# FLEXIBLE THERMAL POWER PLANTS: BRIDGE TO A DECARBONIZED ENERGY SYSTEM

## Practical solutions for System Flexibility : Case Studies

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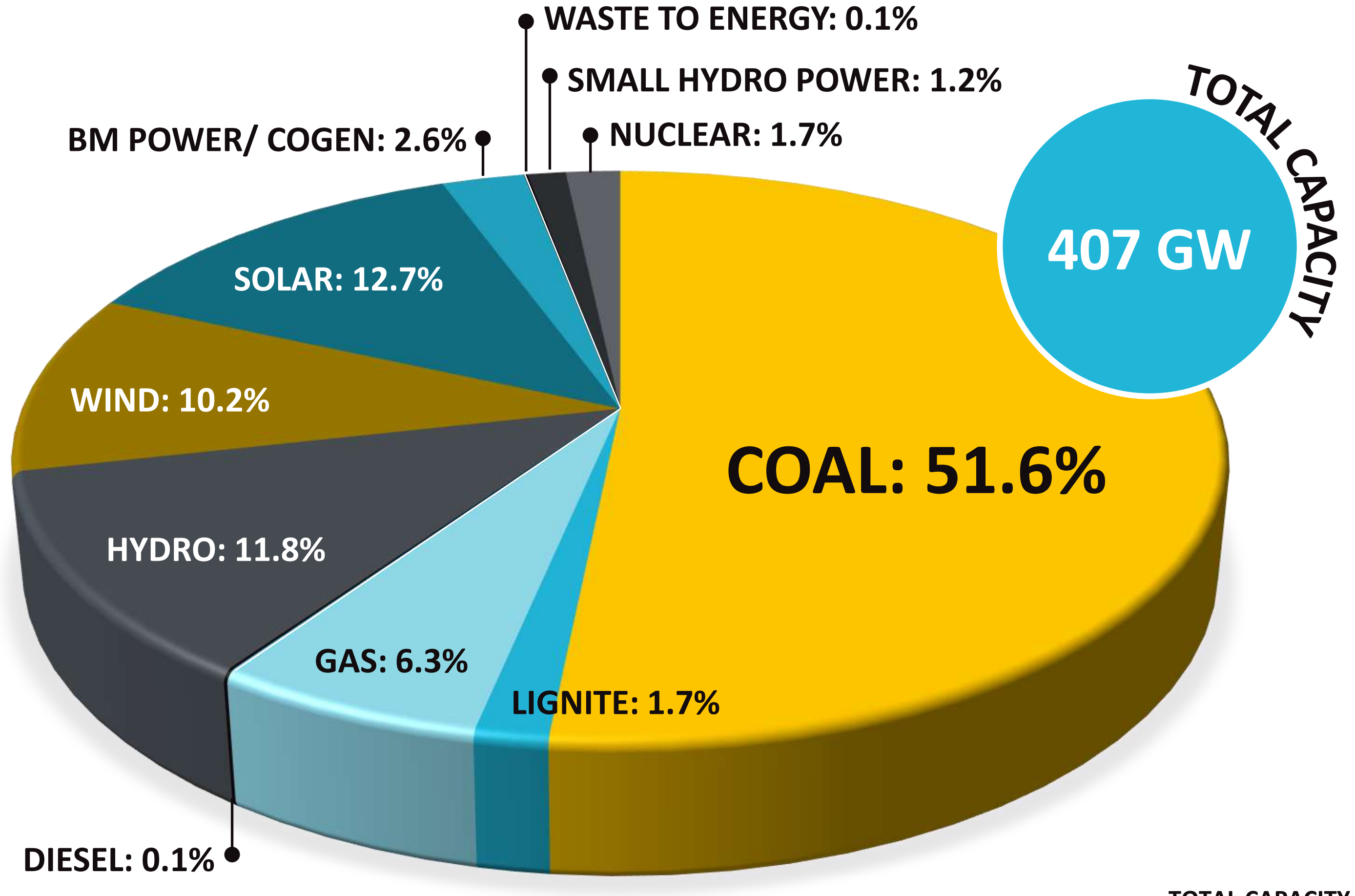
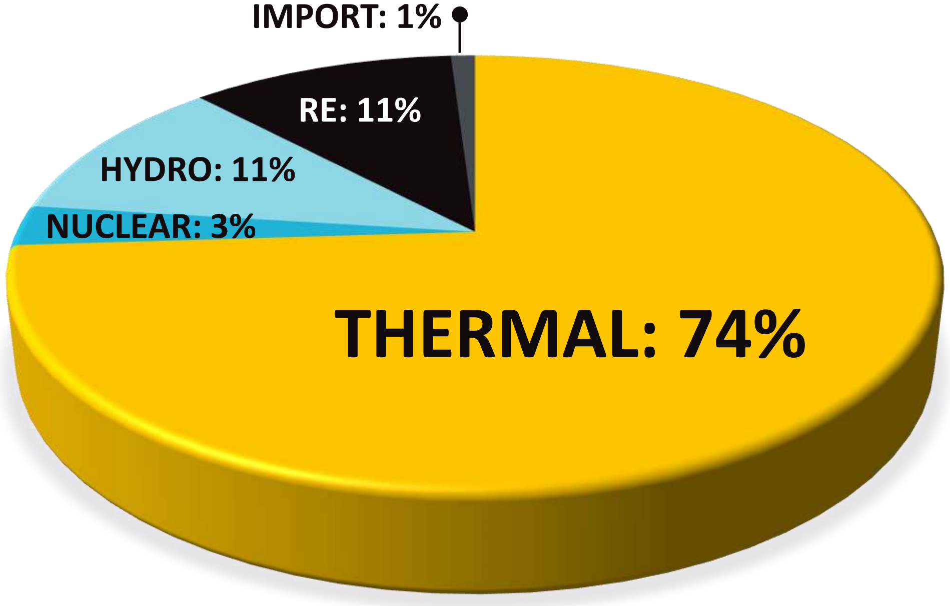
24 November, 2022

# AGENDA

# COAL HAS BEEN THE MAINSTAY OF THE POWER GENERATION IN INDIA

## GENERATING CAPACITY SOURCE



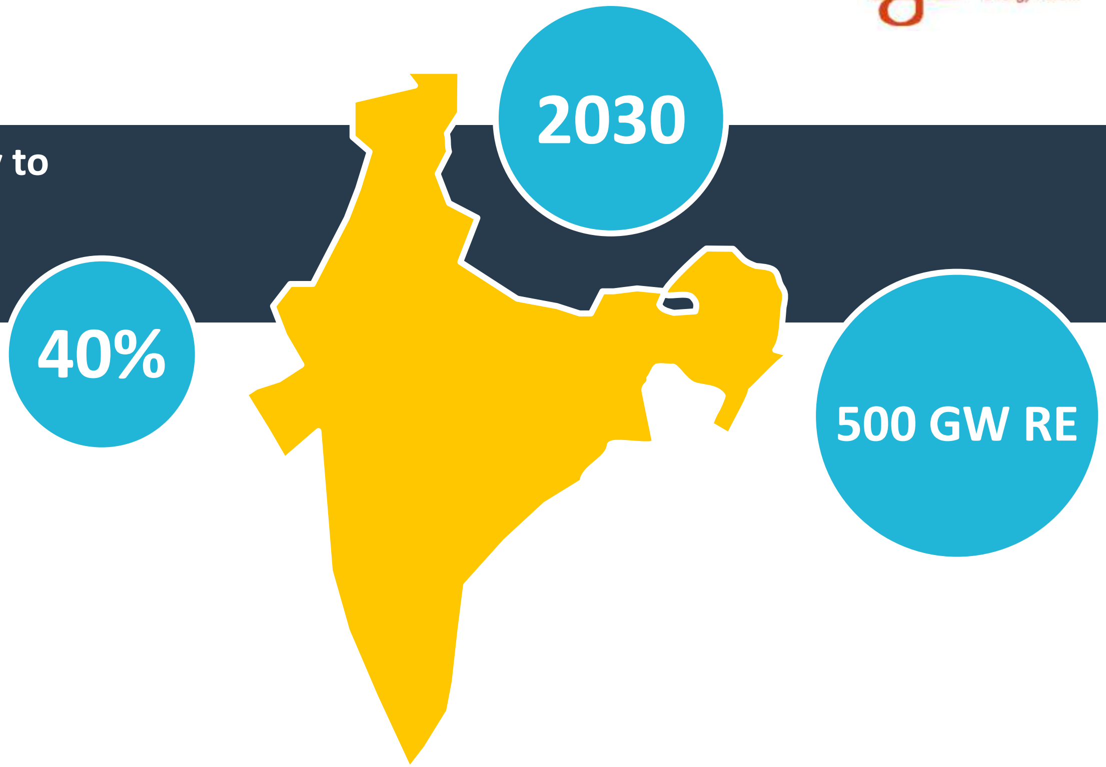



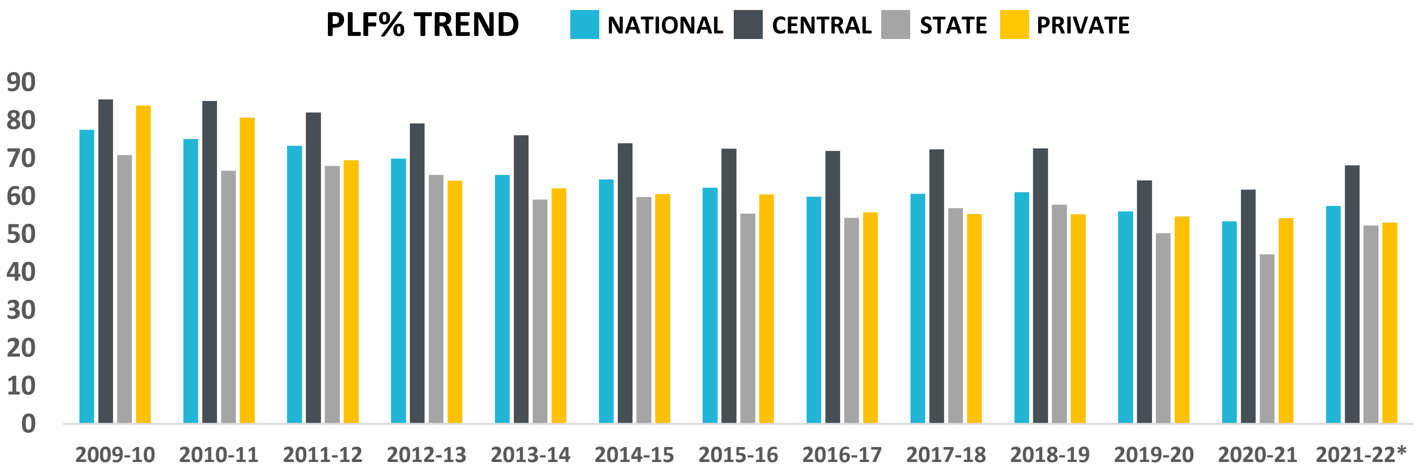

## SOURCEWISE GENERATION

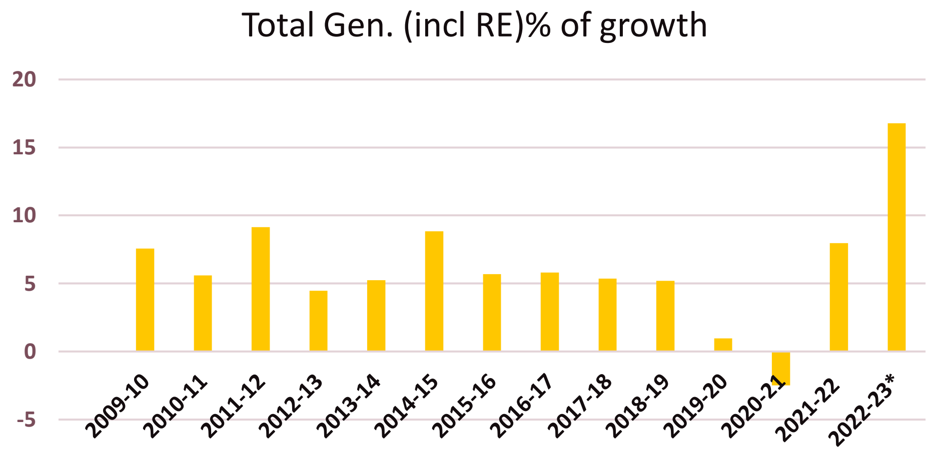
TOTAL CAPACITY as of 31 Oct, 2022

# 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

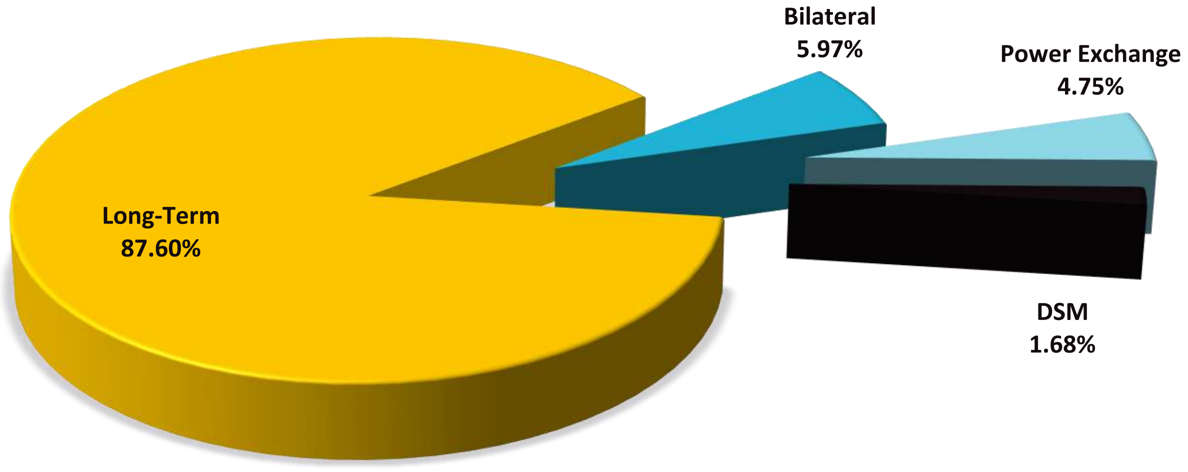


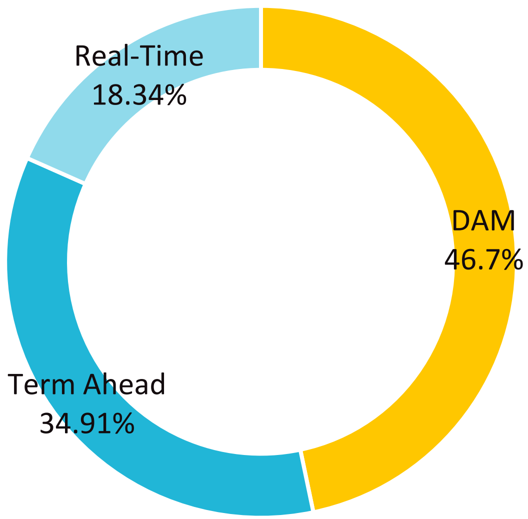
# THE INDIAN ELECTRICITY MARKET

## VOLUME OF VARIOUS KINDS OF ELECTRICITY TRANSACTIONS IN TOTAL ELECTRICITY GENERATION




APRIL 2022

## VOLUME TRANSACTED IN DIFFERENT MARKET SEGMENTS




- Largely Long-term Physical Contracts, Supplies on Day-Ahead Basis & PPAs on Two-Part Tariffs (Capacity Charges & Variable Charges)
- DSM (Deviation Settlement Mechanism) To Address Intra Day Energy Requirements As Well As System Imbalances
- AGC in ISGS Stations
- SCED
- Flexibility in Generation & Scheduling
- Day-Ahead Market & Real Time Market
- Compensation Mechanism for Part Load Operation

# WHAT ARE THE MODES OF FLEXIBLE OPERATION?

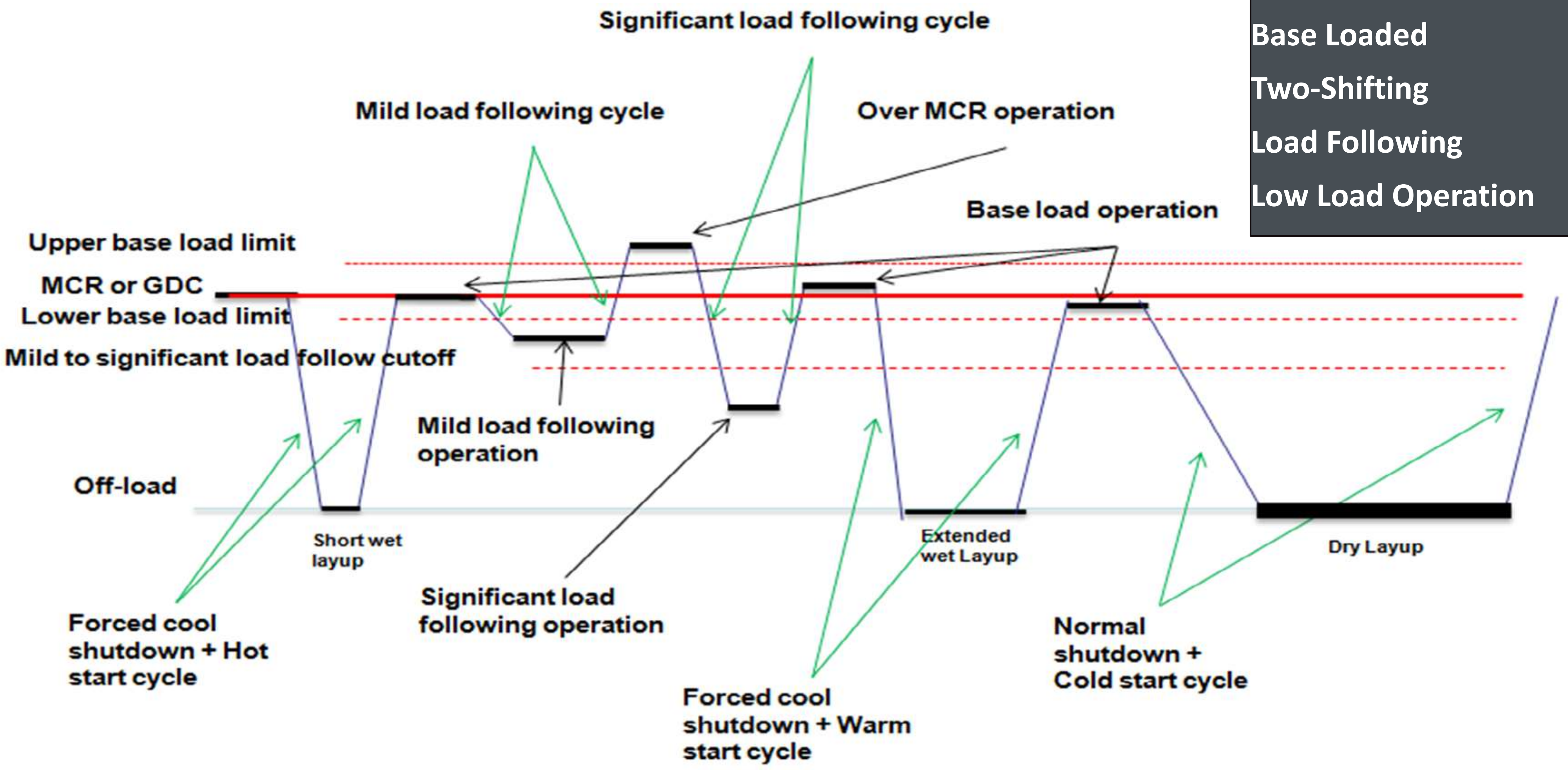
Extended Load

Base Loaded

Two-Shifting

Load Following

Low Load Operation




EPRI

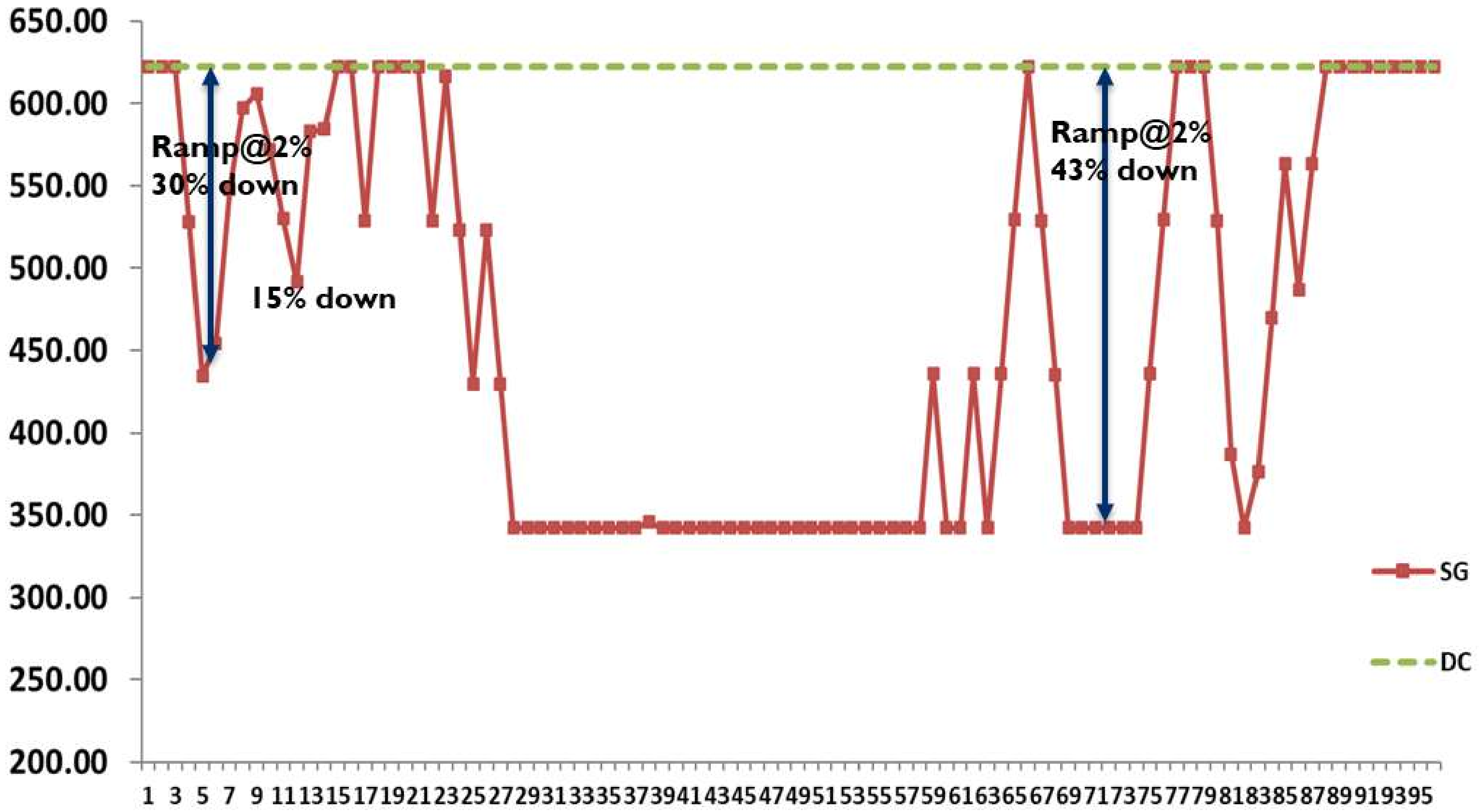
# REAL EXAMPLE
## SCHEDULING OF A UNIT & THE EFFECT

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 >2lakhs INR for the generator, which the
**GENERATOR HAS NO WAY TO RECOVER** from the present regulatory mechanism

are the
**SYSTEM OPERATORS, UTILITIES & POLICY MAKERS ALIGNED?**

is this an
**ECONOMIC DISPATCH?**

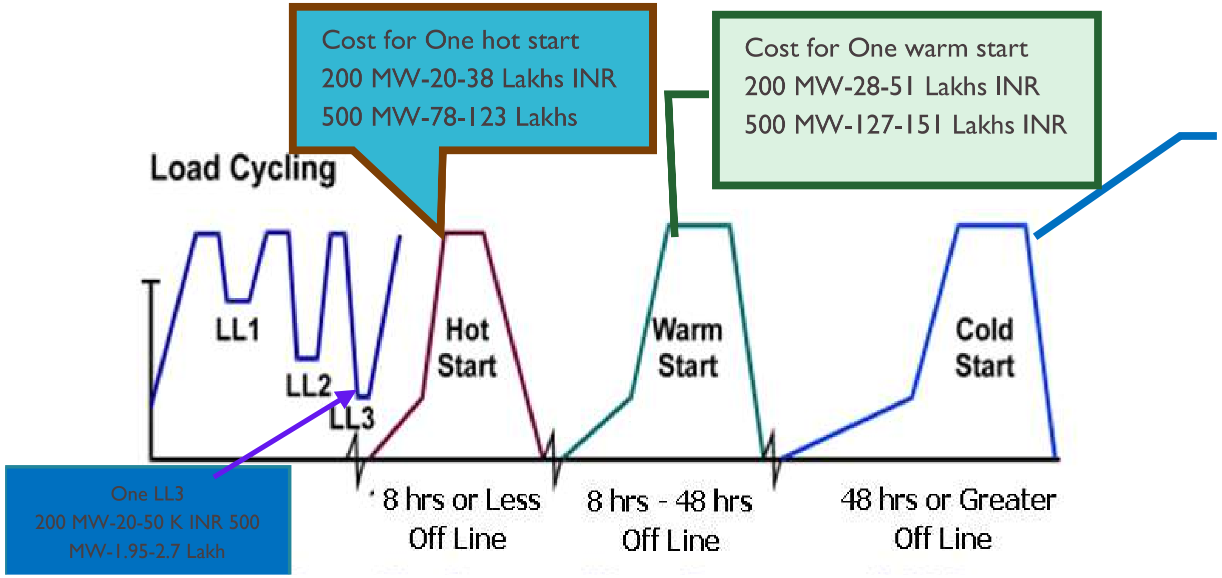



**RISKS**

- Safety Issues
- O&M Cost – Under Recovery
- Cost of Failures
- Efficiency Loss
- Increased Emissions

**OPPORTUNITIES**

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




LOAD CYCLING HOT STARTS WARM STARTS COLD STARTS

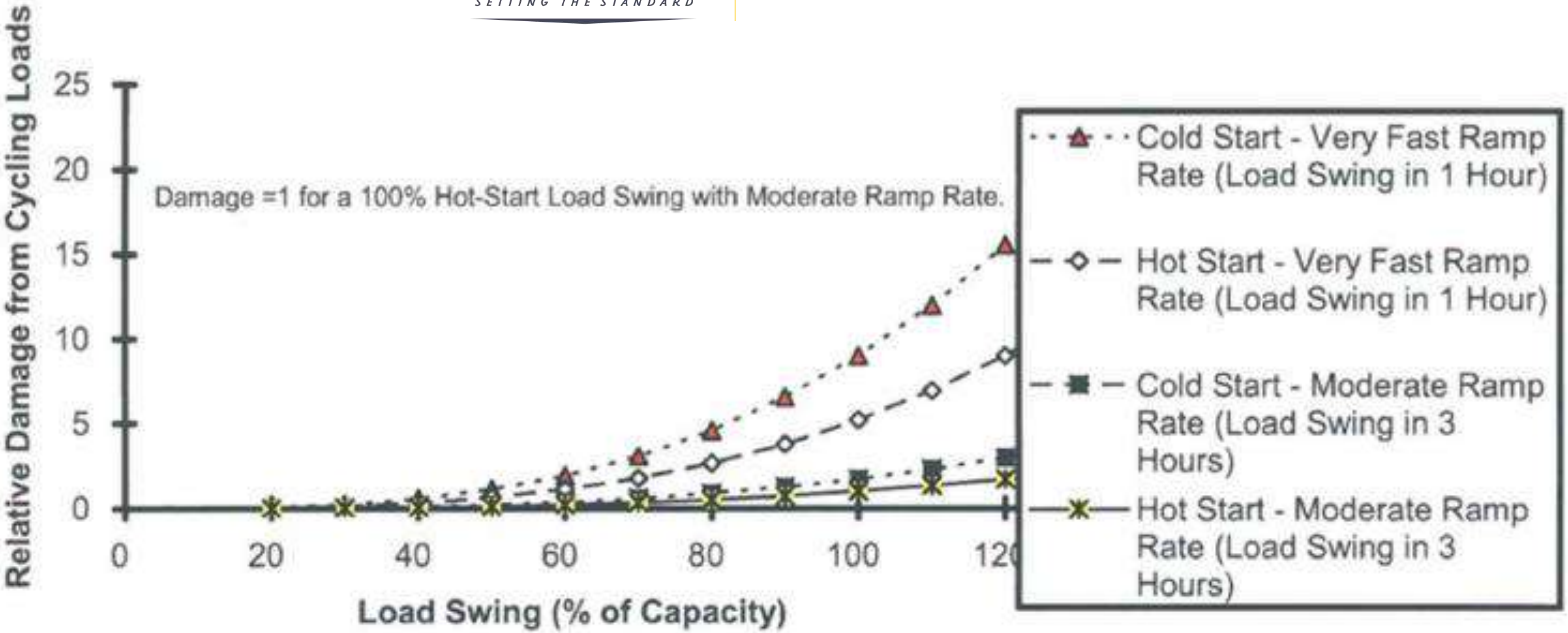
DAMAGE

# WHY
## DO YOU NEED TO PREPARE FOR REDUCING THE LEVEL OF MINIMUM LOAD?

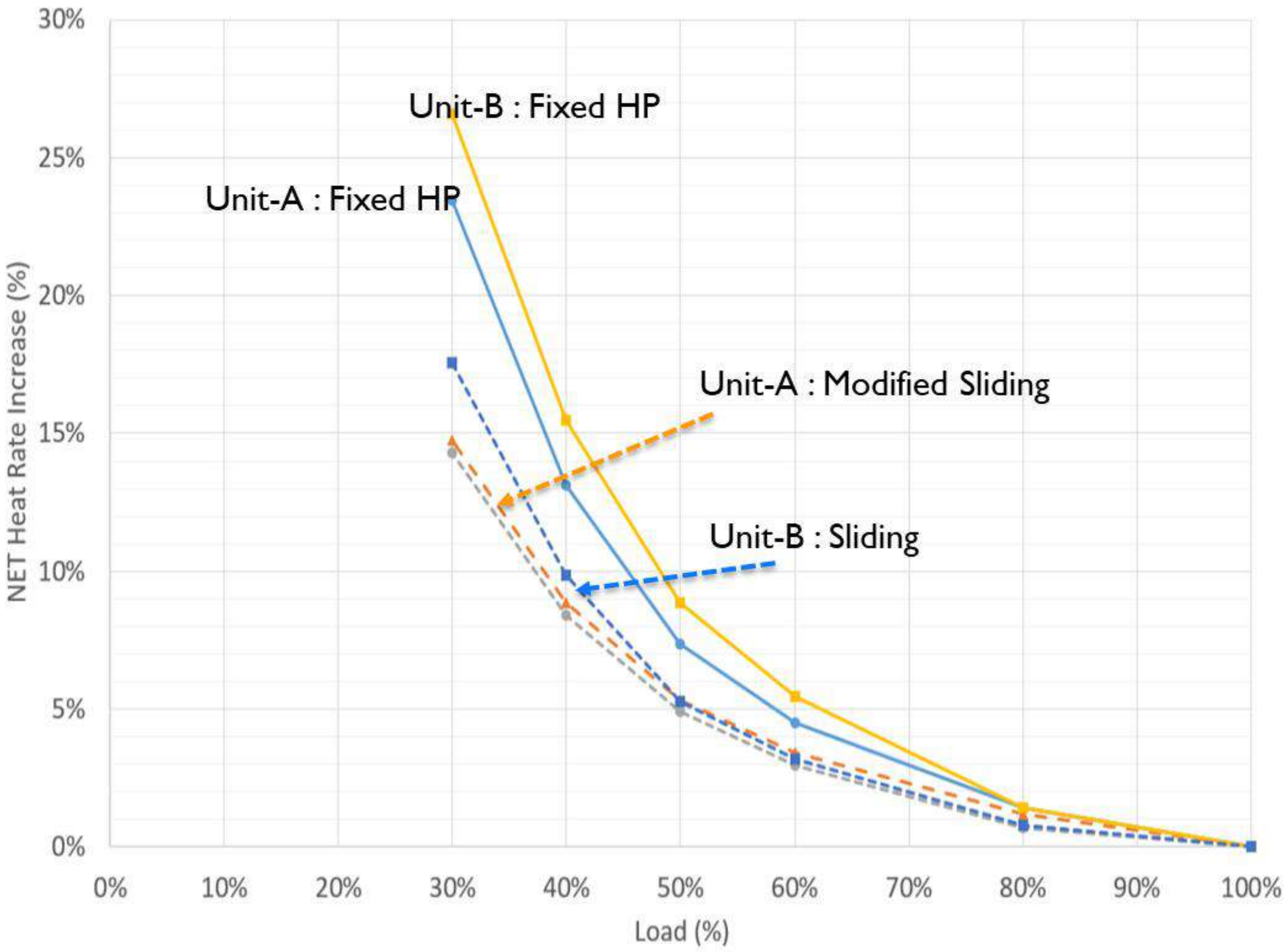
| UNIT SIZE | 200-250 MW | 500 MW |
|---|---|---|
| Load Following Cost (US$) | 260-650 | 2500-3500 |
| Hot Start Cost (US$) | 26k-50k | 100k-159k |
| Warm Start Cost (US$) | 36k-66k | 165k-200k |
| Cold Start Cost (US$) | 54k-118k | 225k-340k |

# RAMPING COSTS

## STANDARD CURVE



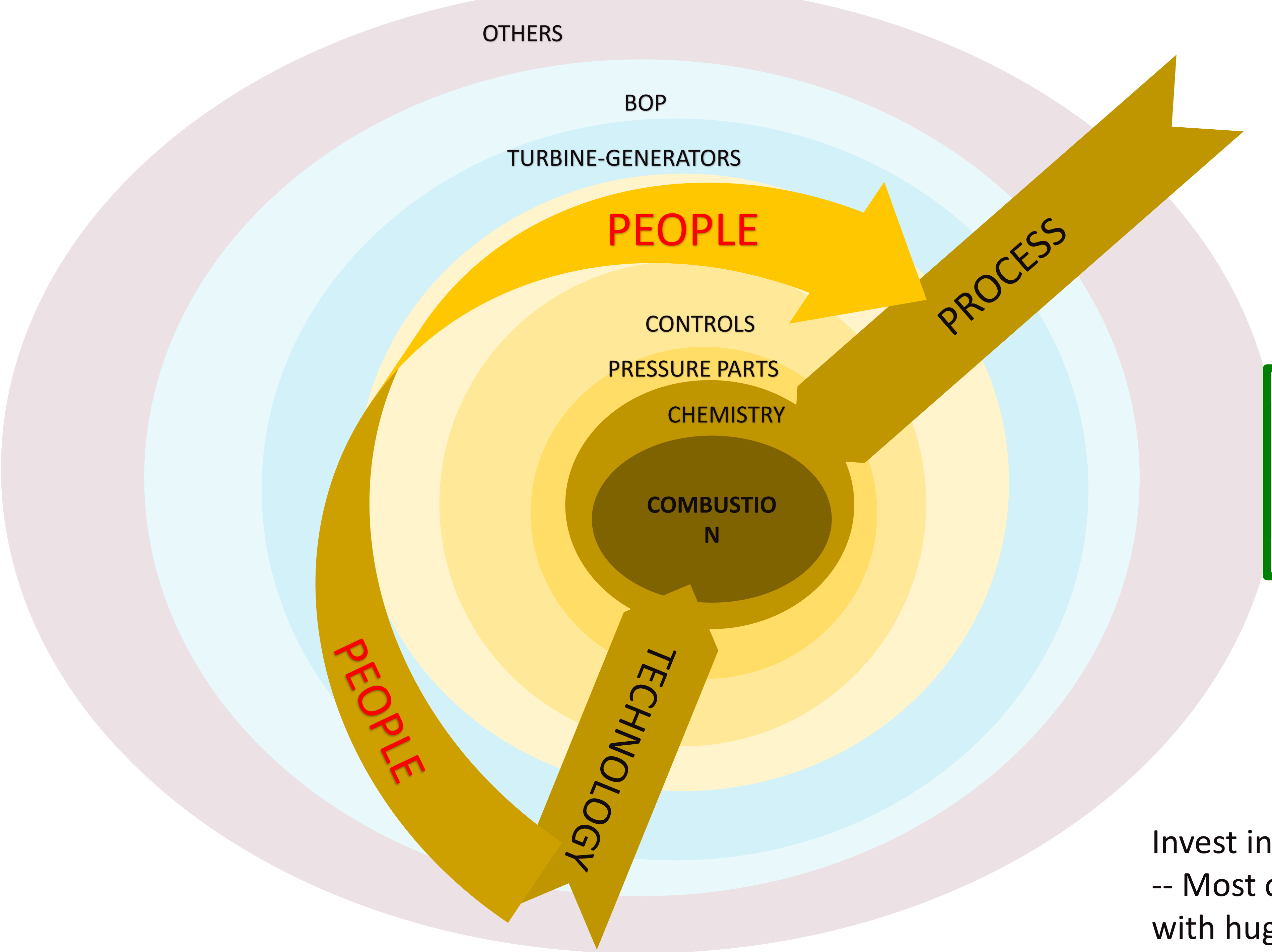
# EFFICIENCY ISSUES




- Burner Performance
- Combustion Issues
- Fuel Issues
- Furnace Heat Balance
- Waterwall Cleanliness
- Refractory & Casing Issues
- Expansion Joint & Duct Failures
- Fan Issues
- Burner Damper/ Tilt Issues

# RELIABILITY CONCERNS

| | | |
|---|---|---|
| Tube Failures | Outages Caused by Control Issues | Casing/ Refractory Failures |
| Burner Failures | Chemistry Issues | FAC |
| Boiler Auxiliary Failures | HEP Issues | Design Issues |
| Start-Up, Shutdown & Cycling Issues | Fuel Piping Failures | Other Issues |




**No magic solution or one-fit-for all solution**

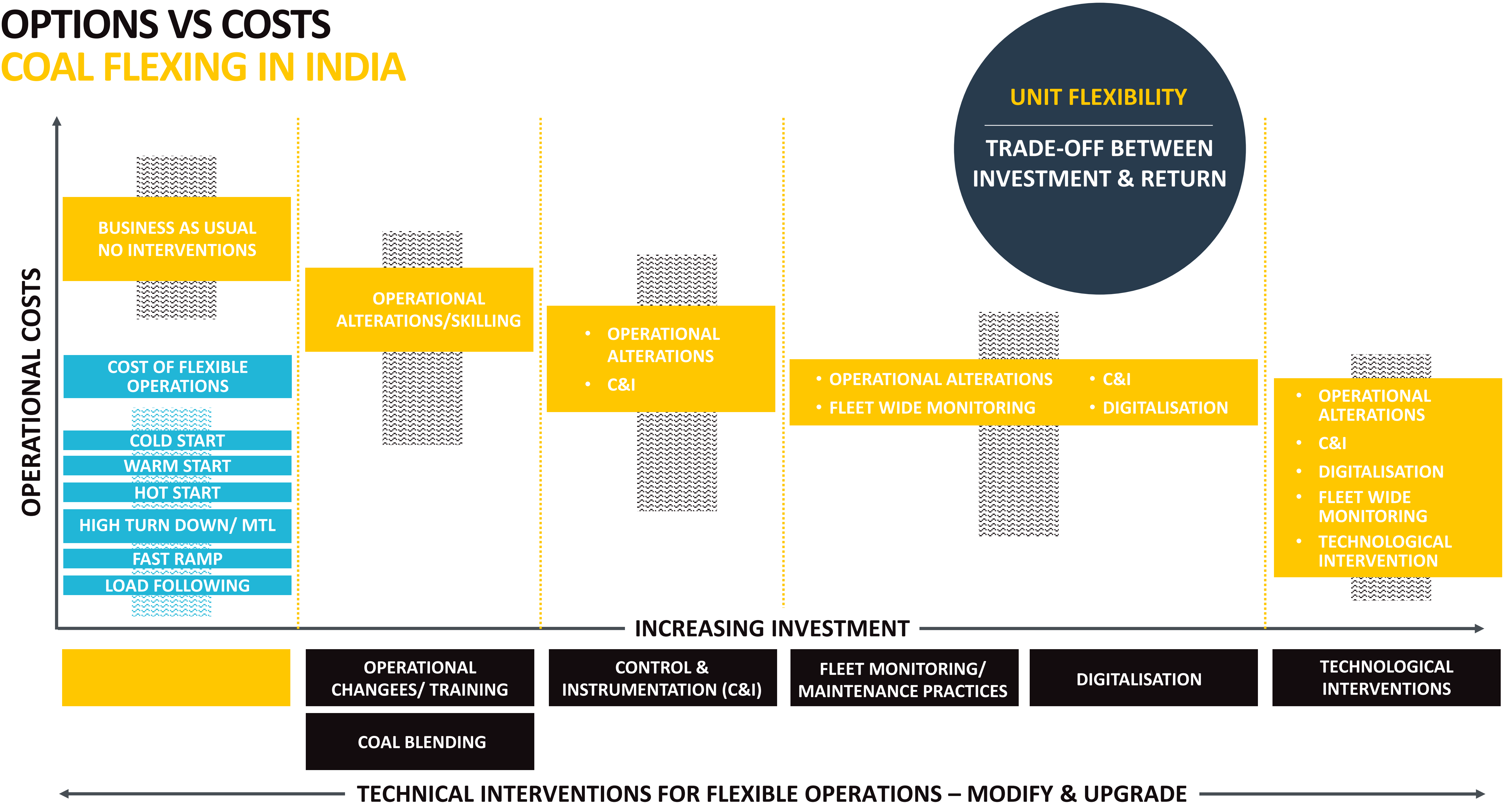
Flexible operation needs a comprehensive approach

Invest in capacity building
-- Most cost effective solution with huge pay back

# HARSH REALITIES OF CYCLIC OPERATION

- Flexing with lack of awareness, can be **DISASTROUS**
- Cycling causes **DAMAGE** and when equipment degrades, performance degrades
- Damage not immediate but **ACCUMULATED** and not easy to quantify
- By the time symptoms of damage is visible it may have become **VERY COSTLY** to correct
- Flexible operation is a difficult mode of operation and even the most conservative approach will increase plant **O&M COSTS** along with per MW variable costs
- Plants that can operate flexibly to meet market conditions while minimizing the financial impact of operating in this environment will continue to be dispatched at least for the near future
- Investments in **RETROFITS** can enhance the flexibility to a large extent
- Revisiting the **O&M PROCEDURES, TRAINING & DIGITALIZATION** support can enhance flexibilization
- **COMPREHENSIVE APPROACH NEEDED INVOLVING**
- **PEOPLE, PROCESS & TECHNOLOGY**

# OPTIONS VS COSTS
## COAL FLEXING IN INDIA



# BENCHMARKING
# METRICS & KPI

**Knowing the COMPONENT-WISE CYCLING COSTS is Necessary for deciding Maintenance Schedules**

**DEFINING from Different Perspectives**

- Minimum Load, Ramp Rate, Start-Up Time & Reserves

**MEASURING Metrics & Quantifying**

- Cost Components – EHS, EFOR, EOH & Reliability

**OPERATIONALISATION of Sources, Options & Preparedness for Coal-Based Plants**

- Merit Order based on Variable Cost, Heat Rate & Emissions

**COMPENSATION/ INCENTIVISATION within Regulatory Framework, Market Structure & Mechanisms**

- Ancillary Service, DSM, AGC & Real-Time

**FLEXING & OPERATING** – choosing which units to **FLEX** is based on **TECHNICAL CAPABILITY & MARKET MECHANISMS** and to **OPERATE** is based on the **VALUE** it can provide to the system

- Ramping
- Start-Up Time
- Off-Line Capabilities
- Spinning Reserves Capability
- Primary Reserves Capability
- Minimum Stable Generation
- Automatic Voltage Regulation (MVAr)

**DEFINING NEW FLEXING PRODUCTS**

- Merit Order Dispatch
- Marginal Cost Pricing
- Opportunity Cost Pricing
- Price Discovery

**KPI**

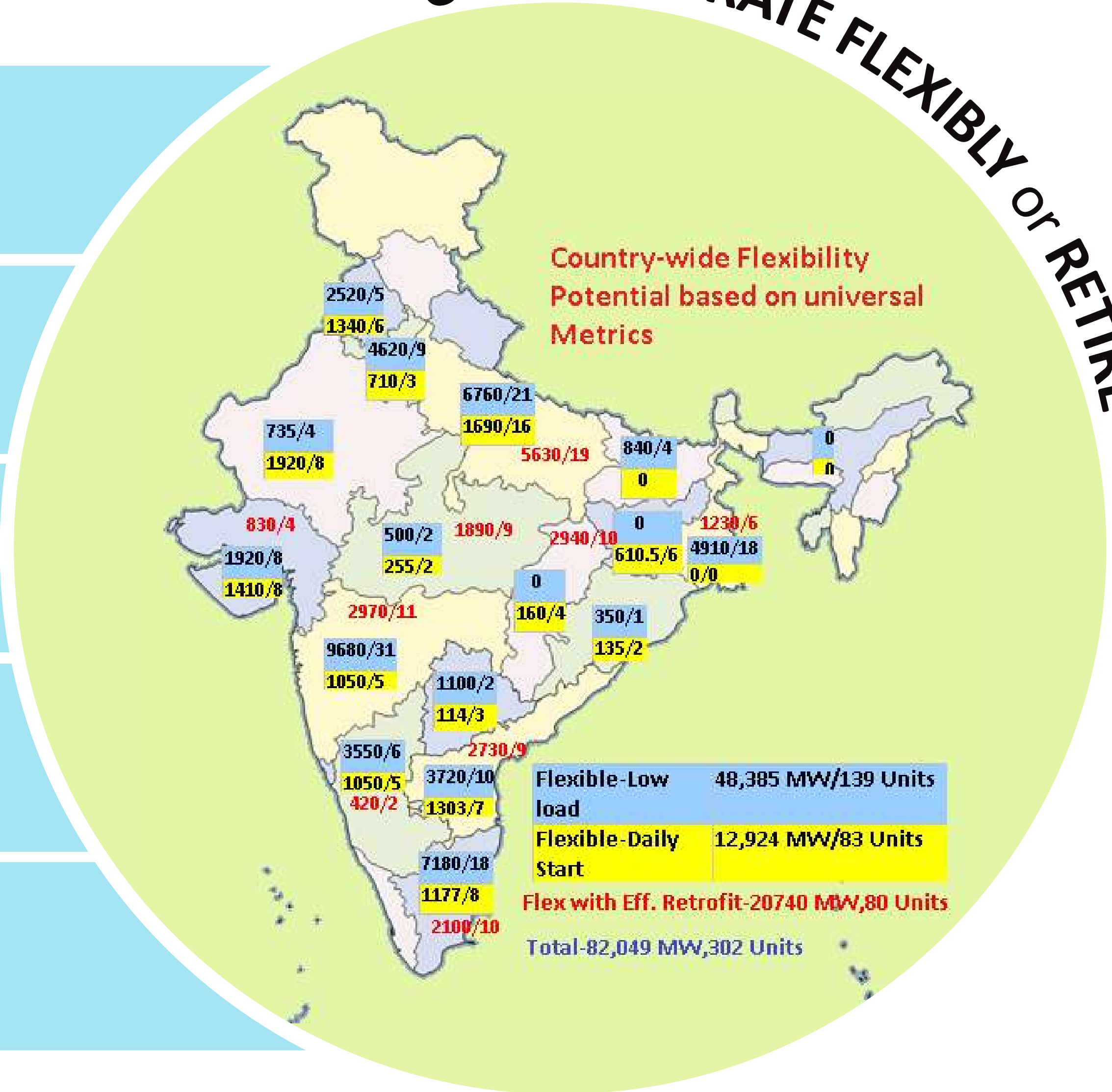
- Simple to Understand & Calculate
- Include Cost-Benefit Approach
- Prioritise
- Include Techno-Economics/ Market Based
- Generalisability/ Easy to compare across Units

One KPI could be **Economic Weighted Availability Factor** – availability has different value when there is demand & high market price which can be useful in planning for maintenance to enable the unit to deliver flexibility services when required.

# CATEGORISATION OF UNITS
# FOR DIFFERENT MODES OF OPERATION

CEA ▶ OPERATE FLEXIBLY or RETIRE

| CATEGORY | METRICS |
| --- | --- |
| **Base Load** 140GW/299Units | ECR<< State M.O.<br>GCV < 2800,VM<15%<br>Supercr. (except 14 Units) |
| **Flexible-Low Load** | ECR=> State M.O.(>Rs.2.5/KWH)<br>GCV >2800,VM > 15% |
| **Flex with Efficiency Retrofit** | Units>25 Years<br>Unit size-200 and above<br>HR> 2500 |
| **Flexible Daily Start** | ECR>> State M.O.<br>(unlikely to get schedule in 2022)<br>HR>2500, GCV>3400 |
| **Retire/ Replace** | >25Years<br>HR>2600<br>Unit sizes<200 MW |




**CEA'S ORDER MANDATES UNITS (TOTALLING 82 GW) TO OPERATE FLEXIBLY OR RETIRE**

# CASE STUDIES
# INCLUDING PILOT TESTS & INTERVENTIONS

# CASE STUDIES
# EXAMPLES

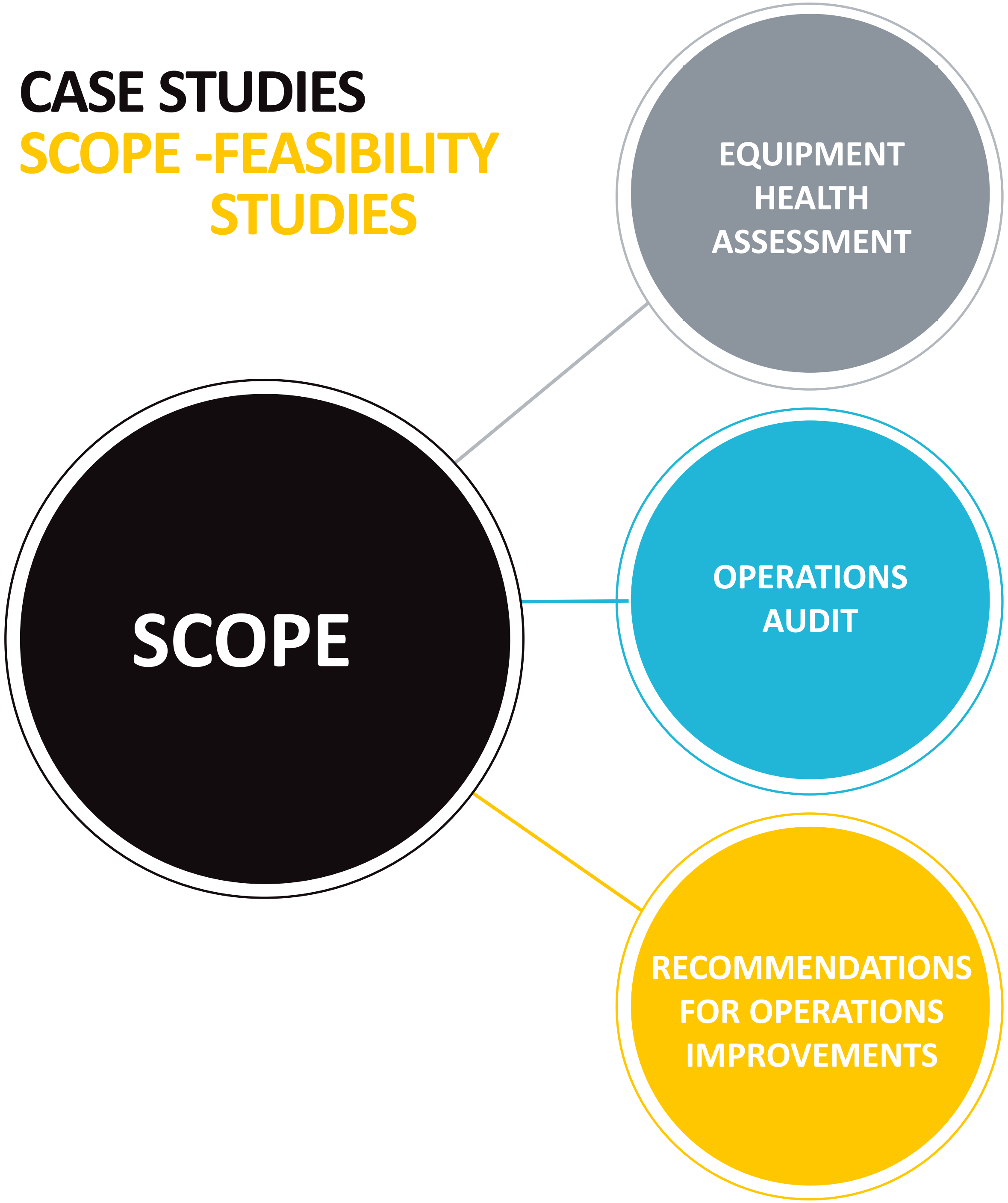
## GLOBAL

- **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, Eraring Station Flexibility and 2-Shift Operation** – Analysis, Australia
- **EPRI** – Effect of Flexible Operation on Boiler Components: Theory and Practice

## INDIA

- **Damage Assessment & Cost of Cycling Studies**
  - NTPC Ramagundam
  - NTPC Jhajjar
  - GSECL Ukai (2 units)
- **Feasibility assessment & pilot tests**
  - NTPC-Dadri, Simhadri, Mauda, Vindhayachal, Farakka
  - DVC Andal, Tata Maithon, Sagardighi
- **Regulatory Support**
  - Inputs for CEA & CERC, through USAID's GTG-RISE programme
  - **Implementation**
  - Dadri- Condensate throttling, Mill Auto Scheduler
  - **Capacity Building**
    - Knowledge dissemination

# CASE STUDIES
## SCOPE -FEASIBILITY STUDIES




### EQUIPMENT HEALTH ASSESSMENT

- Is there any damage?
- What are the damage mechanisms?
- How fast is the damage progressing?
- When will the damage cause failures?
- Are there any low probability but high impact risks?

### OPERATIONS AUDIT

- Operating Procedures Review
- Startup & Shutdown
- Protocols (Standing Orders)
- Generation Deficiencies & Incidents Documentation/ Reporting
- Training
- Performance Tests vs Design
- Review of Generation Statistics (FOR, EFOR, Availability, etc.)
- Maintenance & Inspection Schedules, Predictive Maintenance Tools, Spare Usage, SOW
- Digitalisation Maturity
- Usage of Predictive & Condition Assessment Tools
- Design Review & Requirement of Retrofits

### RECOMMENDATIONS FOR OPERATIONS IMPROVEMENTS

- Recommendations for Capital Projects To Reduce Cyclic Damage
- Review & Critique Cycling Cost Methods Used By Utility
- Development of Improved Cost Estimates
- Recommendations on use of Improved Cycling Cost Information in System Operations & Planning

# Varying Coal Quality posed a major challenge to flexibilization(during test runs)

| | GCV (KCal/Kg) | VM | ASH |
|---|---|---|---|
| A | 4000 | 18% | 36% |
| | 3400 | 14% | 40% |
| B | 4600 | 21% | 34% |
| | 3700 | 18% | 37% |
| C | 6000 | 22% | 30% |
| | 3300 | 15% | 42% |
| D | 3937 | 19% | 47% |
| | 2683 | 15% | 42% |

Target Minimum Load- below 40%

- Burning each grade of coal will require a different operating Regime, which needs to be defined.
- Maintaining combustion stability with Varying coal quality along with varying loads is challenging
- Operating Procedures need to be revisited
- Sufficient, Accurate, Reliable measurements needed

| Table No: Samples collected from Coal Stations | | | | | | |
|---|---|---|---|---|---|---|
| Sample | Moist (%) | 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 |
| 18 | 4.79 | 22.11 | 41.77 | 31.33 | 62 | 3937 |

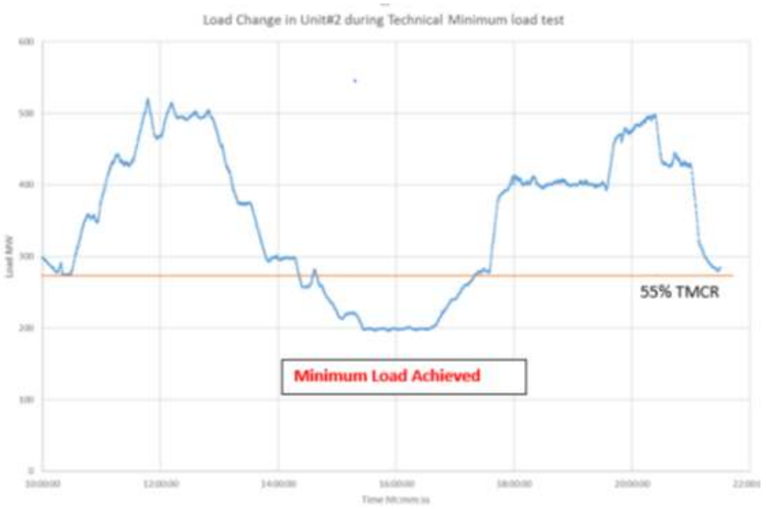
# Challenges in preparing Units for reducing their level of minimum load ?

# PILOT TESTS
# FOR MINIMUM LOAD & RAMP RATES

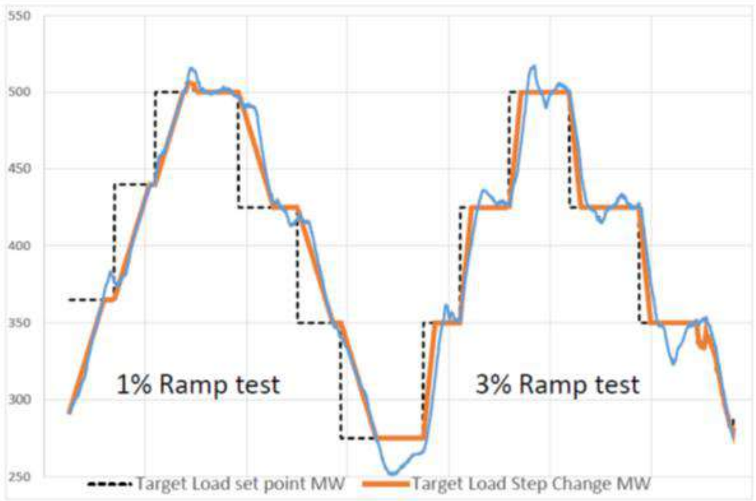
To prepare **INDIA'S COAL POWER PLANTS PILOT STUDIES**, test runs were conducted under the directions of MOP and supported by USAID, IGEF, and Jcoal. Important stakeholders included: OEMs *(GE, Siemens, BHEL),* Intertek, VGB , Engie Lab, NTPC, GSECL, KPCL, DVC, Tata Power, WBPDCL & UPPDCL.

## PILOT LOCATIONS

- **NTPC Jhajjar Power Plant (500 MW)**
  Jhajjar District, Haryana, India at 28.4892° N & 76.3557° E
- **NTPC Ramagundam Power Plant (200MW)**
  Peddapalli District, Telangana, India at 18.7589° N & 79.4555° E
- **NTPC Dadri (200 & 500MW)**
  UP. India at 28.5985° N & 77.6087° E
- **NTPC Simhadr (500 MW)**
  Visakhapatnam, Andhra Pradesh, India at 17.5961° N & 83.0875° E
- **GSECL Ukai TPP (200 & 500 MW)**
  Vagda, Gujarat at 21.2121 ° N & 73.5606° E
- **Anpara A (500MW)**
  Sonbhadra District, Uttar Pradesh, India at 24.2049° N & 82.7832° E
- **Bellary (500MW)**
  Karnataka, India at 15° 11′ 31.5″ N & 76° 43′ 03.8″ E
- **Tata Maithon (500MW)**
  Jharkhand, India at 23° 49′ 13″ N & 86° 45′ 36″ E
- **DVC, Andal (500MW)**
  WB at 23° 34′ 55.61“ N & 87° 11′ 8.62“ E




# TEST RUNS




## LOW LOAD

- From 500MW to 198MW & BACK with hold points
- 500-360 MW- 5mills
- 360MW-300MW- 4mills
- 300MW-275MW-4mills
- 275-198MW-3 mills (C,D,E)

## TURNDOWN OF MILLS

- Loading of mills were reduced till 50% load
- If any mill was required to be loaded below 50%, it was with drawn and other mills loaded

## REVIEW OF SLIDING PRESSURE CURVE & PA FLOW CURVE

## UNIT ASSESSMENT WITH HP HEATERS BYPASS

## RAMPING

- Ramp up/down  of 1%, & 3% were checked at different load range
- CMC on except during ramp up @3% from 360-500MW when CMC response was very fast (CMC made off)
- There was a difference in CMC response and actual ramp achieved at lower loads (for 3% ramp)
- Unacceptable deviation in parameter (SH Temp, RH, excessive SH spray)
- Due to thermal shock, falling of big sized clinker which dislocated SC chain
- Sliding pressure needed to be modified
- BFP R/C valve (full open/close) posed problems in drum level control

## CONCLUSION

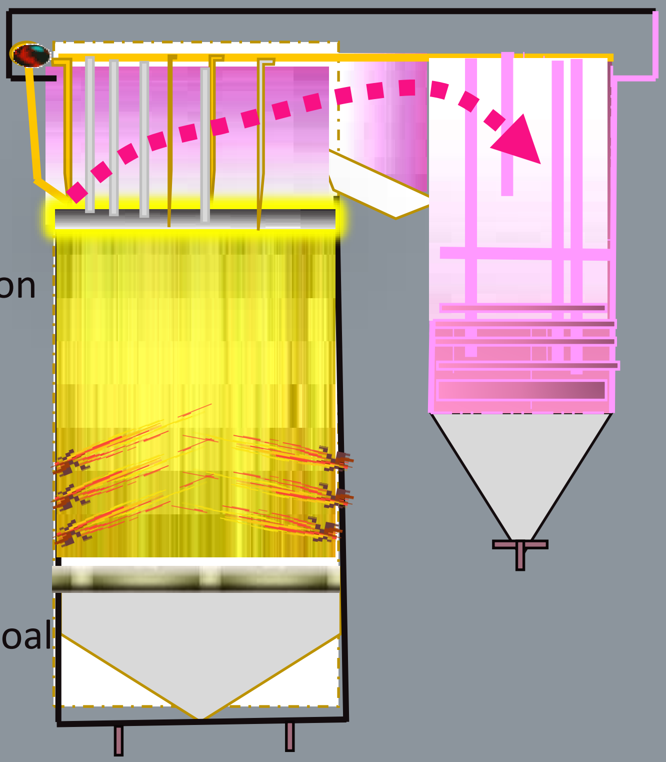
- Upgrade of C&I system needed
- Changes in operational procedures (eg- Soot blowing, Burner tilt operation, air flow, mills selection & turndown)

# TEST RUNS
## COMMON ISSUES

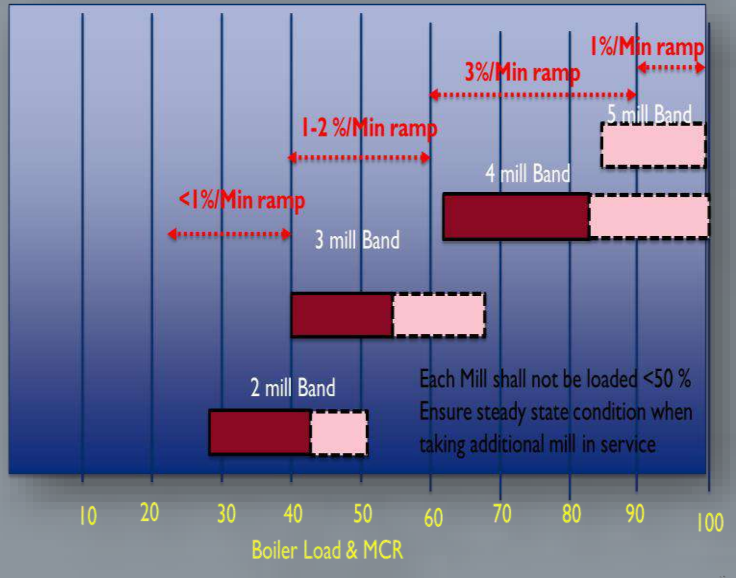
- In all the test runs conducted, it was observed that **CONTROL LOOPS** were not tuned for low loads
- Burner tilts were on **MANUAL** – key variable having significant influence on steam temperature parameter control
- More number of mills than required were kept in service to take care of the exigencies of **MILL TRIPPING**
- **PRIMARY AIR FLOW** maintained higher than anticipated values as mills were operated at full mill air flow irrespective of the mill loading
- **SECONDARY AIR FLOW** is very much less than the desired level resulting in no or low windbox dP at part loads
- **WB PRESSURE** was improved by closing the secondary air dampers of the mills that were not in service & optimising the primary air flow
- **STEAM COIL APH** was not available/not used regularly
- **SLIDING PRESSURE** was in service – needed modification
- The **PARTIAL STEAMING OF ECO** occurred at low load which can be allowed only for a short time
- Increase in **SH TEMPERATURE** during load ramping
- **HIGH SH SPRAY**
- Jerky operation of **FEED WATER FLOW** on opening of the recirculation valves at low load
- The analysis of **DIRTY AIR FLOW** results reveals that there is a good degree of imbalance in coal flow across the pipes at low load

# COMBUSTION OPTIMISATION

- **Coal fineness**
- **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
- Windbox pressure
- Burner Tilt
- Flame scanners
- Coal fineness
- Selection of burner



Flame scanners modifications
Burner modification



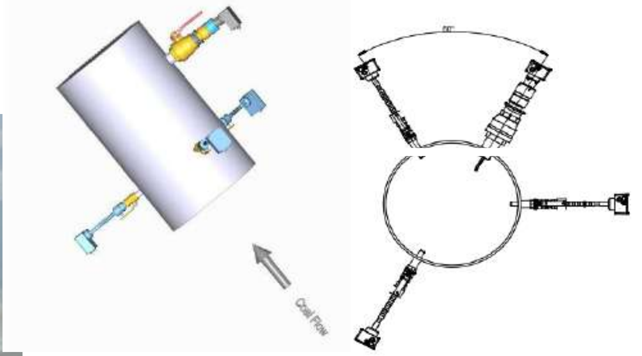

Fuel Firing System Optimization Package
for low load oprn:
- Air/Fuel ratio
- Coal pipes dynamic balancing
- Auto mill scheduler /start/stop
- Coal analyser

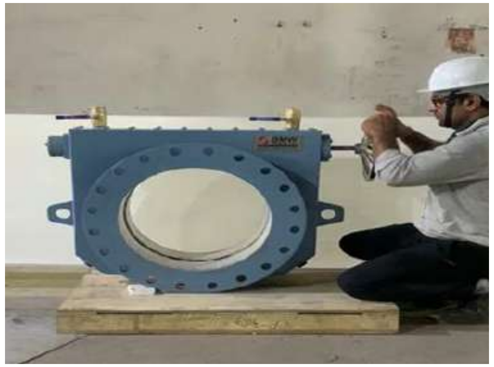
Auto Coal Sampler

# DYNAMIC COAL FLOW MONITORING AND MANIPULATION SYSTEM

Trending and manipulation Based on Real time measurements

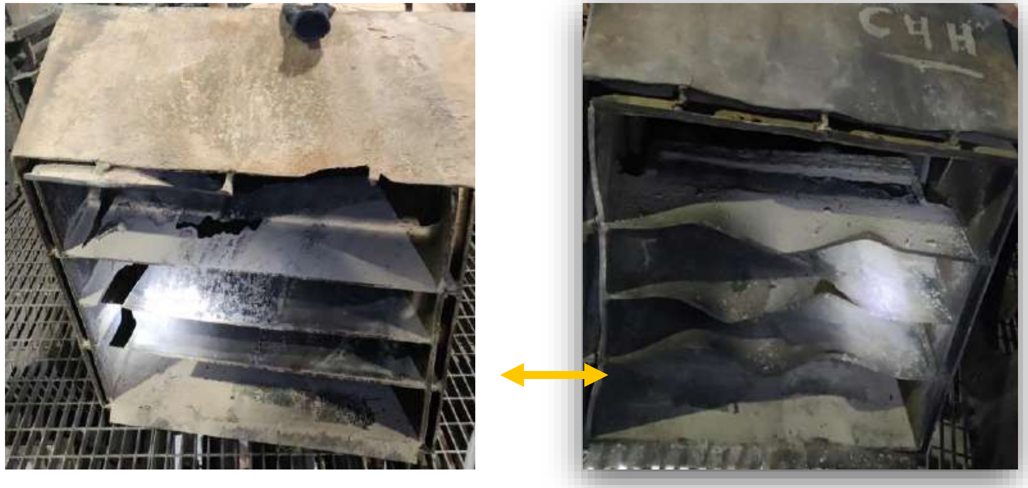
- Coal Mass Flow in each pipe
- Coal Roping Area identification
- Coal Temperature in each pipe
- Coal Velocity in each pipe
- Coal Flow Balancing
- DP across Variable Orifice
- Automatic Coal Pipe Balancing by Variable Orifice (Future proposal)

- 3 Mass Flow sensors (microwave based) placed at $120^0$ 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

# Unbalanced flow- Unequal fuel/air distribution across coal pipes



Two burner nozzles of the same mill

Erosion due to Coal Roping

# DYNAMIC COAL FLOW BALANCING

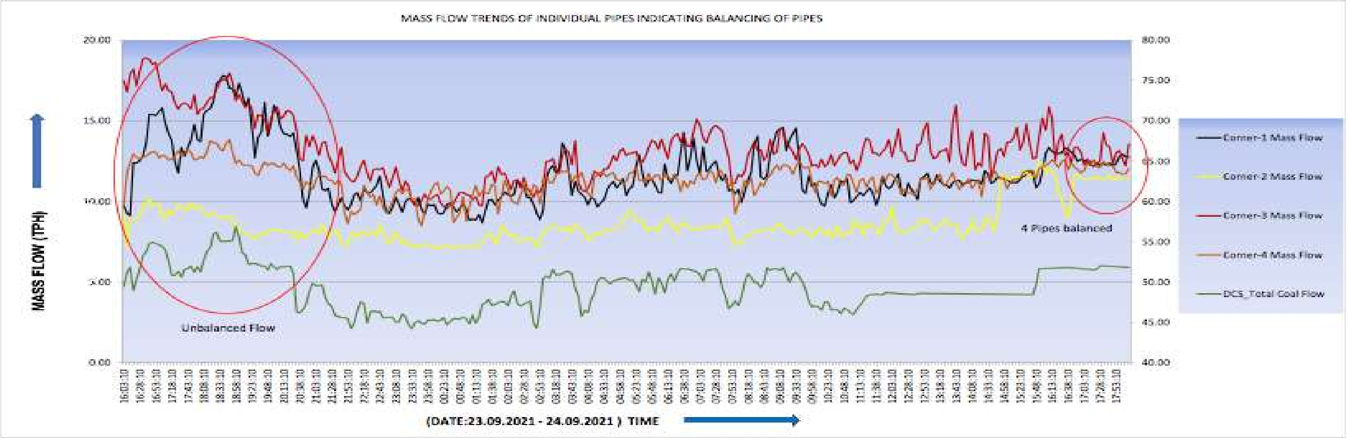
## Before Balancing

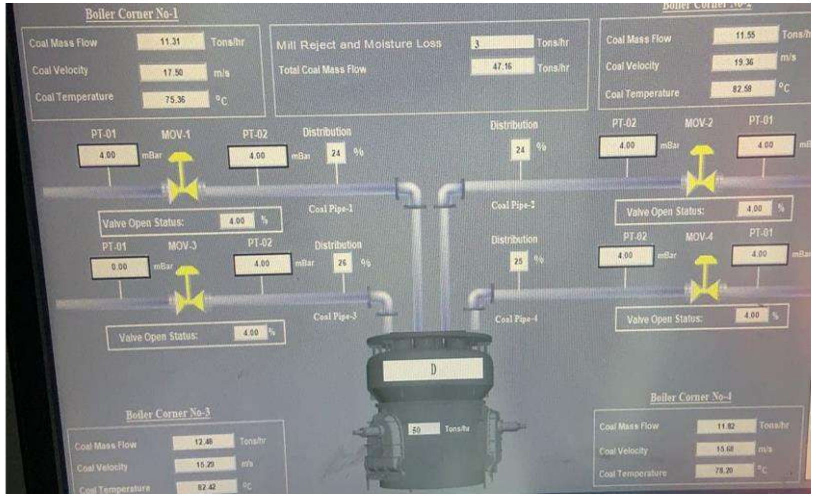
| | Mass Flow (TPH) | Percentage Mass Flow | Theoritical Equal (TPH) | Percentage Deviation |
|---|---|---|---|---|
| Total(Mill) | 47.2 | 100% | | |
| Corner-1 | 11.44 | 24.24% | 11.80 | -3.05% |
| Corner-2 | 8.96 | 18.98% | 11.80 | -24.07% |
| Corner-3 | 17.44 | 36.95% | 11.80 | 47.80% |
| Corner-4 | 9.35 | 19.81% | 11.80 | -20.76% |

## After Balancing

| Mass Flow (TPH) | Percentage Mass Flow | Theoritical Equal (TPH) | Percentage Deviation |
|---|---|---|---|
| 47.16 | 100% | | |
| 11.3 | 23.96% | 11.79 | -4.16% |
| 11.55 | 24.49% | 11.79 | -2.04% |
| 12.48 | 26.46% | 11.79 | 5.85% |
| 11.82 | 25.06% | 11.79 | 0.25% |

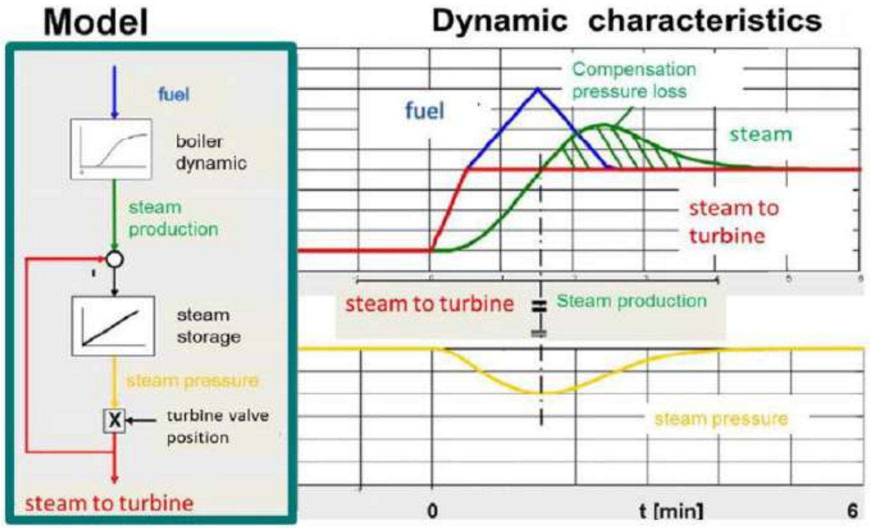
| Coal Pipe | Initial Setting - BHEL RECOMMENDED ORIFICE OPENING | Final Setting - ORIFICE OPENING TO ACHIEVE BALANCED FLOW |
|---|---|---|
| D1 | 100% | 98% |
| D2 | 74.5% | 85% |
| D3 | 70% | 51% |
| D4 | 78% | 76% |

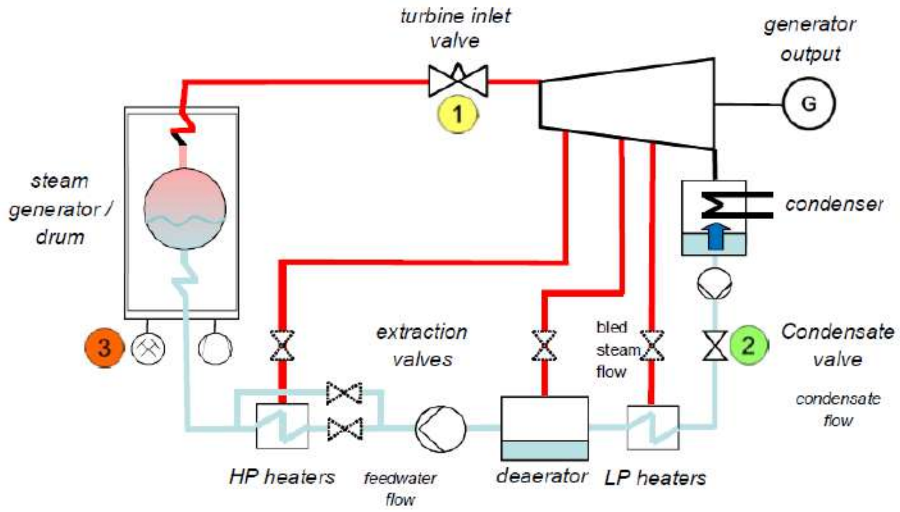


# IMPLEMENTATION OF
# FLEXIBILIZATION RETROFITS

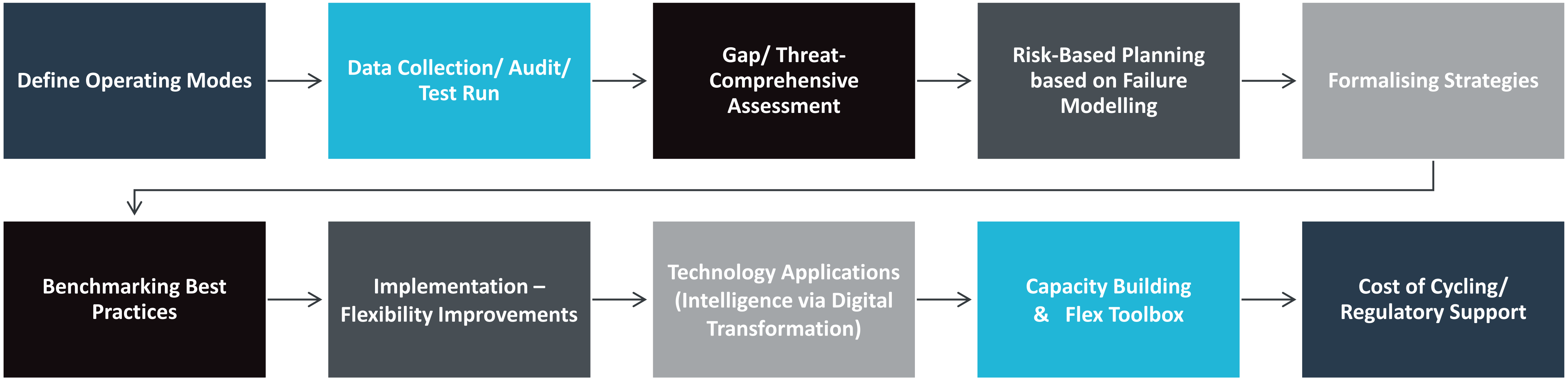
- Condensate throttling at NTPC, Dadri
- Mill Auto Scheduler – Auto-Start of Mills & Fans
- BFP R/C Valve – Replacement with control valve
- Online Coal Analyzer
- Boiler Fatigue Monitoring System



# FLEXIBLE OPERATION OF FLEET
## ROADMAP

AWARENESS | PREDICTABILITY | RISK MANAGEMENT | OPTIMISATION



# DAMAGES DUE TO
# FLEXIBLE OPERATION

UNDERSTANDING THE DAMAGES
DUE TO **FLEXIBLE OPERATION**
LEADS TO COSTS & SAFETY IMPLICATIONS

# 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

# EXAMPLES OF TYPICAL DAMAGE MECHANISMS

**CORROSION**

- Acid phosphate corrosion
- Under deposit corrosion
- Caustic gouging
- High temperature corrosion
- Below dew point corrosion
- Out of service corrosion
- FAC
- DNB

**OVERHEATING**

- Short Term
- Long Term

**CRACKING**

- Stress Corrosion Cracking
- Thermal Fatigue
- Corrosion Fatigue
- Cyclic fatigue
- Fatigue
- Creep
- Creep Fatigue

**PITTING**

- Corrodants
- Oxygen
- Hydrogen Damage

**EROSION**

- Ash
- Saturated Steam
- High Pressure Water
- Loose Connections
- Mechanical Rubbing
- Gases
- Contamination
- Fouling
- Thermal Quenching

# CRACKING OF
# THICK WALL COMPONENTS

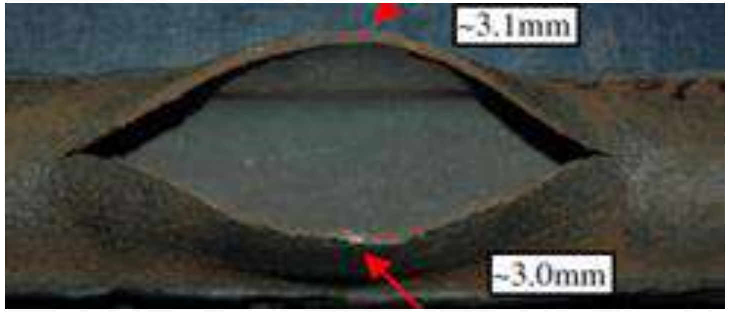
- **RAPID TEMPERATURE TRANSIENTS** during Starts/ Shutdown & Ramping Operation
- **TYPICALLY SHUTDOWN OPERATION IS CRITICAL**
- When cold water is fed during Hot Start-Up – **LEADS TO QUENCHING**

**CRACKING OF LIGAMENT BETWEEN STUBS**

**PIPE CRACKING**

# FAILURES DUE TO
# TEMPERATURE TRANSIENTS & ACID DEW POINT CORROSION

## TEMPERATURE TRANSIENTS

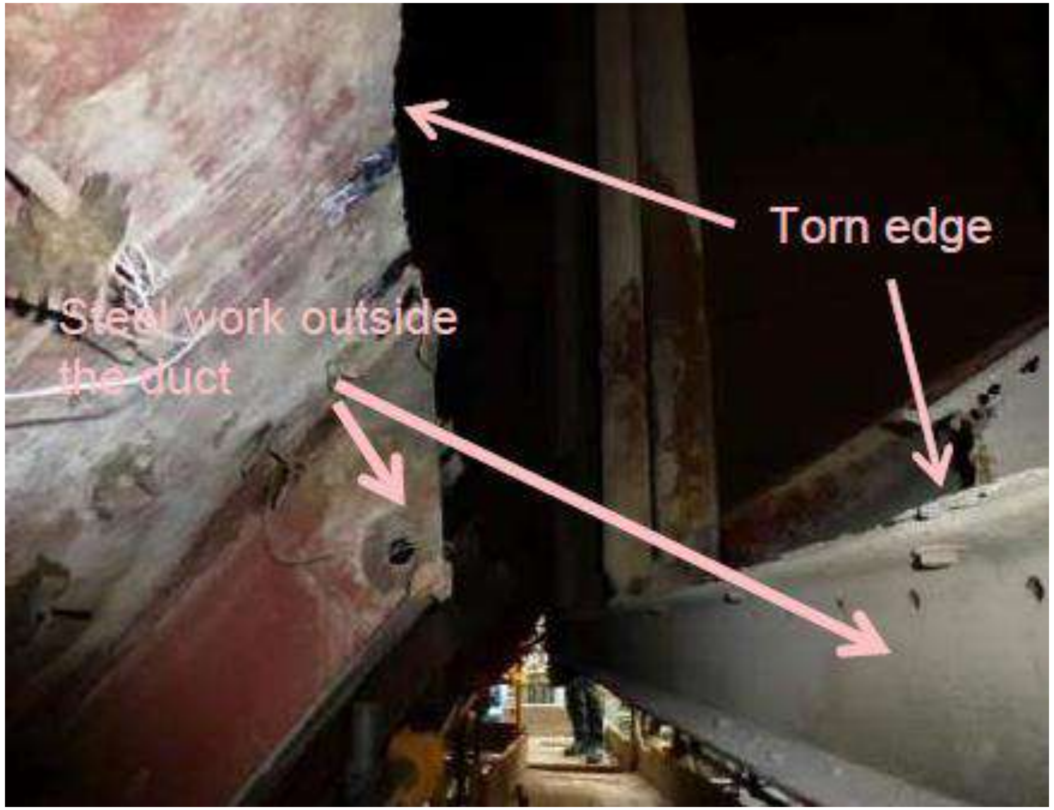



**WW FAILURE – 3 HOURS OF START-UP**
(SHORT-TERM OVERHEATING)

**SH LT OVERHEATING**
(SHORT-TERM OVERHEATING)

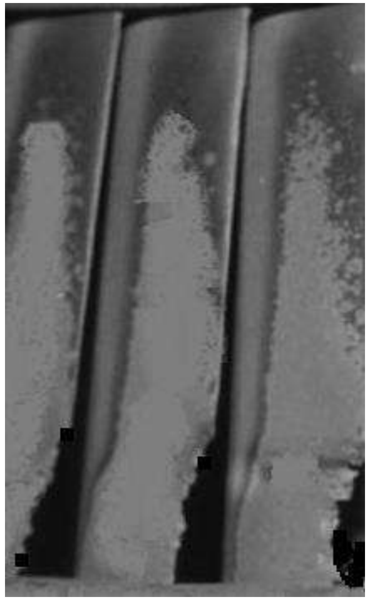
- Inadequate steam flow
- Drainage is critical (operation in auto)
- Ensure adequate flow in SH

## ACID DEW POINT CORROSION




**ESP COLLAPSE**
Continuous operation with Flue Gas temperature close to acid dew point

# DAMAGES TO TURBINE BLADES
## EXFOLIATION/ PITTING



EXFOLIATION

DAMAGE TO SEALS

PITTING

PITTING

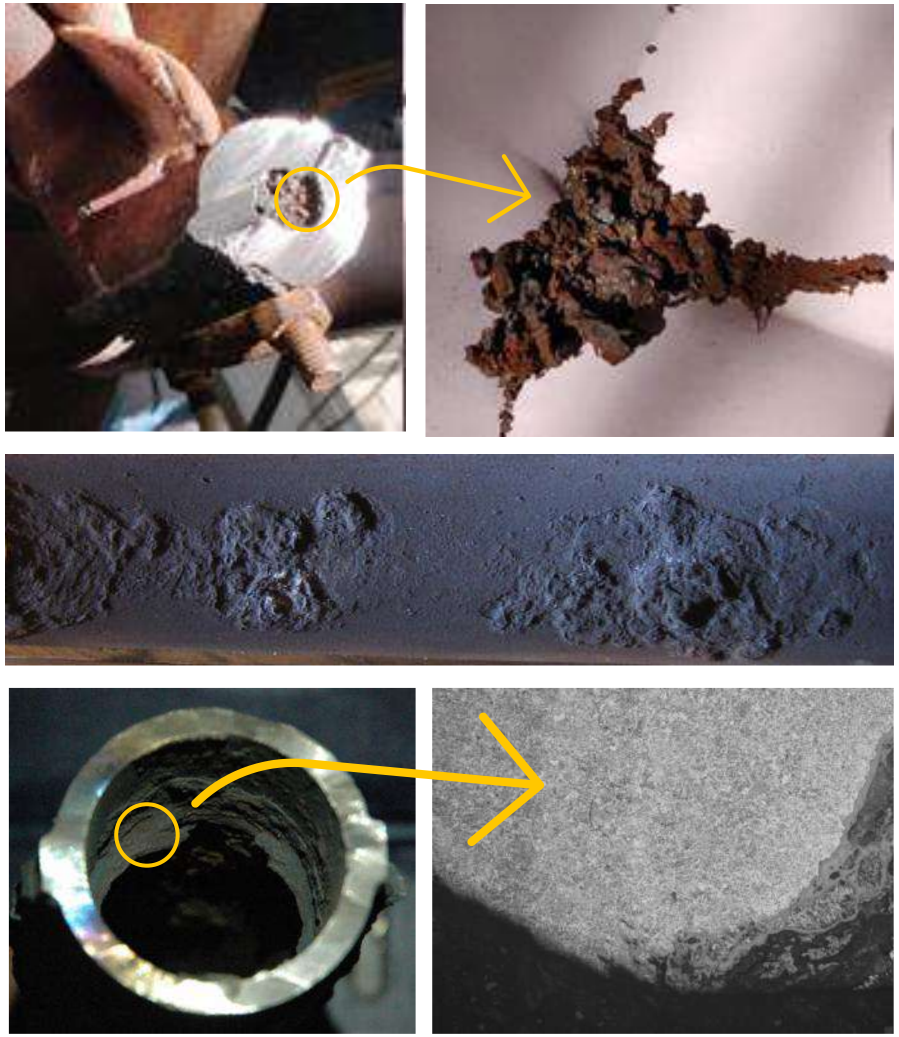
**OTHER AREAS** include:

- Turbine Valves
- Damages due to Uneven Expansion
- Hammering in Pipelines

**COMMON REASONS** for **DAMAGES** apart from **TEMPERATURE TRANSIENTS** are:

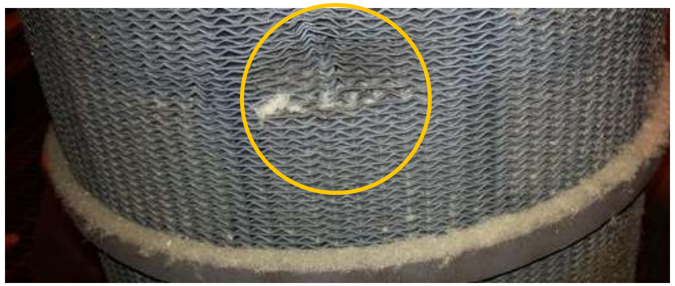
- Excessive Use Of Spray & Water Carry Over
- Chemistry
- O2 Ingress

# CHEMISTRY RELATED DAMAGES



SCALE DEPOSITS

## TURBINE SIDE STRAINERS DAMAGE



PITTING

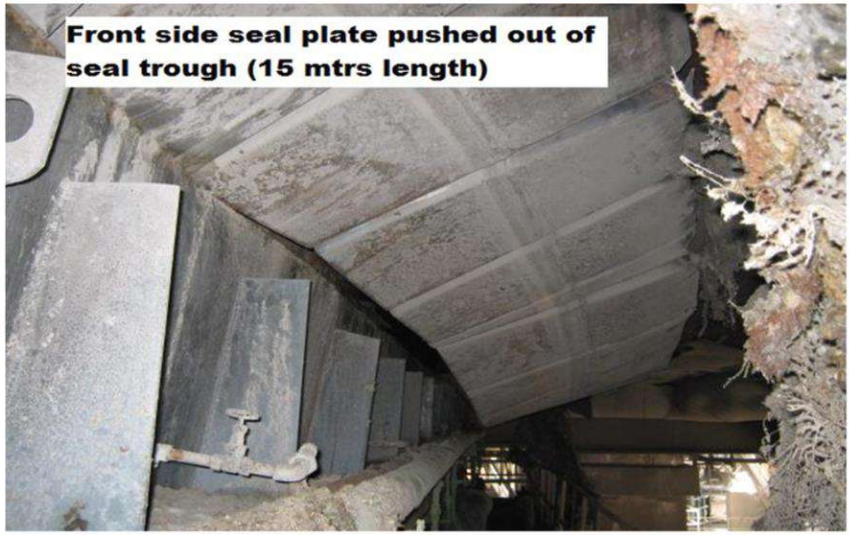
# PA FAN
# STALLING

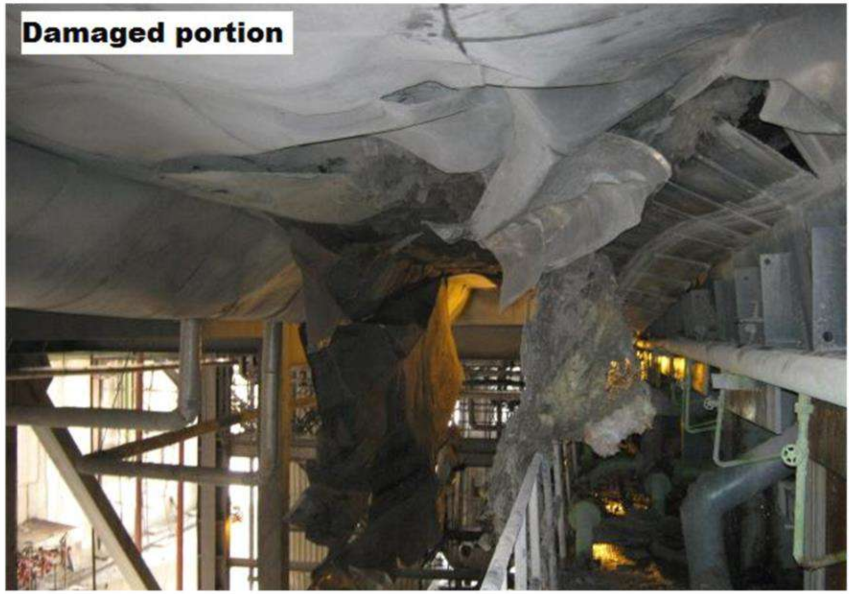
Typically, in stations where there two PA fans for full load, at low load, **STALLING** is common

Unless operating procedures are modified, there can be **SEVERE DAMAGE**

# BOTTOM ASH EXPLOSION
## DURING LOW LOAD OPERATION






Damages to the "S" panel.

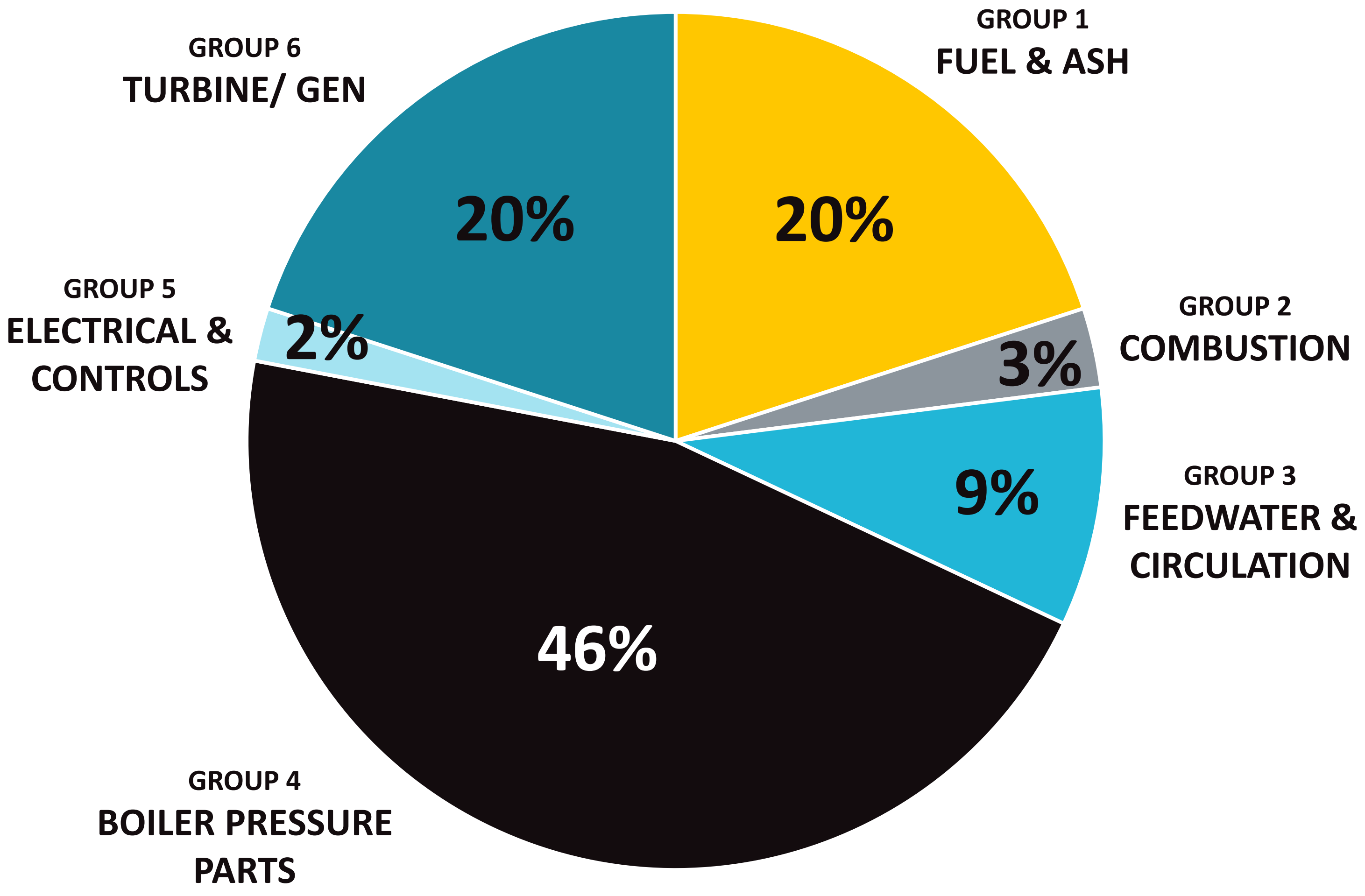

Bow in horizontal tubes of front S panel.


Location of failed tubes

# UNDERSTANDING THE DISTRIBUTION OF TOTAL COSTS OF DAMAGE

- **NECESSARY** to tailor the Overhauling & Maintenance Intervals of Units supported by Data
- Analysis of Component-Wise Cost Data is **IMPORTANT**
- Predictive Tools
- Estimated Weekly Damages
- EFOR & Life Management Actions
- Intertek COSTCOM, AWARE, EPRI, GE …

**ANNUAL COST OF CYCLING DISTRIBUTION**



# SUMMARY

Flexible operation does not have a one-fit-for-all solution

The mode of flexible operation will depend on the market context, fuel costs, plant design, vintage

Interventions and Investments for flexible operation have to be based on cost-benefit analysis.

The first thing for flexible operation is awareness of the damage mechanisms and the cost & risks associated with each type of flexible operations – with awareness, there can be a huge reduction in the costs of cycling

Flexible operations will need changes in operating procedures, a different approach with respect to inspection strategy and outage intervals/ scope

Tools are available for managing plant integrity, improving reliability and part load efficiency

Preparations for flexible operation needs a comprehensive approach (people, process, and technology)

Indo-German Energy Forum

# Thank You for your Attention

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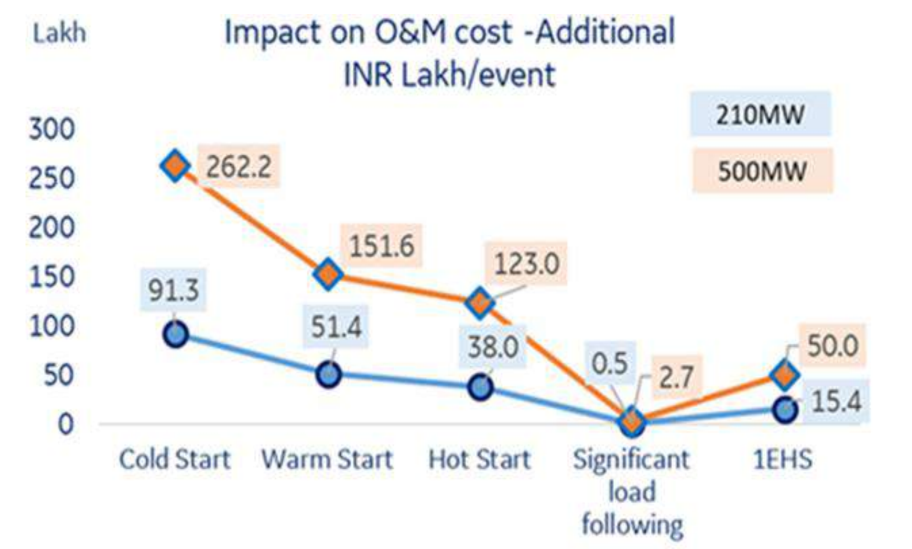
# REDESIGNING TARIFF STRUCTURE TO REFLECT COST OF FLEXING

## REGULATORY INTERVENTIONS FOR ENHANCING FLEXIBILISATION

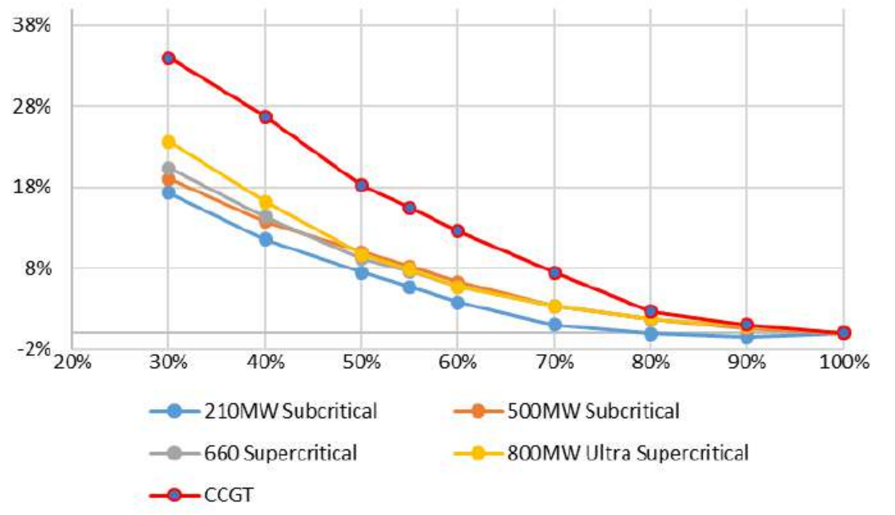
# TYPICAL COSTS OF DELIVERING FLEXIBLE POWER
## FOR RE-INTEGRATION FROM COAL

**COST OF FLEXIBLE OPERATIONS**

| FACTORS | PARAMETERS |
|---|---|
| ENERGY CHARGES | • Start-Up Cost increases due to increase in<br>  • Heat Rate<br>  • APC<br>  • Oil Support |
| O&M COST | • Increased EFOR<br>• Accelerated Life Consumption due to<br>  • Start-Ups<br>  • Load Following |
| FIXED COST | • Accelerated Life Consumption will have impact over unit availability in long-term<br>• EROF can impact unit availability in short-term |
| ENVIRONMENTAL IMPACT | • Specific (Kg/MWh) Nox, Sox & CO emissions will be somewhat higher at unit levels while flexing<br>• Overall emission would reduce for flexible units due to reduced coal usage<br>• Significant adverse impacts are very unlikely due to installation of emission control devices |




% Deviation of Net Heat Rate at Various Load Conditions



# IMPACT ON TARIFF

## FC + ECR – 200P/KWH

| TYPICAL 200/210 MW UNIT | | UNIT LOADING % | DUE TO HR | ADD O&M | START-UP ALL | TOTAL IMPACT (FC+VC) |
|---|---|---|---|---|---|---|
| | | | ADDL. PAISA/KWH | | | |
| | MINIMUM LOAD WITH SIGNIFICANT LOAD FOLLOWING | 90% | 0 | 0 | 0 | 0 |
| | | 80% | 0 | 0 | 0 | 0 |
| | | 70% | 2.1 | 3.31 | 0 | 5.4 |
| | | 60% | 7.5 | 3.31 | 0 | 10.8 |
| | | 50% | 15 | 3.31 | 2.5 | 21.3 |
| | | 40% | 23.2 | 3.31 | 2.5 | 29 |
| | | 30% | 34.6 | 3.31 | 2.5 | 40.5 |
| | WEEKLY START | --- | 23.2 | 60.22 | 14.8 | 98.2 |
| | DAILY START | --- | 7.5 | 257.39 | 35.2 | 330.1 |

| TYPICAL 500 MW UNIT | | UNIT LOADING % | DUE TO HR | ADD O&M | START-UP ALL | TOTAL IMPACT (FC+VC) |
|---|---|---|---|---|---|---|
| | | | ADDL. PAISA/KWH | | | |
| | MINIMUM LOAD WITH SIGNIFICANT LOAD FOLLOWING | 90% | 1.1 | 0 | 0 | 1.1 |
| | | 80% | 3.4 | 0 | 0 | 3.4 |
| | | 70% | 6.7 | 7.15 | 0 | 13.8 |
| | | 60% | 12.6 | 7.15 | 0 | 19.7 |
| | | 50% | 20 | 7.15 | 0 | 27.2 |
| | | 40% | 27.6 | 7.15 | 0 | 34.8 |
| | | 30% | 38 | 7.15 | 0 | 45.2 |
| | WEEKLY START | --- | 27.6 | 69.18 | 10.7 | 107.5 |
| | DAILY START | --- | 12.6 | 307.74 | 43.5 | 363.8 |

# COMPENSATION PROPOSED
## INDIA

**AGAINST HEAT RATE LOSS**

| S. NO. | UNIT LOADING AS A % OF INSTALLED CAPACITY OF THE UNIT | INCREASE IN SHR AS A % FOR SUPERCRITICAL UNITS | INCREASE IN SHR AS A % FOR SUPERCRITICAL UNITS |
|---|---|---|---|
| 1 | 85 & 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 ADMISSIBLLE |
|---|---|---|
| 1 | 85 & 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 |

Minimum Turndown 55% **MANDATORY &** Below 55% **OPTIONAL** with Provisions for Compensation

# OIL COMPENSATION
## FOR EVERY START

OVER & ABOVE
7$^{TH}$ START/ YEAR

| OIL CONSUMPTION PER START-UP (KL) | | | |
|---|---|---|---|
| **UNIT SIZE** | **HOT** | **WARM** | **COLD** |
| 200/ 210/ 250 MW | 20 | 20 | 50 |
| 500 MW | 30 | 30 | 90 |
| 600 & Above MW | 40 | 60 | 110 |

**Additional Oil Consumption Proposed for LOW LOAD OPERATION because of Loss of Reliability**

**Up to 0.5ml/ Kwh**

# COST COMPENSATION
## EXAMPLES

### INDIA

- CERC vide issuance of 4th Amendment to IEGC Regulations 2010, notified the Technical Minimum in respect of a unit(s) for CGS or ISGS as 55% of MCR loading or Installed Capacity of such unit(s). Amended regulations also provide for compensation for the following:
    - Heat Rate Degradation
    - Increased Auxiliary Consumption
    - Increased Oil Consumption

- Coal based plants operating on flexible modes i.e., Pmin < 55% and subject to cycling, load following, and two-shifting require additional compensation mechanisms/ allowances for increased CAPEX and OPEX costs
- Regulatory provisions for frequent start-ups & high ramping needs to be evolved
- Ancillary Services need to recognize costs of flexibility (in regulated approaches) or provide a market mechanism which allows for recovery of additional costs

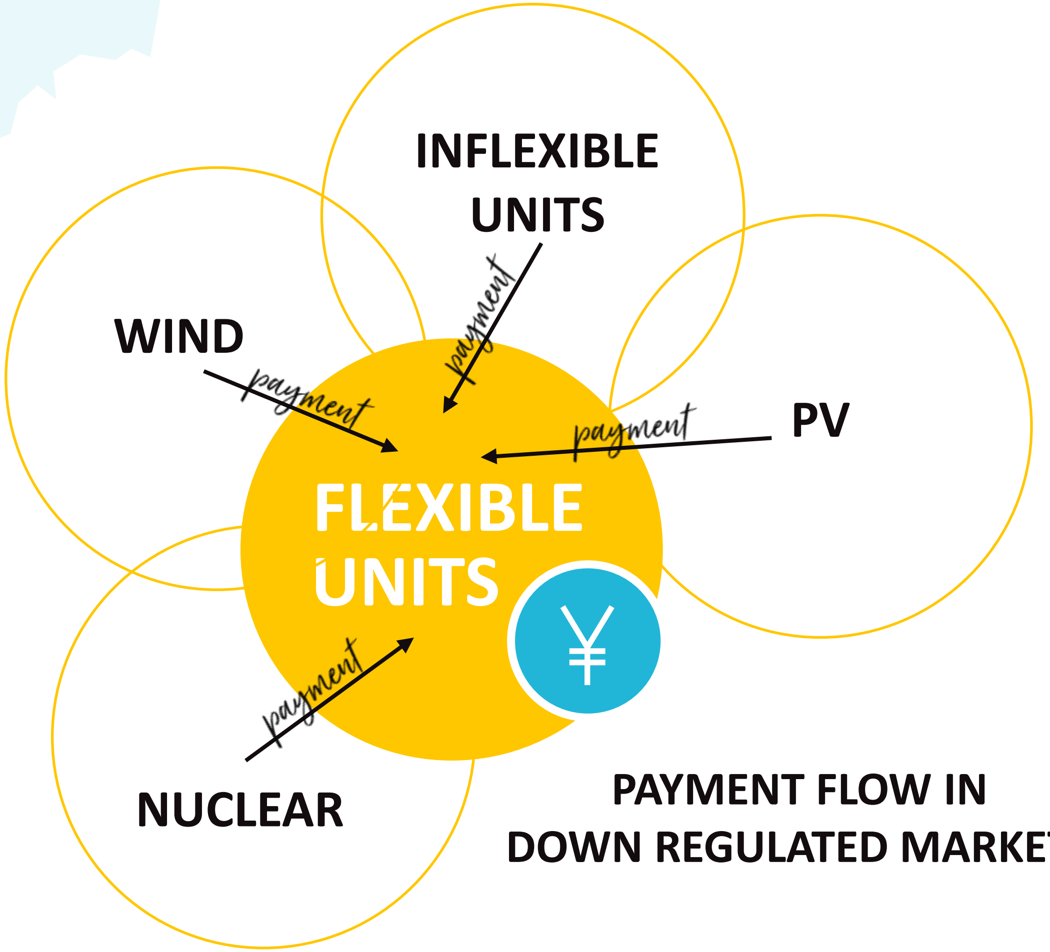
### CAISO

- Supply Offer in CAISO would have the following cost components (considered in the SCED co-optimsation of energy and ancillary markets)
- Start-up costs associated with bringing a resource online from being shut down:
    - Broken down into Cold, Intermediate & Hot Start-Up Costs
- Operational Ramp Rate expressed in megawatts per minute (MW/min) as a function of the operating level - must be a staircase function with up to four segments.
- Transition costs associated with moving from one configuration to another for multi-stage suppliers (MSG)
- Minimum load costs associated with operating the resource at the minimum operating level (Pmin) where a resource cannot drop below without compromising the resource’s operation
- Incremental energy costs associated with producing energy above Pmin at each operating level

# CHINA BENEFITTED FROM THE DOWN REGULATION MARKET

**CHINA**

- Introduced in Northeast China in 2014 encourage investment in flexibility in this area
- Down-regulation became the scarcest of resources in the system Concept D-R market - punish inflexible power plants & reward flexible plants
- A baseline of D-R capability is 50%. Plants operating above baseline when the system has a generation surplus, pay plants operating under the baseline
- The settlement on a 15-minute basis
- The total cost is allocated proportionally to those power plants that operate above the baseline during that time period
- The curtailed electricity has been reduced by about 1/3




PAYMENT FLOW IN DOWN REGULATED MARKETS

# CAPEX FOR PREPARATION UNITS FOR FLEXIBILISATION

| | INTERVENTION | COST '000" US$ | IMPLEMENTATION TIME (MONTHS) |
|---|---|---|---|
| 1 | Boiler Model for Temperature Optimization | 150 | 6 |
| 2 | Mandatory Control Upgrades Minimum Load | 250 | 12 |
| 3 | Installation of Two Feedwater Recirculation Valves | 100 | 6 |
| 4 | Mandatory Control Upgrades Ramp Rates | 200 | 9 |
| 5 | Further Flexibility Enhancement by Controls | 500 | 6 |
| 6 | Coal Flow Balancing (Five Mills) | 500 | 6 |
| 7 | Condition Monitoring | 300 | 6 |
| 8 | Sootblower Optimization | 150 | 6 |
| **TOTAL** | | **2150** | **12** |

**CAPEX** would vary across the units depending on:

- Design
- Vintage
- Historical Operation Modes
- Coal Quality
- Degree of Flexibilization required from the unit

**It is in the range of INR 20 Crore (US$ 2.2 Million) to 50 Crore (US$ 5.5 million)**

# POLICY & REGULATORY GUIDELINE
## INDIA

### NATIONAL RENEWABLE ENERGY POLICY

- Focusing on accelerating the use of Clean & Renewable Energy (500 GW by 2030)
- Strengthens “Must-run” Status of RE Provisions of RPO – minimum purchase of 5% (2011) & enhanced to 21 % from 2022
- Proposed Electricity Amendment Act – 2020/21 Provisions for Penalty on **NOT MEETING** the RPO & doubling every successive year on default
- Bundling of RE with Thermal Energy
- Minimum Adequate Capacity Resources
- Ensuring Payment Security Mechanisms (Institutional Mechanisms)

### POLICY INTERVENTIONS ON THERMAL PLANTS TO ENABLE THEM TO SUPPORT RE INTEGRATION

- Part Load Compensation for ISGS Units
- Incentivisation for Increased Ramp Rates
- Market Intervention (AGC, RTM, Ancillary Service)
- CEA’s Guideline for Flexibilization of Thermal Plants
- Technical Minimum load @55 % & Ramp Rate of 3% (Sub-critical)/ 5% Super-critical Mandatory
- Plants to achieve capability of 40% min load within 3 years after Interventions/ Retrofits

# CASE STUDIES
# INCLUDING PILOT TESTS

# MARKET DRIVERS OF FLEXIBILIZATION OF COAL UNITS

- Renewables Transition in India
- Falling renewable costs, increasing market penetration & intermittency issues
- Increasing Requirements of Ancillary Services, DSM, AGC
- Fuel economics-non-pit head stations will have Costlier Fuel
- Tightening Environmental Legislation
- Inadequacy of Other Balancing Resources
- Transition to Electricity Market Mechanisms

# IMPACT OF MARKET DRIVERS ON POWER PLANT

- Shift from Base-load to Flexible Mode of Operation
- Rapid Increase in Unit Starts- Even in New Plants
- Increased need for Load Following
- Reduction in Minimum Load
- Need to Operate Flexibly even with Wider Grades of Coal
- Off-Design Operation and Fuels including Co-Firing (Recent Policy Mandate)
- Need for Refurbishment, Upgrades and Life Extension – Capital Costs
- Plant Lay-up & Standby Requirements
- Uncertain Environment for Investments
- Some Assets become Unviable unless they adapt for survival
- Increased Operational Costs