PATHWAYS FOR CARBON MANAGEMENT IN THE CEMENT INDUSTRY

A sector-coupled energy-system analysis with focus on Baden-Württemberg

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RESILIENT

FINAL WORKSHOP

Planning Europe's Energy Infrastructure under Uncertainty

THE CHALLENGE

A large share of cement emissions is process-inherent: calcination releases CO_2 regardless of the kiln fuel. Decarbonisation therefore depends on how cement plants interact with electricity, hydrogen, oxygen, CO_2 transport and storage.

RESEARCH QUESTION

Which combination of electrolytic oxygen, CO_2 networks and flexible grinding supports least-cost cement decarbonisation in a climate-neutral energy system?

2050

climate-neutral system target

CASE & MODEL

Baden-Württemberg is resolved into 12 planning regions with six clinker-producing sites; the rest of Germany is represented by four regions and neighbouring countries by one node each.



ENDOGENOUS CEMENT MODULE

The optimisation selects between classic and oxyfuel production, fuel supply, carbon capture, oxygen supply from ASU or electrolysis, CO_2 use/storage and temporally flexible grinding via clinker storage.

Classic + capture | **Oxyfuel** | **O_2 co-product** | **Flexible grinding**

SCENARIO LEVERS

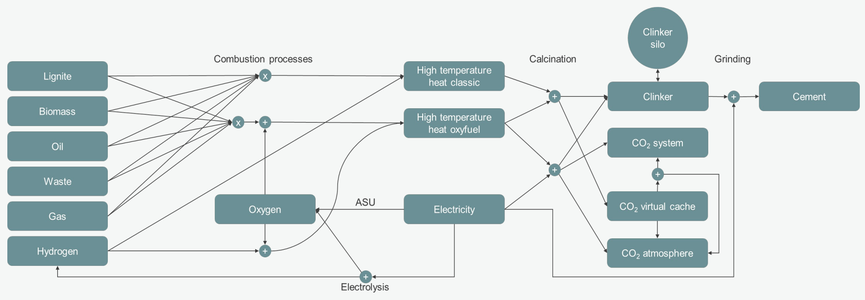
Six scenarios isolate three infrastructure and operational choices:

O_2 from electrolysis	**Very high impact**
CO_2 transport network	**System-wide impact**
Flexible cement grinding	**Operational impact**

MODEL SCOPE

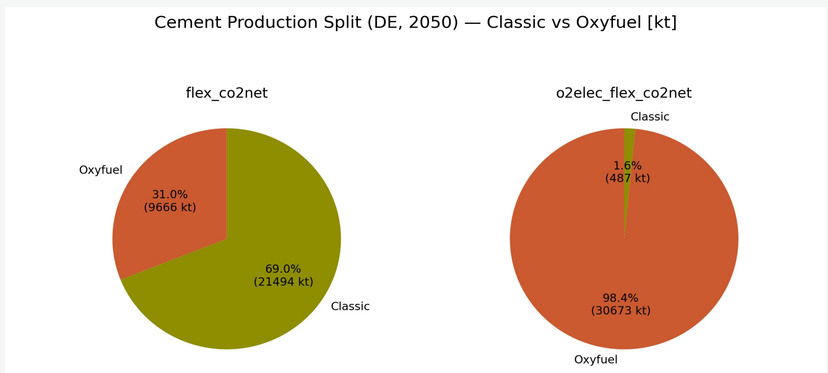
- Linear, cost-minimising capacity expansion and dispatch
- Brownfield pathway: 2020 → 2030 → 2040 → 2050
- Full 8,784-hour chronology
- Electricity, hydrogen and material flows linked across regions

HOW THE CEMENT SYSTEM IS REPRESENTED



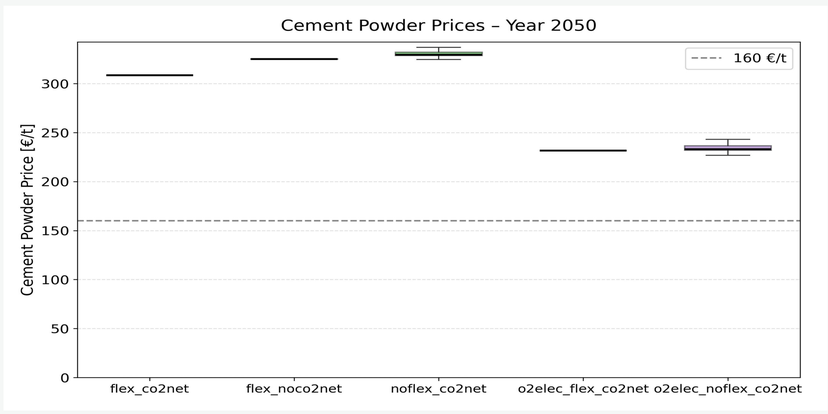
Fuel and electricity inputs are linked to classic or oxyfuel heat, calcination, CO_2 capture and clinker grinding. Oxygen storage decouples oxyfuel demand from electrolyser dispatch.

KEY RESULT 1: OXYGEN CHANGES THE ROUTE



With electrolytic oxygen, the model shifts almost completely to oxyfuel cement production. Without it, oxyfuel supplies roughly one third of annual cement output.

KEY RESULT 2: COSTS AND FLEXIBILITY



Electrolytic oxygen is the dominant cost lever

Flexible grinding mainly smooths hourly marginal-cost variation; it does not eliminate energy demand, but shifts it in time.

HEADLINE FINDINGS

25–30%

lower model-derived cement costs with electrolytic oxygen

0.2–5%

cost reduction from an available CO_2 grid

1.2–6.6%

cost reduction from flexible grinding

SYSTEM CONSEQUENCES

NO CO_2 NETWORK

Captured CO_2 is redirected towards hydrogen-intensive utilisation. European direct-air-capture capacity rises by around 60% in the analysed scenarios.

O_2 STORAGE

Buffers the oxygen co-product and enables continuous oxyfuel operation without materially reshaping electrolyser dispatch.

REGIONAL EFFECTS

System-wide electrolysis siting changes little overall, but local effects can be substantial where cement production and oxygen demand coincide.

PLANNING IMPLICATIONS

1. **Plan cement conversion, electrolysis, oxygen storage and CO_2 infrastructure jointly.**
2. **Treat oxygen as a valuable co-product, not a waste stream, where oxyfuel cement is feasible.**
3. **Use flexibility for temporal cost smoothing, while testing real silo and site constraints.**

TAKE-AWAY

In the analysed climate-neutral system, oxygen co-produced by electrolysis is the strongest single lever for cost-effective oxyfuel cement. CO_2 transport determines whether captured carbon is stored or converted with hydrogen, while flexible grinding primarily reduces temporal cost volatility.

These are system-level optimisation results, not plant-level investment prescriptions or market-price forecasts.

Acknowledgement

Funded by the German Federal Ministry for Economic Affairs and Climate Action through RESILIENT, grant no. 03EI4083D.

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Sources

Paper draft and project presentation materials.
Selected results for Germany and Baden-Württemberg, 2050.