Product Name: AI Cement Quality Co-Pilot
Version: v1.0 Prototype
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1. Purpose

The AI Cement Quality Co-Pilot is designed to assist cement plant engineers in monitoring, analyzing, and optimizing kiln operations and clinker quality. It combines real-time process telemetry, automated QC data from Robolab-prepared samples, and microscopy/XRD images with AI (ML + Vision + Gemini LLM) to deliver prescriptive, explainable recommendations.

The goal is to improve clinker quality consistency, reduce energy costs, and lower CO_2 emissions through intelligent, scalable automation.

2. Background & Opportunity

Cement industry challenges:

- High variability in clinker quality.
- High energy costs and CO_2 emissions.
- Limited actionable insights from current rule-based systems.

Existing solutions (e.g., Cementron, ABB Expert Optimizer) are:

- Primarily rule-based.
- Do not integrate lab QC or microscopy data.
- Lack contextual, explainable recommendations.

Opportunity: A **multi-modal AI assistant** that combines **process data, lab results, and images** to guide engineers with actionable insights.

3. Objectives & Goals

- Enable real-time monitoring of kiln health and clinker quality.
- Provide prescriptive recommendations instead of raw alarms.
- Leverage Google Cloud AI tools for scalable, cloud-native deployment.
- Deliver an intuitive co-pilot interface (Combination of dashboard and chatbot).
- Support sustainability goals by reducing energy use and CO_2 footprint.

4. Scope

In-Scope (Prototype):

- Data ingestion from SCADA/DCS - (BigQuery).
- Lab/QC data integration (XRD, microscopy) via Robolab - LIMS - upload.
- Image classification using Vision AI / Vertex AI (alite vs belite, crystal size).
- ML models for trend detection and anomaly prediction.
- LLM (Gemini) for fusing results and generating recommendations.
- Web/Tablet UI (Streamlit prototype) with dashboard and chatbot.
- Alerts for kiln anomalies (e.g., risk of ring formation).

Out-of-Scope (Prototype):

- Closed-loop autonomous kiln control (full automation).
- Deployment across multiple plants (covered in future roadmap).

5. User Stories

- *As a **kiln engineer,*** I want to upload microscopy/XRD images so that the system can analyze clinker phases and crystal size.

- *As a **process operator,*** I want real-time alerts if trends indicate ring formation risk so that I can act before failure.

- *As a **QC manager,*** I want to view integrated lab + process data in one dashboard so that I can ensure clinker quality consistency.

- *As a **plant director,*** I want sustainability insights (energy savings, CO_2 reduction) so that I can track progress against ESG goals.

6. Functional Requirements

- **Data Ingestion**
    - Ingest SCADA/DCS telemetry to BigQuery via API.
    - Support Robolab-prepared QC data uploads (XRD, microscopy, wet chemistry).
    - Store image metadata and lab results with timestamps and kiln ID.
- **AI Processing**
    - ML models for anomaly detection & trend prediction.
    - Vision AI models for image classification (alite, belite ratios, crystal size).
    - LLM (Gemini) orchestration for contextual recommendation generation.
- **Recommendation Engine**
    - Rules + AI combo to generate prescriptive suggestions.Example: “Alite crystals too large - reduce burning zone temp by 20°C.”
    - Confidence score for each recommendation.
- **User Interface**
    - Dashboard for telemetry, lab/QC results, image predictions.
    - Chatbot interface for natural-language Q&A.
    - File upload for microscopy/XRD images.
    - Alert notifications (future scope) - (e.g., email/SMS or in-dashboard banners).
- **Integration**
    - Google Cloud services (BigQuery, Vertex AI, Vision AI, Gemini, Pub/Sub, Cloud Run).
    - Export recommendations to plant ERP/MES system (future scope).

7. Non-Functional Requirements

- **Scalability:** Must support multiple kilns and plants.
- **Performance:** Recommendations generated within <1 minute of data ingestion.
- **Reliability:** ≥99% uptime for ingestion pipeline.
- **Security:** Role-based access, encryption in transit and at rest.
- **Maintainability:** Modular architecture for easy model updates.

8. Unique Selling Proposition (USP)

- Only solution integrating **Robolab-prepared QC data + Vision AI + ML + Gemini** into one assistant.
- **Multi-modal AI fusion** - richer insights vs rule-based competitors.
- **Explainable recommendations** - improves trust and adoption.
- **Cloud-native, scalable** - future-ready across multiple plants.

9. Success Metrics

- Reduction in clinker quality variability (e.g., free lime % within spec).
- Reduction in energy consumption per ton clinker.
- Early anomaly detection rate (≥80% before failure).
- User adoption: % of engineers actively using dashboard/chatbot weekly.

10. Future Roadmap

- Phase 2: Pilot deployment across 1–2 kilns.
- Phase 3: Closed-loop integration with kiln control system.
- Phase 4: Multi-plant scaling, predictive maintenance modules.
- Phase 5: Expansion into steel, glass, mining industries.