet temperature
- Pulverized coal flow velocity /Temperature of coal pipes
- Windbox pressure
- Burner Tilt
- Flame scanners
- Coal fineness
- Selection of burner



Flame scanners modifications
Burner modification



Fuel Firing System Optimization Package for low load oprn:
- **Air/Fuel ratio**
- **Coal pipes dynamic balancing**
- **Auto mill scheduler /start/stop**
- **Coal analyser**

Auto Coal Sampler

Combustion Optimizationfor improved part load efficiency

- Balancing of Coal flow across the coal pipes
- Fuel/Air ratio, Combustion air
- Furnace exit gas temperature
- Bottom Ash & Fly Ash Unburnt
- Flue gas temperature and excess air
- stratification Flue gas oxygen /Excess air
- level
- Coal mill inlet/outlet temperature
- **Primary Air header pressure**
- Mill outlet temperature
- Pulverized coal flow velocity /Temperature of coal pipes
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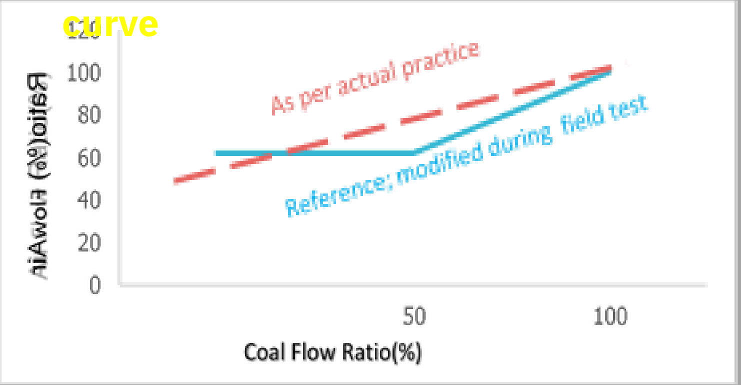
Review of PA flow curve



- The velocity in the coal pipes must be high enough to prevent settlement of coal particles in the coal pipes (not less than 20m/sec)
- The velocity at the burner nozzle must be more than the speed of flame propagation to avoid backfire within the coal pipes (not less than 15m/sec)
- The velocity at the burner nozzle should not exceed the blow-out velocity of the flame. Too high

Individual Secondary air flow measurement

Combustion Optimization for improved part load efficiency

- **Balancing of Coal flow across the coal pipes**
- Fuel/Air ratio, Combustion air
- Furnace exit gas temperature
- Bottom Ash & Fly Ash Unburnt
- Flue gas temperature and excess air stratification
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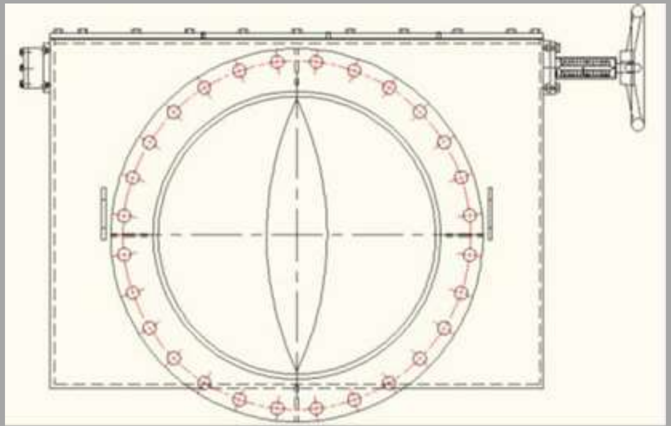

Variable orifices

Combustion Optimization for improved part load efficiency

- Balancing of Coal flow across the coal pipes
- Fuel/Air ratio, Combustion air
- Furnace exit gas temperature
- Bottom Ash & Fly Ash Unburnt
- Flue gas temperature and excess air
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- **Coal mill inlet/outlet temperature**
- Primary Air header pressure
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- Burner Tilt
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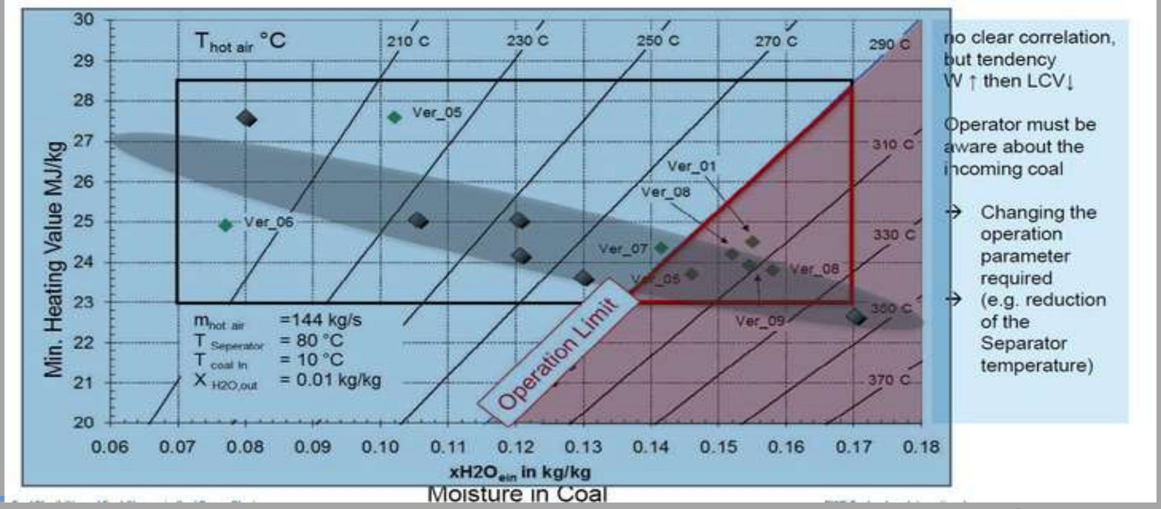
- Selection of burner

In coal with VM below 30%, the mill outlet temperature of 75-800C is recommended by BHEL. With higher VM, 55-650C is recommended (BHEL). However, International literature suggests a temperature in the range of 70-930C **with low VM coal (15-30%) and a range of 60-800C.**

Maintaining a slightly higher mill outlet temperature at low loads will help faster stabilization of the flame. Another consideration for mill inlet temperature w.r.t. the moisture in coal. A general thumb rule can be used – 10-15% moisture-mill i/l temperature of around 2700C, 10-8% moisture-2500C, <8-6%-2300C, <6%-2100C,>15%-2900C. The mill outlet temperature should be the final check point.



Source: RWE Technology International

DYNAMIC COAL FLOW MONITORING AND MANIPULATION SYSTEM

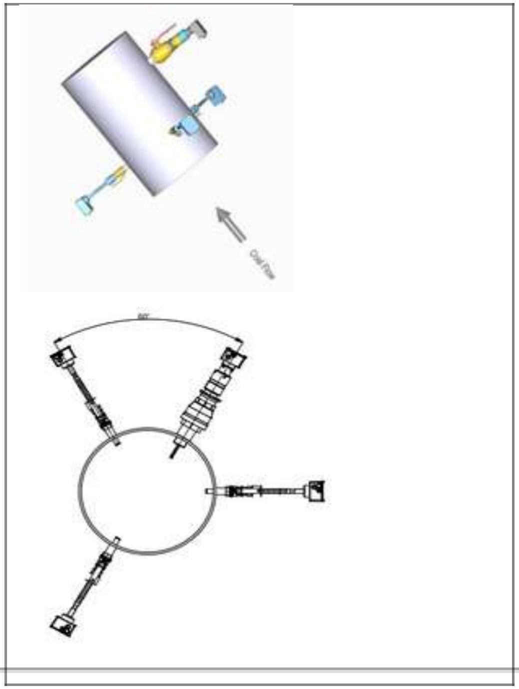
Severe unbalancing of coal flow distribution across pipes seen at stations. This was evidenced by the differential erosion and overheating pattern in the coal pipes. The distribution changes significantly during low load operation and change of other parameters.

The coal flow balancing/distribution has been tested successfully at 4 stations in India, recently with good results.

The following was carried out at the 3 stations:

Trending and manipulation Based on Real time measurements

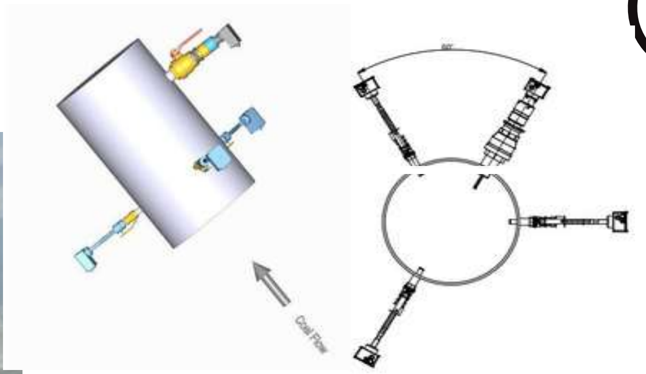
- Coal Mass Flow in each pipe
- Coal Roping Area identification
- Coal Temperature in each pipe
- Coal Velocity in each pipe
- Coal Flow Balancing
- DP across Variable Orifice
- Automatic Coal Pipe Balancing by Variable Orifice (w.i.p)



DYNAMIC COAL FLOW MONITORING AND MANIPULATION SYSTEM

Trending and manipulation Based on Real time measurements

- Coal Mass Flow in each pipe
- Coal Roping Area identification
- Coal Temperature in each pipe
- Coal Velocity in each pipe
- Coal Flow Balancing
- DP across Variable Orifice
- Automatic Coal Pipe Balancing by Variable Orifice (Future proposal)



- 3 Mass Flow sensors (microwave based) placed at 1200 apart)
  - Measures mass flow & indicates coal roping.
- Velocity sensors(Electrostatic based) placed 500mm above the mass flow sensors.
  - Measures coal particle velocity and temperature.
- Monitoring software integrated with system

DYNAMIC COAL FLOW BALANCING

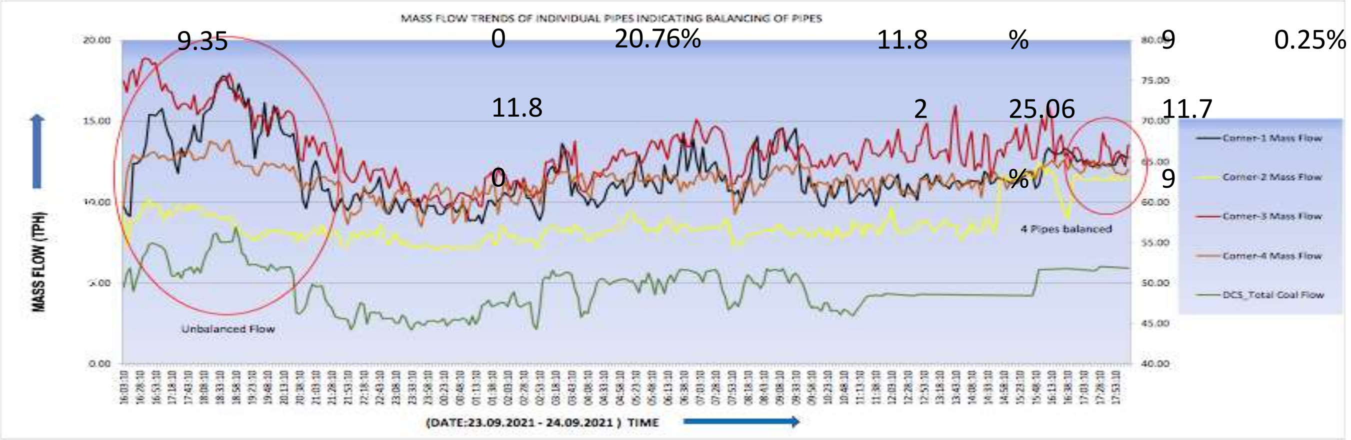
Before Balancing

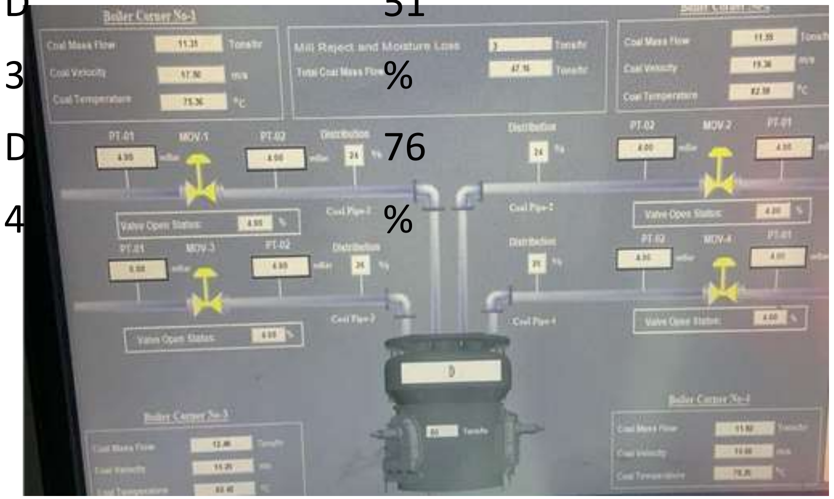
	Mass Flow (TPH)	Percentage Mass	Theorit i cal Equal (TPH)	Percenta g e Deviation
Total(Mill)	47.2	Flow		
Corner-1	11.4	100%	11.8	-3.05%
Corner-2	4	24.24%	0	-
Corner-3	8.96	18.98%	11.8	24.07%
Corner-4	17.4	36.95%	0	47.80%
	4	19.81%	11.8	-
	9.35		0	20.76%
			11.8	
			0	

After Balancing

Mass Flow (TPH)	Percentage Mass Flow	Theoriti c al Equal (TPH)	Percenta ge Deviatio n
47.1 6	100 %		
11.3	23.96	11.7	-
11.5	%	9	4.16%
5	24.49	11.7	-
12.4	%	9	2.04%
8	26.46	11.7	5.85%
11.8	%	9	0.25%
2	25.06	11.7	
	%	9	

Coal Pipe	Initial Setting - BHEL RECOMMENDED ORIFICE OPENING	Final Setting - ORIFICE OPENING TO ACHIEVE BALANCED FLOW
D	100%	98
1	74.5%	%
D	70%	85
2	78%	%
D		51
3		%
D		76
4		%





HR

OPTIMISATION

Airflow and Air In-Leakage Management
FEGT management
Fundamental Performance Optimization Efforts

- O_2 measurement & Management
- CO measurement

System Equipment Improvements

- Mill Optimization
- Burner Management
- Advanced/Adequate Instrumentations

Fuel Quality Management

- Consistency for Optimization
- Coal Air ratio

Heat Retention and Reduced Load Operations
Real-Time Monitoring of KPIs
Integration of Combustion Optimizers
Smart soot blowers

Digital Solutions

- Combustion optimiser
- Mill Auto scheduler
- Online coal analyser
- Online PF coal flow measurement
- Variable orifice
- Condensate throttling
- Thermal Performance
- TLA/ OLA
- Realtime cost calculation

Variable frequency drive

Structured APC reduction programme

Maintenance practices(Mills, burners, ait in leakahes, insulation)

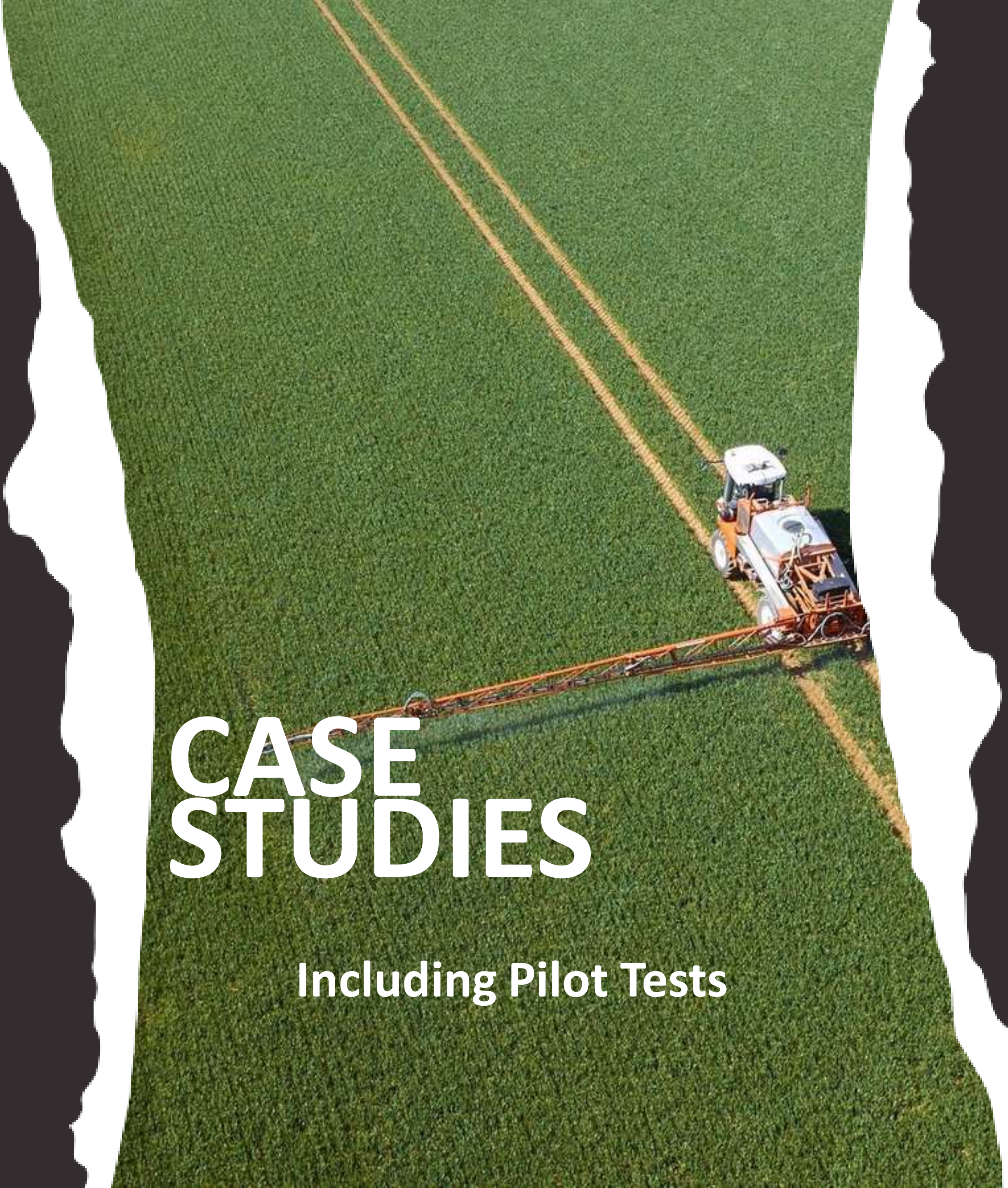
COMPENSATION PROPOSED- INDIA

Against Heat Rate Loss

S. No.	Unit loading as a % of installed capacity of the unit	Increase in SHR (for supercritical units) (%)	Increase in SHR (for sub-critical units) (%)
1	85 and above	Nil	Nil
2	80	0.66	0.76
3	75	1.19	1.45
4	70	1.96	2.40
5	65	2.84	3.56
6	60	3.67	4.79
7	55	4.92	6.59
8	50	6.15	8.60
9	45	7.40	10.21
10	40	8.81	12.14

Against APC Loss

Sl. No	Unit loading (% of MCR)	% degradation in AEC admissible
1	85 and above	Nil
2	80	0.10
3	75	0.25
4	70	0.40
5	65	0.55
6	60	0.75
7	55	0.95
8	50	1.20
9	45	1.55
10	40	2.10



CASE STUDIES

Including Pilot Tests

CASE STUDIES

In India…

Damage assessment and cost of cycling studies at:

- NTPC Ramagundam
- NTPC Jhajjar
- GSECL Ukai(2 units)

AWARE:

- Vedanta Jharsuguda
- TSPL

Regulatory Support:

Inputs for CEA & CERC, through USAID's GTG-RISE programme

GTG-RISE-Knowledge dissemination

Global…

NREL: Cost-Benefit Analysis of Flexibility Retrofits for Coal and Gas-Fueled Power Plants

NREL: Power Plant Cycling Costs

NREL: Western Wind and Solar Integration Study

PMJ: Renewable Integration Study

Electricity Supply Board of Ireland —Cost of Cycling for Irish Electric Supply Board

Public Power Corporation of Greece —Assistance on Phase I Cost Forecasting for PPCG

Origin Energy, EraringStation Flexibility and 2-Shift Operation Analysis, Australia

EPRI: Effect of Flexible Operation on Boiler Components: Theory and Practice

COMBUSTION ISSUES DURING LOW LOADS

- Fuel Quality issues
- Mills Performance
- Burner Performance
- Furnace Heat Balance
- Ensuring Waterwall Cleanliness
- Refractory & Casing Issues
- PA Fan Issues
- Burner Damper/ Tilt Issues
- Other

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DISCLAIMER

Thanking You on Behalf of!

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