

CO₂ mineralisation via fuel cells

How to make CCS profitable

Finding Petroleum CCS Forum
Geological Society, London, 15th September 2010
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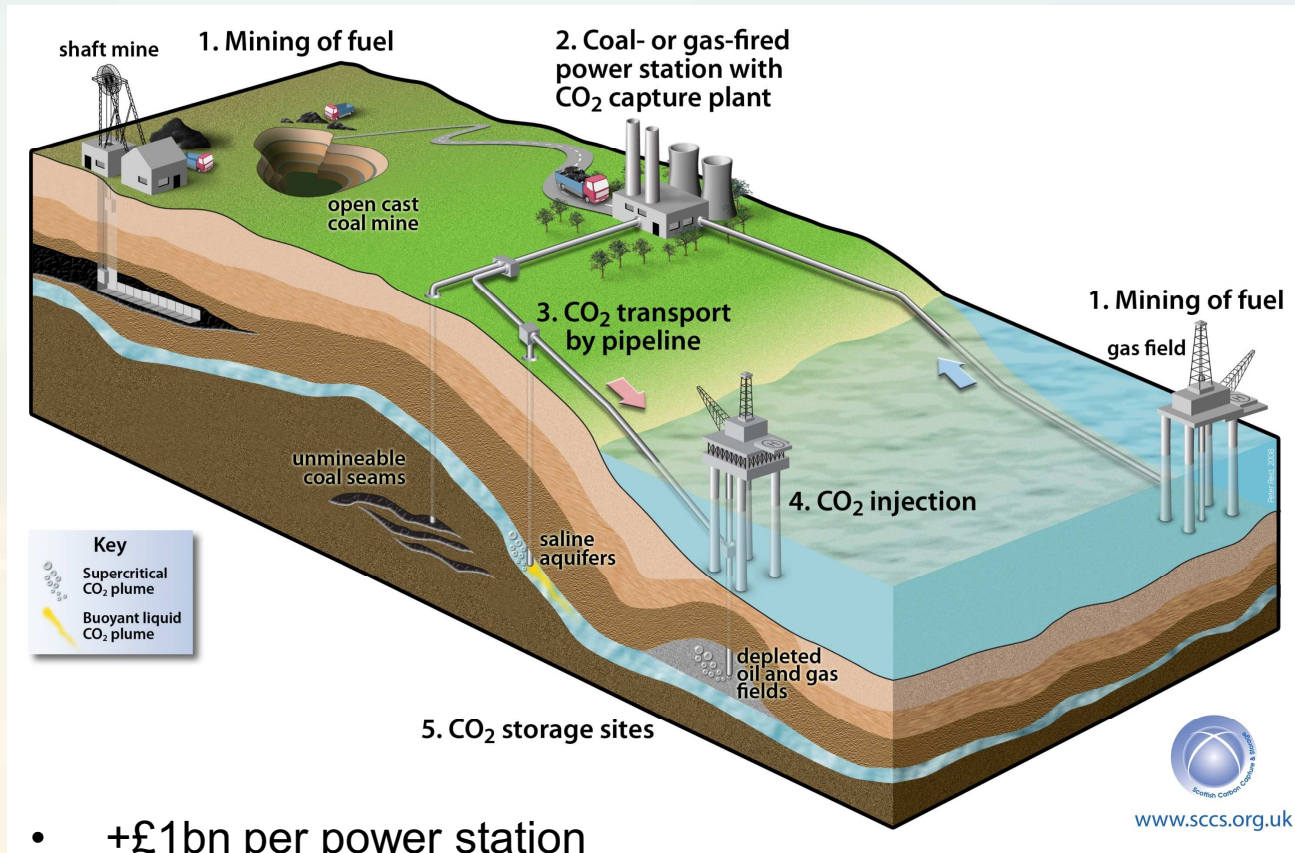
Cambridge Carbon Capture

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Mineralisation - issues I'll address

- Why do we need to consider alternatives to CCGS?
- What is mineralisation & How is it done?
- Can CO₂ mineralisation address global scale emissions?
 - are sufficient input minerals available?
 - can we make use of the materials outputs?
 - does it create new environmental problems?
- Cambridge Carbon Capture – uniquely efficient approach using fuel cells
- Profitability & market opportunity
- Pros & cons v. conventional CCS

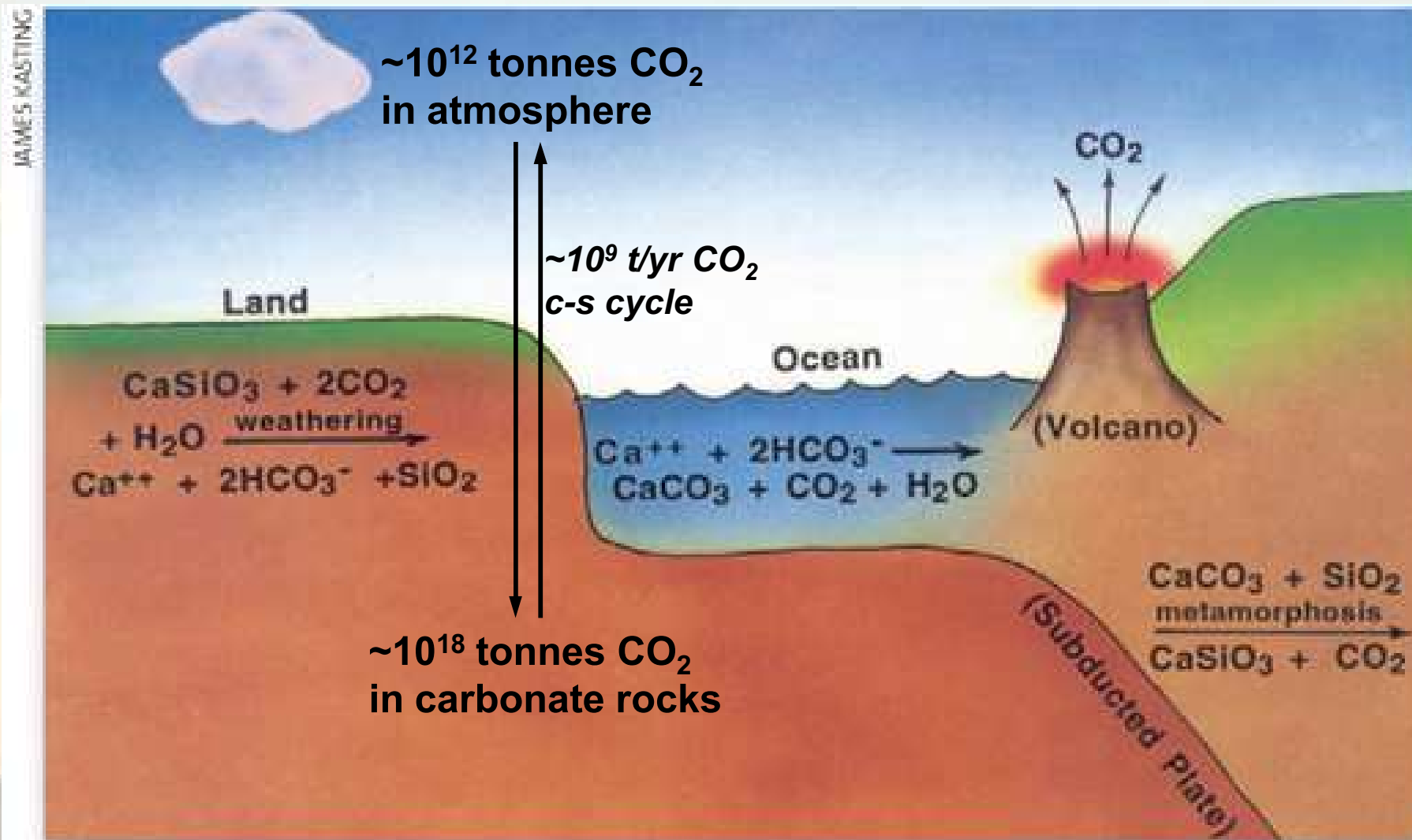
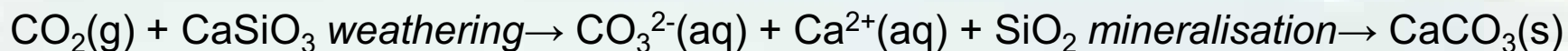
What's wrong with geological CCS?



- +£1bn per power station
- ~30% parasitic energy; ~30% electricity cost increase
- £/MWh CCS coal > £/MWh nuclear & onshore wind
- ~€40-90/tonne CCS >> €15/tonne ETS price

- Will CCS **costs** fall fast enough?
- When will **ETS** price > costs?
- Decades until CCS **investable**?
- CO₂ storage fees?
- Will the **public** accept CO₂?
- Utilities have other options.
- **China** will not let CCS risk growth.

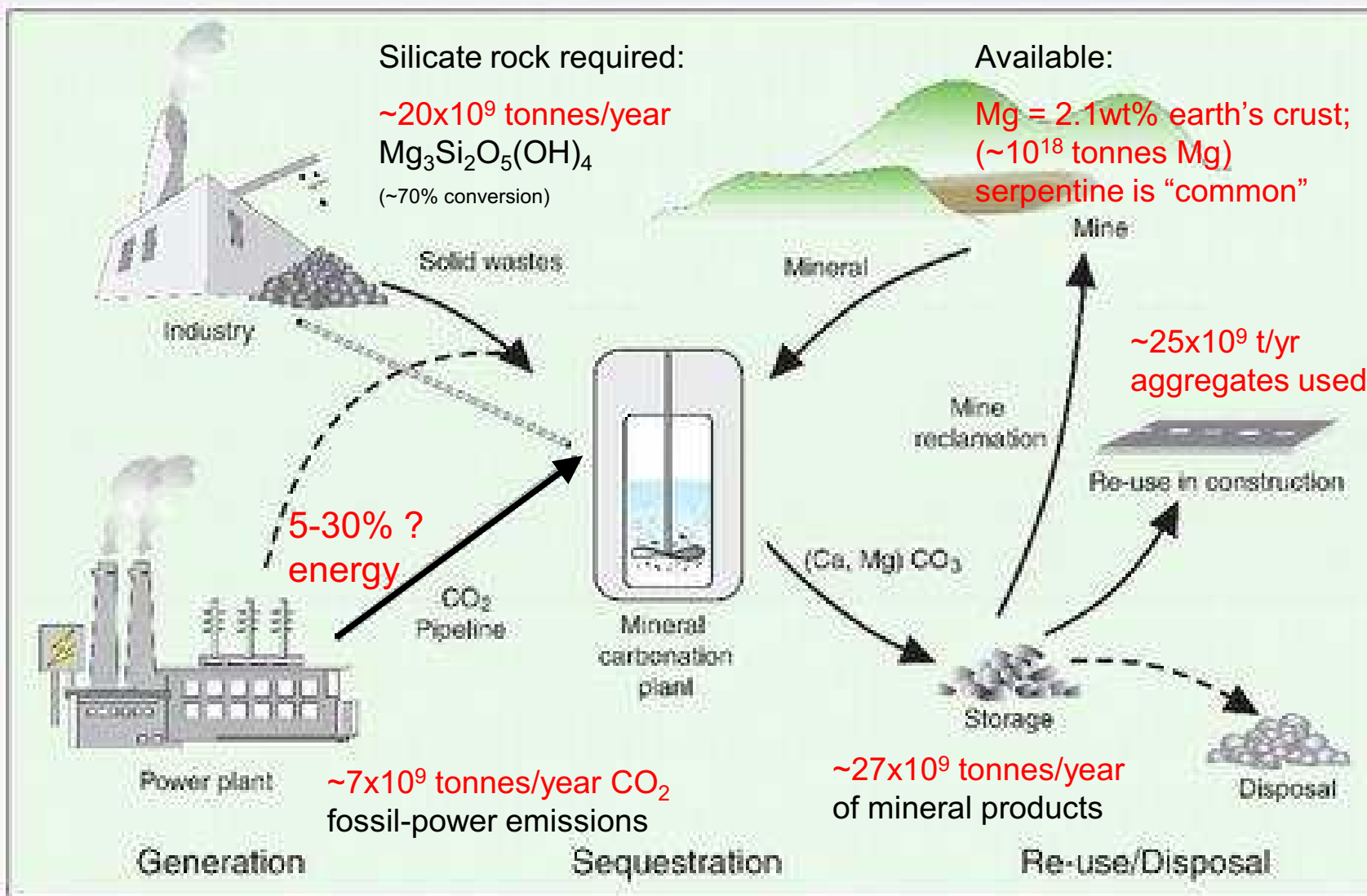
Carbonate-silicate cycle



How to do CO₂ mineralisation

- Essentially: CO₂ + source Ca/Mg/Fe = limestone / HCO₃⁻
 - pH, temperature, water, pCO₂, source: phase, chemistry, size
 - exothermic, but more energy is needed to overcome kinetics
- Gas-solid phase reactions:
 - CO₂(g) + combustion ashes = aggregates + heat (easy, but not scaleable)
 - CO₂(g) + heat-activated silicate rocks = aggregates (slow & energy intensive)
 - e.g. happens naturally with mine tailings: 1-50 kt/CO₂/year/mine
- Aqueous-phase reactions:
 - chemical activation/digestion of silicates or wastes
 - brines & liquid waste sources of Ca/Mg ions
 - CO₂ + water(high pH) + Ca/Mg salts = (bi)carbonates + silica + residual metals

Global scale feasibility?



First find your Group II element...

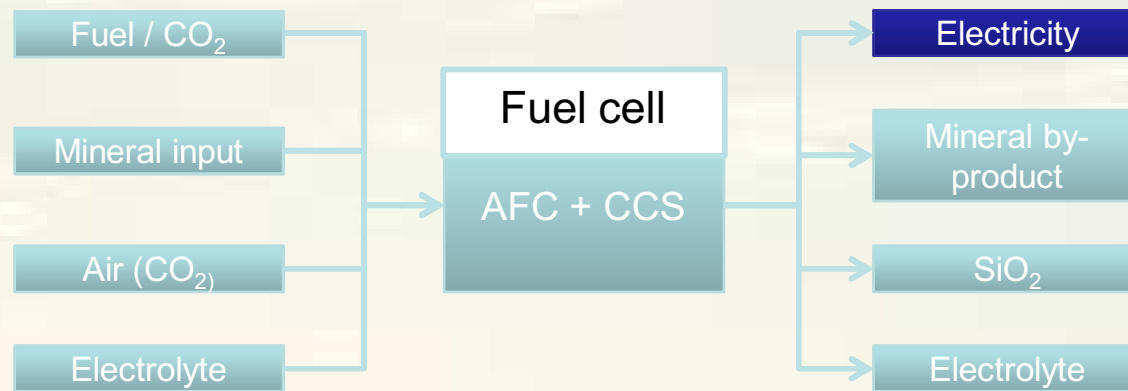
(CCC's preferred digestion processes)

- closed-cycle, alkaline digestion of serpentine to convert to Mg hydroxide and by-product silica
- closed-cycle, pH-swing ammonium bisulphate digestion to extract Mg salts (& by-product silica & metals) from serpentine rock
- both processes offer:
 - hydroxide for aqueous-phase capture of CO_2
 - Mg (or Ca) salts to precipitate solid carbonates
 - separation of chemical products
 - low-energy treatment; closed-loop (no chemical inputs or wastes)

Using fuel cells to mineralise CO₂

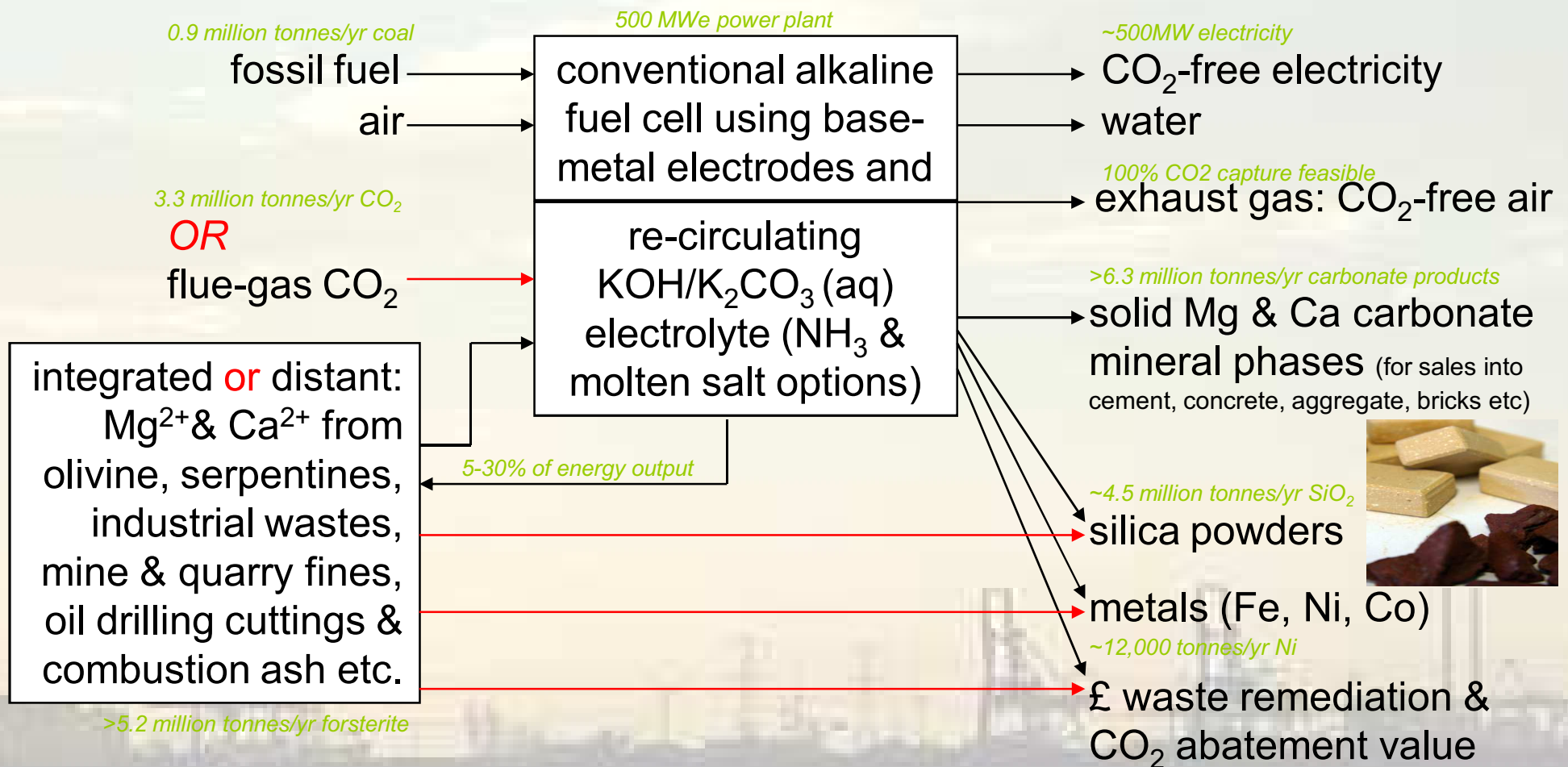
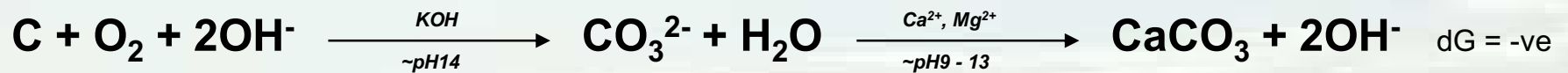
(CCC's unique technology)

- carbon → CO₂ gas = ~400kJ/mole
- carbon → CO₃²⁻ solid = ~470kJ/mole
- using a fuel cell allows some of this extra 15% energy to be released as electricity – to offset energy required to digest/activate mineral feedstock



- hydroxide flowing through the fuel cell captures the CO₂ into solution as carbonate
- Mg (or Ca) added in to the carbonate solution regenerates the hydroxide & sequesters the CO₂ as a solid carbonate mineral
- the “fuel” can be CO₂ in flue gases or hydrocarbon fuels

500MW power station (an illustration)



How can it be profitable?

- £420bn revenues (materials products + CO₂ abatement)
>
£350bn costs (for CO₂ mineralisation)
- ~8,000TWh/yr coal-fired electricity emits ~7bn t/yr CO₂
- £350 billion/yr – mineralisation cost at £50/tonne CO₂
- £330 billion/yr – global market for product materials
- £90 billion/yr - abatement value at ~£13/tonne CO₂
- £3300 bn (period 2010-2050) – global spend on CCS technology (IEA estimate)
- global annual power growth ~2.5% + ~2% replacement

Today's market drivers for CO₂-m

- Waste remediation
 - Stabilisation of leachable metals reduces disposal costs of hazardous wastes (up to £100/tonne)
- Competition for £bns CCS demonstration funds
 - Bidding utilities need to show that CCS can be economic beyond subsidised demonstration stage of CCGS
 - Practicality in absence of CO₂ pipeline & storage infrastructure
- High-value metals extraction
 - digestion of low-grade mine ores & wastes to extract residual high-value metals & chemicals
- Clean development mechanism
 - CO₂ abatement revenue if process done in developing countries
- Low-carbon building materials
 - Eco-markets emerging, but no current financial drivers

Mineralisation v. CCGS

- Revenues from mineral products cover costs of CCS
- No waiting for pipeline or storage infrastructure
- No safety concerns of supercritical CO₂ storage leakage
- Works where there are no empty aquifers or oil/gas wells
- Can start small in high-value niches & scale from there
- Can integrate & replace flue-gas desulphurisation
- Can consume historic & unwanted grades of fly-ash
- Mineral products can replace aggregates mining
- ...but significant logistics challenges
 - supply & storage of feedstock mineral 3-10X larger than coal
 - transport, storage & supply chain development for products

Conclusions & where next?

- **CO₂ mineralisation is compatible with global-scale power emissions:**
 - more than enough silicate rock to capture 7bn T/yr CO₂
 - aggregates market = mineralisation process output
- **CO₂ mineralisation can be profitable (& quicker to implement)**
 - revenues from aggregates, chemicals, waste remediation, metals & minerals
 - revenues from clean-electricity (& CO₂ abatement)
- **CCC fuel cell process offers lower-energy/cost route**
 - Offset energy for kinetics by recovery from thermodynamics
- **Demonstration of power-station scale mineralisation needed**
 - Real-world data on mineralisation energy inputs, total costs & chem eng design
 - Learning curves to optimise & reduce costs of processes
 - Development of supply chain for feedstock & output materials
 - policies to incentivise/require low-carbon construction materials
 - R,D&D needed to maximise process product values (e.g. use of SiO₂)
 - R&D needed on other mineralisation chemistry, energetics, feedstock availability

Thanks

- ***Cambridge University***
- ***Centre of Innovation in CCS (U.Nottingham)***
- ***Technology Strategy Board***
- ***Cambridge Enterprise***
- ***EEDA***
- ***Renewables East***

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