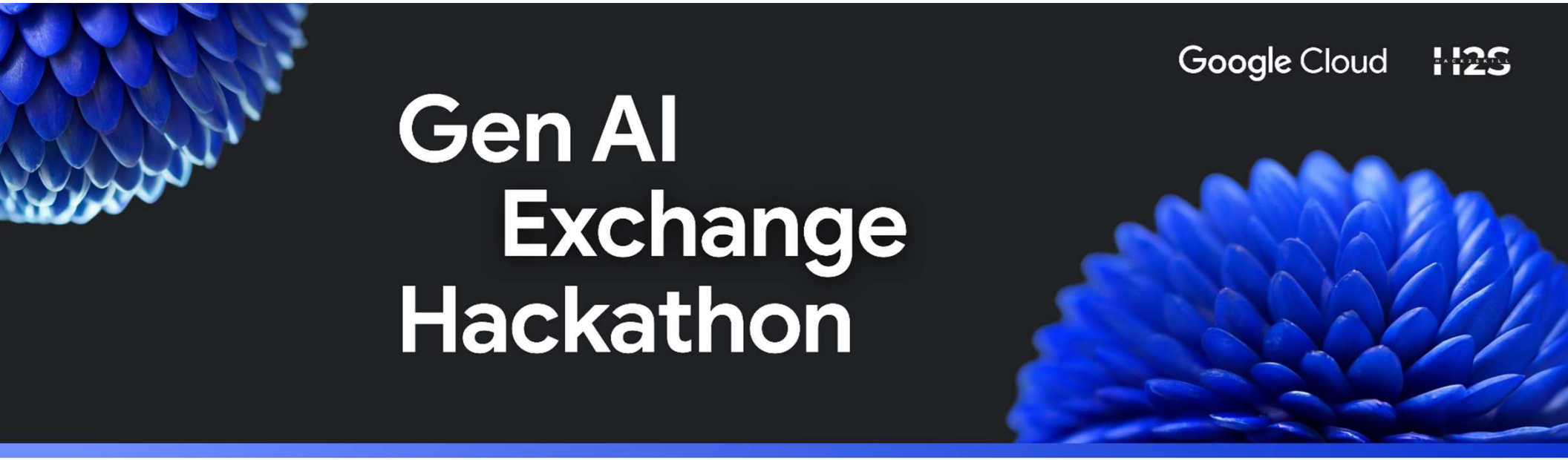


Team Name : Vertex Vanguard

Team Leader Name : Manish Gupta

Problem Statement : Create a Generative AI–driven platform for autonomous cement plant operations that optimizes energy use, quality, and sustainability across processes.

Product summary

Key Processes of Cement Plant Under Focus

Blending (Raw Mix Preparation)

Raw materials (limestone, clay, etc.) are **ground into a fine powder** called "raw meal" and **blended** to ensure a uniform chemical mix.

5 hours lag →

Pyroprocessing

The raw meal is **superheated** in a kiln (up to 1450 degree C), causing a chemical reaction to form **clinker**, the main component of cement.

→

Grinding (Finish Milling)

The clinker is **cooled and ground into an extremely fine powder**, with gypsum added to control how quickly the final cement product hardens.

The Cost of Complexity: Unlocking Efficiency in Pyroprocessing

Problem Statement:

The core challenge in cement is **cross-process inefficiency**.

1. **Energy Loss:** Cement is among the most energy-intensive industries in India. Kiln operations demand constant balancing (heat, flow, fuel) leading to significant wasted energy.
2. **Quality Lag:** Clinker quality is determined by inputs from **5 hours prior** (residence time). Operators lack the prescriptive insight to correct quality issues *before* the clinker is ruined.
3. **Siloed Systems:** Data streams are often siloed (Blending → Kiln → Quality), preventing the holistic, real-time optimization required for **autonomous operations**.

Our Solution:

A Generative AI-powered platform for autonomous, cross-process optimization.

1. **Energy:** Reduce Specific Thermal Energy by 3% - 5% via autonomous kiln control.
2. **Quality:** Stabilize Clinker Free Lime % by predicting quality fluctuations 5 hours in advance and generating prescriptive control setpoints.
3. **Sustainability:** Maximize the use of alternative fuels through predictive modeling of diverse fuel combinations.

The Autonomous Control Loop: Fusing Time-Series Data & Vision

This AI platform establishes a unified, predictive control layer by continuously analyzing plant data from various sources, generating prescriptive setpoints instead of mere alerts.

Core Function	Data Inputs & Processing	Output & Value
1. Predictive ML Core (The 'Science')	Ingests **11 key operational parameters** from sensors across Blending and Pyroprocessing. This data fusion includes real-time values for energy prediction and **5-hour lagged values** for quality prediction.	Simultaneously predicts **two critical KPIs** (Quality & Energy) based on their respective timeframes, enabling cross-process foresight and autonomous decision-making.
2. Continuous Visual Inspection (The 'Sight')	Periodically monitors high-resolution images from **two key locations** using Google Cloud Vision: **- Kiln Flame:** Analyzes flame stability, color, and shape (real-time combustion quality). - **Conveyor Belt:** Analyzes raw meal composition and contamination (input quality variability).	Provides **qualitative context** for the AI agent. This data feeds into the Generative AI (Gemini) layer, making recommendations smarter, more robust, and grounded in observable reality.
3. Generative Recommendation	Fuses the two predictive KPI scores with the qualitative visual context (Vision AI) and operational data history (BigQuery).	Generates a single, coherent, natural language **prescriptive recommendation** (e.g., "Increase Limestone Feed Rate by 0.5% in the next 15 minutes to stabilize predicted Clinker Free Lime at 4.5 hours.").

Innovation, Impact, & Alignment

Maximizing Score: Innovation, Cross-Process Impact, & Alignment

Innovation & Uniqueness

Cross-Process Time-Series ML: We successfully trained models using a **5-hour lag** for quality prediction and **real-time** data for energy prediction, linking two traditionally siloed process stages (Blending to Pyroprocessing).

Generative Prescriptive Control: Fusion of structured data (11 sensors) with unstructured data (Cloud Vision) to generate natural language, **prescriptive setpoint recommendations** instead of simple alerts (e.g., "Increase X by Y% to stabilize quality in 4 hours.").

Vision-Enhanced Autonomy: We leverage **Cloud Vision** to introduce qualitative feedback (Kiln Flame/Raw Meal analysis) into the autonomous loop, making the system safer and smarter than relying on numerical data alone.

Impact & Benefits

Energy & Cost: Enables the safe, autonomous maximization of Alternative Fuel Use and reduces **Specific Thermal Energy** (Model 2 KPI) by an estimated **3% - 5%**.

Quality & Stability: Provides **5-hour foresight** on Clinker Free Lime quality, drastically reducing wasted clinker and ensuring product consistency (addressing the quality lag problem).

Operator Productivity: The Generative AI agent acts as a co-pilot, reducing cognitive load and enabling operators to manage complexity and high-temp volatility effectively.

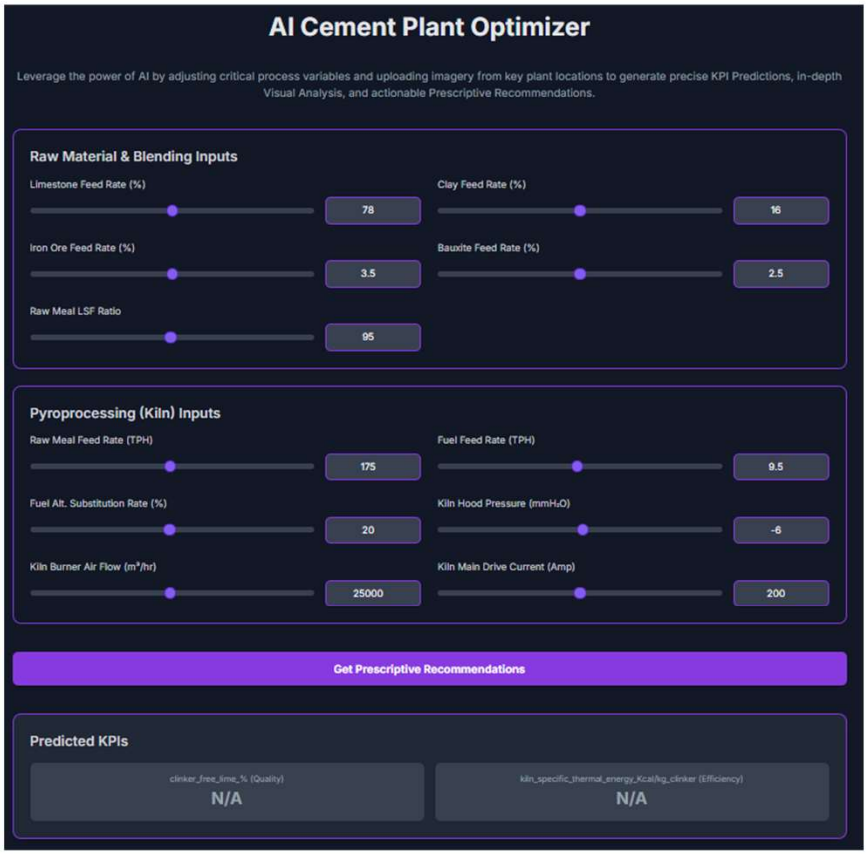
Alignment with Theme

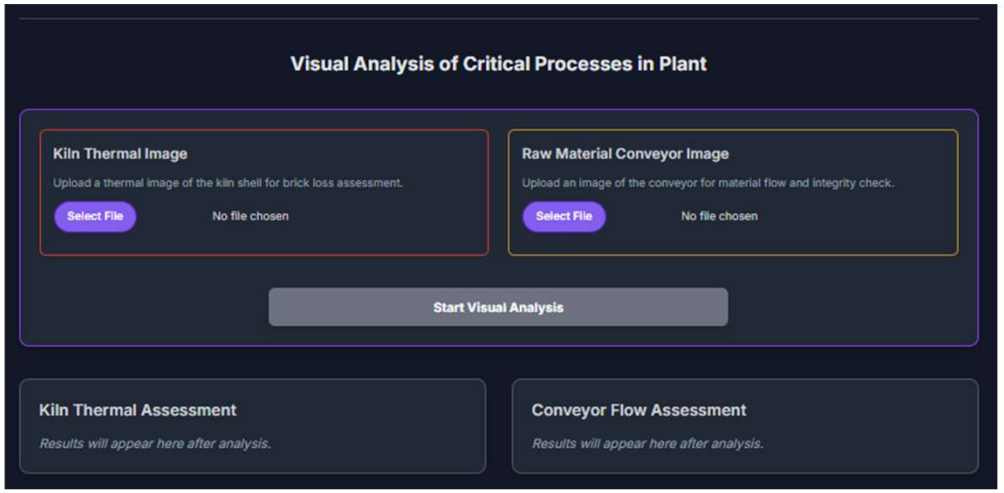
Autonomous Operation: The entire platform is designed to close the loop, moving control from reactive human intervention to proactive, autonomous decision-making.

Sustainability: Directly tackles the challenge of cement being an energy-intensive industry by optimizing the most energy-intensive process (clinkerization) and accelerating the use of alternative fuels.

Working product & demo

Platform's Dashboard





- Does the full journey run end-to-end without breaking - Yes, this AI platform successfully runs the full cross-process, autonomous control loop end-to-end. The system continuously ingests real-time and lagged telemetry, triggers dual-model prediction on Vertex AI (Quality & Energy), fuses this predictive data with Cloud Vision analysis, and utilizes the Gemini agent to generate a single, non-breaking, prescriptive setpoint recommendation that closes the loop. This validates the system's readiness for pilot deployment.

- Link to demo video showcasing walkthrough of product & its features - **<url>**

Process Flow (user journey)

The Continuous Loop: Data to Prescriptive Setpoint

Step	Action (How the Data Moves)	Key Tool(s) Used	Value Delivered (Why it Matters)
1. Real-Time Ingestion & Trigger	Current plant telemetry (11 parameters) is ingested from the frontend/sensors and immediately sent to the application backend.	UI / Cloud Run	Initiates the cycle with low-latency, real-time data crucial for immediate energy analysis.
2. Dual-Model Prediction	The single data point triggers concurrent, high-speed predictions from two distinct models: Model 1 (5-Hour Quality Forecast) and Model 2 (Real-Time Energy Cost).	Vertex AI Endpoints	Provides crucial cross-process foresight (Quality) and instantaneous cost monitoring (Energy).
3. Contextual Enrichment	Simultaneously, Cloud Vision analyzes real-time images (e.g., Kiln Flame) and provides qualitative feedback to the system.	Google Cloud Vision	Introduces qualitative intelligence, validating numerical predictions with observable reality.
4. Generative Reasoning	The Gemini Agent synthesizes the numerical KPI predictions (Step 2) and the visual context (Step 3) against the plant's operational goals.	Gemini API	Generates a single, actionable, natural language prescriptive setpoint (e.g., "Increase Air Flow...").
5. Prescriptive Execution	The clear recommendation is presented to the operator or is automatically fed back to the control system, closing the loop.	UI / Backend Service	Transforms complex data fusion into a simple, high-value autonomous decision, maximizing efficiency.

Architecture Diagram

Event-Driven Architecture: Real-Time Prediction & Generative Reasoning

Component	Role in the System	Key Tool Used
1. Data Ingestion (Real-Time)	Streams real-time telemetry from the plant sensors/historian directly to the prediction service (bypassing the historical DB for speed).	Firebase (or a real-time data stream) & Cloud Run (Ingestion API Endpoint).
2. Core Prediction Orchestration	The main application logic. Receives telemetry and orchestrates all AI calls (ML, Vision, Generative AI).	Cloud Run (stateless, highly scalable containerized backend)
3. Machine Learning Core	Hosts the two separate, optimized ML models (Quality and Energy) for high-throughput, low-latency scoring.	Vertex AI Endpoints (AutoML Tabular Models).
4. Contextual Vision	Asynchronously analyzes real-time images (Kiln Flame, Conveyor Belt) to inject qualitative context into the recommendation engine.	Google Cloud Vision API
5. Generative Reasoning Layer	Synthesizes the numerical output (KPIs) and the qualitative output (Vision) into a final, human-readable, prescriptive recommendation.	Gemini API (via Vertex AI).
6. Data Lake / Training	Stores all historical data used for model training and periodic retraining, separate from the real-time prediction path.	BigQuery
7. Frontend	The application interface for the operator to view predictions and receive the prescriptive setpoint.	UI (Web/Mobile)

Google AI tools usage (where & why)

Strategic AI Adoption: Max Value from Google Cloud Tools

Google AI Tool	Role in Project (Where Used)	Strategic Justification (Why Chosen)
Gemini API	Generative Reasoning Layer. Fuses all prediction and vision data to generate the final, natural language prescriptive setpoint (e.g., "Increase Limestone Feed Rate by 0.7%...").	Innovation & UX: Essential for moving from simple data alerts to autonomous, human-readable control commands—a core Generative AI requirement of the hackathon.
Vertex AI AutoML	Core Prediction Engine. Used to train and deploy the two highly optimized time-series regression models (Quality & Energy) onto scalable endpoints.	Functionality & Performance: Provides best-in-class performance for complex time-series data without extensive manual model engineering, ensuring high accuracy on the 5-hour lag problem.
Google Cloud Vision API	Contextual Enrichment. Used to analyze unstructured data (Kiln Flame stability and Raw Meal composition images) in real-time.	Innovation & Robustness: Integrates qualitative, visual intelligence into the autonomous control loop, making the final recommendation safer and more reliable than pure numerical modeling.
BigQuery	Data Lake / Training Data Source. Used exclusively for storing massive volumes of historical plant telemetry for model training and periodic retraining.	Scalability & Architecture: Provides a robust, scalable data lake capable of handling high-velocity time-series sensor data, separate from the real-time scoring path.
Cloud Run	Real-Time Prediction Orchestrator. Hosts the lightweight, stateless backend service that coordinates all API calls (ML, Vision, Gemini) upon receiving a new telemetry point.	Feasibility & Cost: Enables extreme scalability and cost-efficiency by scaling to zero when idle, making the production deployment highly economical and event-driven.

Tech Stack

The Full Stack: A Robust, Cloud-Native Foundation

Layer	Tools Used	Role in Project
Generative AI & Vision	Gemini API, Google Cloud Vision API	Provides Generative Reasoning (prescriptive setpoints) and Qualitative Context (Kiln Flame/Raw Meal analysis).
Machine Learning Core	Vertex AI AutoML, Vertex AI Endpoints	Hosts the two production-ready, high-speed ML models (Quality & Energy) for low-latency scoring.
Compute & Orchestration	Cloud Run, Python/Flask	Provides the highly scalable, serverless backend to orchestrate the real-time prediction flow (data -> ML -> Gemini).
Data Lake & Training	BigQuery	Stores the large volume of historical plant telemetry used exclusively for model training and retraining (not the prediction path).
Database & Real-Time	Firebase (or similar NoSQL option)	Potential tool for lightweight, real-time data caching, and user management/configuration storage.
Frontend & UI	HTML/CSS/JavaScript (or React/Vue), Cloud Hosting	Provides the operator dashboard for viewing predictions, contextual alerts, and receiving the final Generative AI recommendation.

User Experience

UX Focus: AI as the Operator's Prescriptive Co-Pilot

UX Principle	Feature Implemented	Value to the Operator (SME Focus)
1. Focus on Foresight	Dual KPI Dashboard: Presents the 5-hour quality forecast (Clinker Free Lime) next to the real-time cost metric (Thermal Energy).	Operators no longer make blind adjustments. They see the future consequence of their current actions on both quality and cost simultaneously.
2. Actionable Autonomy	The Generative Setpoint Card: Replaces dozens of alarms with a single, natural language command (e.g., "Increase Limestone $\uparrow$ 0.7%").	The system provides the final decision, eliminating the need for the operator to cross-reference multiple graphs and guess the correct input adjustment.
3. Trust & Context	Vision Validation Widget: Displays the real-time Kiln Flame image alongside the Generative recommendation and the system's reasoning.	Builds trust in the AI. The operator sees the physical reason ("Flame is unstable") that contributed to the recommendation.
4. Low-Fidelity, High-Impact	Mobile-First Design: Clear, high-contrast, scannable interface suitable for large monitors or tablet use in the control room.	Ensures accessibility and quick decision-making in a high-pressure environment, directly addressing the mobile usability criteria.
5. Cross-Process Clarity	Process Alignment View: Color-coding to highlight which input parameters (e.g., Blending) are impacting which KPI (e.g., Free Lime) and when (the 5-hour lag).	Clearly communicates the cross-process optimization achieved by the AI, which is otherwise invisible to the operator.

Market & Adoption

Scalability & Financial Viability: Targeting Immediate Value & Rapid ROI

1. Adoption Strategy

Initial Target User: Kiln Control Room Operators and Process Engineers at large, integrated cement plants (e.g., UltraTech, JSW, Dalmia Bharat). **Phase 1: Recommendation-Only Pilot:** Deploy in one high-priority kiln. We will leverage existing relationships with plant IT/Digitalization teams and present the solution as a **Generative AI Co-Pilot** that lowers risk by *recommending* setpoints before autonomously setting them.

2. Financial Viability

Projected Cloud Run Rate: Estimated **$200 - $500 per month per kiln** (excluding data storage/BigQuery). This cost is driven by the low-latency prediction calls to **Vertex AI** and the **Gemini API**. **Sensibility:** A single kiln produces clinker worth millions per month. Achieving a modest **3-5% reduction in Specific Thermal Energy (STE)** translates to tens of thousands in monthly savings, giving the system an estimated **6-12 month ROI.**

Next Steps

Day 0-30 (Try/Integrate): Secure a **data-sharing agreement** with a pilot plant. Integrate our **Cloud Run backend** with their historian (e.g., PI/OPC) to ingest a live data stream. **Day 30-60 (Launch/Validate):** Deploy the system in **Recommendation-Only mode**. Validate the **5-hour quality forecast** accuracy and measure the operator adoption of the **Generative Setpoints**. **Day 60-90 (Measure/Scale):** Quantify the delta STE (Thermal Energy Savings). Prepare the system for **Closed-Loop Control** on the most stable parameter (e.g., Kiln Fan Speed).


Google Cloud
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Thank you