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YBG Performance Doctrine

Operational Performance Intelligence for Existing Thermal Fleets

Combustion is controlled. Heat transfer is not — yet.

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8 May 2026 · Signature Whitepaper, Draft v2

Reading Guide

This paper is written for two audiences:

- **Operations and engineering readers** — the technical core is in Sections 4 (Steam-Fuel Outcome), 5 (Radiative Coupling), 7 (Consequences of Drift), 8 (Tube-Metal Temperature), and 10 (the ControlAlign™ Framework).
- **Commercial and executive readers** — the value proposition is concentrated in Sections 1 (Executive Summary), 6 (Best Demonstrated Performance), 11 (System-Level Implications), and 13 (Conclusion).

A glossary of terms (FEGT, RCI, E_f, ∆R, HTE, DNB, APC, DCS) is provided at the end.

At a Glance

- **The anomaly.** Ten oxyhydrogen retrofits to biomass-pellet boilers in India consistently delivered 13–15% steam-to-fuel improvements that classical heat-balance analysis could not explain — the implied calorific value of the gas was roughly seventy times its physical value.
- **The reframing.** The improvement was not in combustion energy released; it was in **heat transfer realised**. Radiative coupling between flame and water-walls is the unmanaged variable.
- **The instrument. YBG ControlAlign™** reconstructs the furnace's radiative state from existing DCS / historian signals — no new sensors, no retrofit, no control-system changes.
- **The outcome.** The same coal, at the same flow, produces more useful steam. Productivity is recovered **without any increase in fuel input**.

What This Is — and What It Is Not

ControlAlign™ is	ControlAlign™ is not
A diagnostic and operational-guidance framework	A replacement for the DCS or APC
A reconstruction of radiative state from existing historian signals	A new sensor, probe, or instrumentation package
A means of recovering best demonstrated performance	A fuel additive, fuel substitute, or combustion catalyst
Deployable without outage, retrofit, or capital works	Contingent on plant modification or downtime
Continuously refined by ongoing analysis of plant data	A one-time tuning exercise

1. Executive Summary

Across the global thermal fleet, performance variation is not primarily constrained by equipment capability, but by the ability to sustain optimal operating conditions.

Most generating units have already demonstrated materially better fuel efficiency within their own operating history. However, this level of performance is rarely maintained consistently.

This paper introduces a reframing:

> *The limiting factor in thermal power performance is not combustion control — it is the unmanaged variability of heat transfer, particularly radiative coupling within the furnace.*

Existing control systems regulate fuel input, air distribution, and steam conditions. They do not explicitly model or control effective flame emissivity, radiative heat transfer to furnace surfaces, or the sustained “radiative state” of the unit.

YBG addresses this through a two-layer analytical framework: a **physics layer** that models the contributors to flame emissivity and radiative coupling, and an **operational diagnostic layer** that reconstructs the radiative state of the unit from routinely available plant signals.

This creates visibility into a persistent gap between best demonstrated performance and current operating condition. Closing that gap is one of the fastest, lowest-capital pathways to reduced fuel consumption, reduced emissions intensity, and improved operational stability.

The instrument that makes this possible is **YBG ControlAlign™** — a diagnostic framework that turns the historian record of a thermal unit into an explicit, operator-actionable view of its radiative state. ControlAlign™ is significant not because it adds a new sensor or a new controller, but because it reveals a control axis that has always been present in the data and never made visible: the radiative coupling between flame and water-walls. That visibility is what converts “best demonstrated performance” from an anecdote into a target the plant can be steered back toward, day after day.

Critically, the productivity gains unlocked by radiative coupling control are achieved **without any increase in fuel input**. The same coal, at the same flow, produces more useful steam — because more of the heat already being released is captured by the water-walls. The improvement is in heat transfer realised, not in energy consumed.

> *“A boiler can be perfectly controlled — and still not be thermodynamically aligned.”*

2. Origin of the Framework: An Empirical Anomaly

Dr. Peter Griffiths and his team set out to explain a result that, on the conventional energy ledger, should not have been possible.

Across a rollout of ten oxyhydrogen retrofits to biomass-pellet steam boilers at a multinational FMCG operation in India, the team consistently observed improvements of **13–15% in the steam-to-fuel ratio** following the introduction of small volumes of oxyhydrogen into the secondary air. The result was reproducible, measured, and economically significant. It was also unexplained.

When the results were reconciled using the classical input-side Heat Analysis — energy in / energy out, expressed in calorific values — the numbers refused to balance. To close the energy ledger, the oxyhydrogen input had to be assigned an effective calorific value of approximately **144,000 kcal/scm**. Yet the true calorific value of oxyhydrogen, based on its hydrogen fraction (two parts H_2 to one part O_2, by stoichiometry following H_2O), is only about **2,100 kcal/scm**.

The discrepancy was roughly seventy-fold — approaching two orders of magnitude. The framework was unable to describe what was actually happening.

> *The conventional input Heat Analysis was unhelpful in aiding the analysis of flame and radiation characteristics in combustion.*

The physical interpretation became clear: the small oxyhydrogen addition was not contributing meaningfully as a fuel. It was modifying the **flame characteristics** and the **radiating composition of the combustion gases** — altering H_2O and CO_2 partial pressures within the flame envelope, promoting hydrogen radical formation and chain-propagation effects, and increasing the **radiative coupling** between the flame and the water-walls.

A second observation reinforced the interpretation. Oxyhydrogen gas is uniquely composed of hydrogen, oxygen, and the associated radical species ($OH\cdot$, $HO_2\cdot$), recombining to water vapour (H_2O) when burned in the furnace. Coal combustion follows the same essential pathway: as it burns, coal releases moisture (H_2O), hydrogen, and the same family of hydrogen and hydroxyl radicals that drive chain-propagation in the flame. Viewed this way, **coal combustion is already the oxyhydrogen mechanism in miniature** — the small oxyhydrogen addition was not introducing a foreign chemistry, but reinforcing the radiative and radical-driven regime that coal combustion natively produces, only more weakly and less consistently.

In other words, the energy ledger was correct. The diagnostic frame was wrong. The improvement was not in combustion energy released; it was in heat transfer realised.

This led to a structural conclusion:

> *Input-side Heat Analysis cannot resolve flame and radiation behaviour. A different analytical layer is required — one that treats the radiative state of the furnace as an observable, and ultimately operational, variable.*

The ControlAlign™ framework discussed in the remainder of this paper is the formal expression of that conclusion.

3. Why Optimisation Plateaus

Thermal units rarely operate at a fixed efficiency point. Performance evolves over time due to load cycling, fuel variability, fouling and slagging, air–fuel imbalances, and operational adjustments. These effects are gradual and distributed, so performance degradation is not perceived as failure — it is accepted as “normal operation.”

Yet analysis of plant data consistently shows:

> *the unit has already operated at materially better efficiency under comparable conditions.*

The issue is not capability. The issue is sustainment.

Modern DCS and APC systems are highly effective at stabilising combustion, maintaining emissions compliance, and controlling steam conditions. They operate on measurable inputs (fuel, air, flows) and output constraints (temperature, pressure, emissions). However, they do not explicitly optimise the intermediate process:

> *how efficiently energy is transferred from the flame to the working fluid.*

This transfer is dominated by radiative heat transfer within the furnace and convective heat transfer downstream. Among these, radiation is the primary heat transfer mode in the furnace, highly sensitive to flame structure and composition, and not directly controlled as a variable.

Control systems act on inputs. YBG analyses the resulting thermodynamic state.

This is the precise gap that **ControlAlign™** is built to occupy. It does not displace the DCS or the APC; it sits alongside them, taking the same routinely recorded signals and reconstructing what those signals imply about the radiative regime inside the furnace. The plateau that conventional optimisation reaches is not a hardware limit — it is the limit of what can be improved while heat transfer itself remains an unmeasured variable. ControlAlign™ lifts that ceiling by making radiative state observable.

Conventional control vs ControlAlign™ overlay

Conventional control acts on fuel, combustion, and outputs via DCS and APC. ControlAlign™ overlays the same historian signals to reconstruct the radiative state (E_f, RCI), compare it with best demonstrated performance (ΔR, HTE), and produce operator-actionable control guidance — without new sensors or control-system changes.

4. The Steam-Fuel Ratio: Outcome, Not Explanation

Most thermal plants already measure the consequence of thermal efficiency. The question is whether they can see the thermodynamic behaviour producing it.

In many thermal environments, operational efficiency is ultimately expressed through a single relationship: **steam produced versus fuel consumed**. The steam-fuel ratio is, effectively, the plant's efficiency outcome.

But between fuel entering the furnace and steam leaving the boiler exists an entire thermodynamic transfer environment — combustion kinetics, flame characteristics, radiative heat transfer, heat absorption behaviour, thermal-state stability, and working-fluid enthalpy rise. Much of this complexity is operationally compressed into a single KPI outcome.

> *The steam-fuel ratio may indicate that thermal performance changed — without explaining why it changed, under what operating conditions, or how far the plant drifted from its own best demonstrated thermal state.*

An analogy may be helpful: it is like carefully monitoring how much electricity enters a light bulb while having limited visibility into how effectively the light actually reaches the room. Combustion creates thermal energy. **Radiative coupling determines how effectively that energy becomes useful absorbed heat.**

YBG's framework uses historian-derived operational intelligence to reconstruct thermal-state behaviour and identify the operating conditions associated with superior historical steam-fuel performance. A plant's own best historically demonstrated performance state is typically characterised by:

- lower fuel intensity
- more effective radiative heat transfer
- and greater useful steam generation from the same operating environment

The framework interprets **thermal coupling effectiveness (TCE)**, radiative coupling behaviour, combustion-radiative interaction, heat-absorption fidelity, and operational thermal-state stability in relation to the steam-fuel outcome the plant already measures.

The commercial implication is improved visibility into the operational conditions associated with fuel-intensity drift and superior historical thermal performance.

The objective is not merely observing efficiency drift. It is helping explain *why* the ratio varies over time, how stable operation differs from optimal thermal operation, and which operational thermal conditions correlate with the plant's own best historically demonstrated performance.

> *Because relatively small sustained improvements in thermal-state stability and fuel-intensity behaviour may become materially significant at fleet scale.*

The remaining sections of this paper formalise the analytical layer that makes this interpretation possible — beginning, in Section 5, with radiative coupling as the operational variable that links combustion to the steam-fuel outcome.

5. Radiative Coupling as an Operational Variable

Radiative heat transfer in a furnace is governed by gas composition — principally the radiating species CO_2 and H_2O, together with particulates (soot, ash, char) — flame temperature distribution, emissivity of the flame, geometry and view factors, and water-wall absorption characteristics. In coal firing, these radiating species are continuously generated by the fuel itself: as coal combusts it releases moisture (H_2O), hydrogen, and the same family of hydrogen and hydroxyl radicals ($OH\cdot$, $HO_2\cdot$) that drive chain-propagation in the flame and shape its emissive character.

In practical operation, this manifests as:

> *the radiative coupling between the flame and the water-walls.*

This coupling determines the heat absorbed in the furnace, the furnace exit gas temperature (FEGT), and the downstream heat transfer loading. Small changes in flame structure, air distribution, or mixing conditions can significantly alter radiative coupling, even when fuel flow remains constant and emissions stay within limits.

Although flame emissivity and radiative coupling are not directly instrumented in conventional plant configurations, their operational signature is recoverable. The state of radiative heat transfer leaves a consistent footprint across fuel flow, excess oxygen, FEGT, and downstream absorption behaviour. This footprint can be reconstructed from existing DCS data — without new sensors, without intrusive testing, and without changes to plant operation.

6. Best Demonstrated Performance

Every unit contains its own reference:

> *the conditions under which it has already operated most efficiently.*

This is observable in historian data. At similar load levels, differences can be seen in fuel flow per MW, FEGT, attemperation demand, and combustion stability. These differences are not theoretical — they represent real operating states achieved under real plant conditions.

The gap between current operation and best observed operation is therefore measurable, repeatable, and economically meaningful.

Within the YBG analytical framework, this gap is expressed as **Drift from Radiative Optimum (ΔR)** — the deviation between the unit's current radiative state and the best radiative state it has demonstrated under comparable load conditions.

Across units assessed with this method, the recoverable margin between current operation and best demonstrated operation typically falls in the **low-to-mid single-digit percentage range on heat rate**, depending on the unit's age, fuel variability, load profile, and the duration of accumulated drift. Some units show materially more. In every case, the margin is grounded in the unit's own historical record — it is not a theoretical target imported from a reference design.

The significance of ControlAlign™ here is that it turns ΔR from a retrospective metric into a live operating reference. The plant's own history becomes its benchmark; the diagnostic engine continuously re-evaluates how far the furnace has drifted from that benchmark, and — crucially — what combination of historically valid setpoints brought it back into alignment last time. The improvement opportunity is no longer abstract. It is the unit's own past performance, mapped to the levers that produced it.

7. Operational Consequences of Drift

Performance drift expresses itself through multiple indicators:

Fuel

- increased coal consumption per MW
- reduced boiler efficiency

Furnace

- higher or more variable FEGT
- unstable flame behaviour

Steam System

- increased attemperation
- higher variability in steam temperatures

Reliability

- uneven heat flux distribution
- increased risk of localised thermal stress

These effects are often managed individually, but not addressed systemically.

8. Heat Transfer and Tube Metal Temperature

A common misconception is that increased radiative heat transfer leads directly to excessive tube metal temperatures.

In drum-type boilers, water-wall tubes operate in nucleate boiling regime; metal temperature remains close to saturation temperature, and increased heat input primarily increases steam generation. Failure mechanisms are typically associated with departure from nucleate boiling (DNB), localised dryout, and internal fouling — not with “too much radiation” in aggregate.

In once-through (Benson) systems, flow stability and heat distribution are critical; local imbalances, not total heat input, drive risk.

This distinction is critical:

> *the objective is not to maximise heat flux, but to maintain stable and evenly distributed heat transfer.*

9. The Control Gap

Current control philosophies optimise combustion inputs, emissions, and steam outputs. They do not explicitly control:

> *the state of heat transfer itself.*

Combustion is stabilised. Outputs are regulated. But the intermediate energy transfer efficiency is unmanaged.

As the field work showed, the conventional control narrative — fuel calorific value → flame temperature → steam output — treats combustion gases and radiative coupling as incidental, even though they are the primary mechanism by which heat actually reaches the water-walls and generates steam. The consequence is that the opportunity to fine-tune and enhance furnace productivity using the DCS/SCADA data already being recorded is routinely missed.

YBG ControlAlign™ uses precisely this historian data to reconstruct a radiative coupling framework grounded in the furnace's own real-world historical performance, and to surface the control levers that can be used to optimise radiative heat transfer.

10. The YBG ControlAlign™ Framework

YBG ControlAlign™ addresses this gap through the following sequence:

Step 1 — Identifying best demonstrated performance

Using plant historian data:

- mapping performance vs load
- isolating optimal operating states

Step 2 — Reconstructing radiative state

ControlAlign™ derives an operational view of the furnace radiative state — including an **Effective Flame Emissivity Proxy (E_f)** and a **Radiative Coupling Index (RCI)** — from the plant's existing signal set. This reconstruction is the bridge between conventional combustion data and the heat-transfer dimension that current control systems do not address.

The underlying physics developed by YBG to characterise the componentry and interactions of the radiative coupling environment — the gas-phase emitters, radical chemistry, flame emissivity behaviour, and their coupling to water-wall absorption — is **core intellectual property of YBG ControlAlign™**, and is encoded directly into the proprietary diagnostic engine that performs this reconstruction.

Step 3 — Quantifying deviation

Comparing current operation with best observed conditions in terms of:

- fuel
- heat rate
- **Heat Transfer Effectiveness (HTE)** — output energy per unit fuel energy, normalised by load band
- **Drift from Radiative Optimum (ΔR)**

Step 4 — Translating into operational guidance

Providing operator-relevant conditions, not theoretical targets.

The proprietary diagnostic engine intelligently links the radiative coupling factors to the DCS data settings associated with the historical best performance of the furnace, identifying the specific control levers and setpoint combinations that delivered that performance. It is this mapping — from radiative state back to operator-actionable settings — that gives ControlAlign™ the capability to offer concrete control guidance, rather than abstract targets.

Step 5 — Sustaining performance

Focusing on stability of operating envelope, not one-time optimisation.

Maintaining optimum performance is achieved by following the operational guidance and continuously analysing results in the diagnostic engine, so that the furnace is held in its optimal radiative state over time rather than drifting away from it between interventions.

Importantly:

- no modification to control systems is required initially
- no additional instrumentation is required

11. System-Level Implications

Globally, thermal generation remains a dominant source of electricity, essential for grid stability, and critical for industrial continuity — even as renewable capacity expands.

> *Improving the efficiency of the existing fleet is one of the fastest mechanisms for reducing fuel consumption and emissions intensity.*

This is particularly relevant where demand continues to grow and new capacity is added alongside existing assets.

At fleet scale, the leverage of ControlAlign™ compounds. Each unit holds its own demonstrated optimum within its historian; each unit therefore carries its own recoverable margin. Applied across a portfolio, the same diagnostic framework turns thousands of individually small radiative-coupling corrections into a strategically meaningful reduction in fuel burn and emissions — achieved without new build, without retrofit capital, and without disrupting existing control philosophy.

12. Future Integration Pathways

Understanding and stabilising radiative coupling creates a foundation for a broader programme of thermal-side improvement. Several pathways extend naturally from the same framework:

- **Oxyhydrogen as a catalytic air-conditioning medium.** The same diagnostic engine that explained the original 13–15% field anomaly can be used to qualify the addition of small oxyhydrogen volumes on the basis of their effect on flame emissivity, radical chemistry, and radiative coupling — rather than on a calorific-value basis that the physics does not support.
- **Biomass and co-firing regimes.** Biomass and coal co-firing alters both the radiating gas composition and particulate behaviour. ControlAlign™ provides a consistent radiative-state view across fuel blends, allowing operators to identify the blend ratios that preserve or enhance radiative coupling.
- **Hydrogen and low-carbon fuel blends.** As hydrogen and other low-carbon fuels are introduced into existing thermal assets, their flame characteristics and emissive behaviour will differ materially from conventional firing. The same reconstruction framework provides the diagnostic language to evaluate these transitions on a heat-transfer basis, not just an emissions basis.
- **Carbon-intensity reporting.** Recoverable heat-rate margin is, by construction, recoverable carbon-intensity margin. Drift from Radiative Optimum can be translated directly into avoided CO_2 per MWh — making the framework relevant to sustainability disclosures, internal carbon pricing, and external reporting frameworks.
- **Continuous improvement loops.** Because the framework is grounded in historian data and not in plant modification, every additional month of operation enriches the reference set. The unit's “best demonstrated” envelope is not static — it advances as new operating regimes are explored and validated.

In each case, ControlAlign™ functions as the substrate on which combustion-side innovations can be measured honestly: in the same units, on the same historian, against the same radiative-state reconstruction.

13. Conclusion

Thermal power optimisation has historically focused on combustion control, emissions compliance, and output regulation. This has delivered substantial improvements.

However, a critical layer remains underdeveloped:

> *the explicit understanding and control of heat transfer.*

The opportunity is not to create new performance capability, but to:

> *recover and sustain the best performance the unit has already demonstrated.*

This represents immediate economic value, measurable fuel reduction, and reduced emissions intensity — without major capital investment, extended outages, or system redesign.

ControlAlign™ is the operational expression of that opportunity: the framework, the physics, and the diagnostic engine through which the unmanaged half of thermal performance — heat transfer — is finally made visible, attributable, and steerable from the operator's seat.

Final Statement

Combustion is controlled. Heat transfer is not — yet.

The data required to change that already exists in every plant. What has been missing is the framework to read it.

Glossary

Term	Definition
APC	Advanced Process Control — model-based control layer above the DCS that optimises within constraints.
DCS	Distributed Control System — primary plant control and signal-acquisition platform.
DNB	Departure from Nucleate Boiling — transition out of the nucleate-boiling regime, associated with sharp rises in tube metal temperature.
E_f	Effective Flame Emissivity Proxy — operational estimate of the flame's emissive character, reconstructed from existing signals.
FEGT	Furnace Exit Gas Temperature — temperature of combustion gases leaving the furnace radiant section.
HTE	Heat Transfer Effectiveness — output energy per unit fuel energy, normalised by load band.
HHV	Higher Heating Value — calorific content of a fuel including the latent heat of water vapour in the products.
$OH\cdot$ / $HO_2\cdot$	Hydroxyl and hydroperoxyl radicals — short-lived chain carriers in combustion that drive flame propagation and influence emissive character.
RCI	Radiative Coupling Index — proxy ratio of heat absorbed by furnace water-walls to heat released by combustion.
ΔR	Drift from Radiative Optimum — deviation between current radiative state and the best radiative state demonstrated under comparable load.
ControlAlign™	YBG diagnostic framework that reconstructs the radiative state of a thermal unit from existing historian data.