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PUTTING CARBON IN ITS PLACE

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OUTLINE

- Scientific Motivation
- Enhanced Rock Weathering (ERW)
- UNDO approach to Measurement, Reporting and Verification (MRV)
- Co-benefits
- Impact

Man announces he will quit drinking by 2050

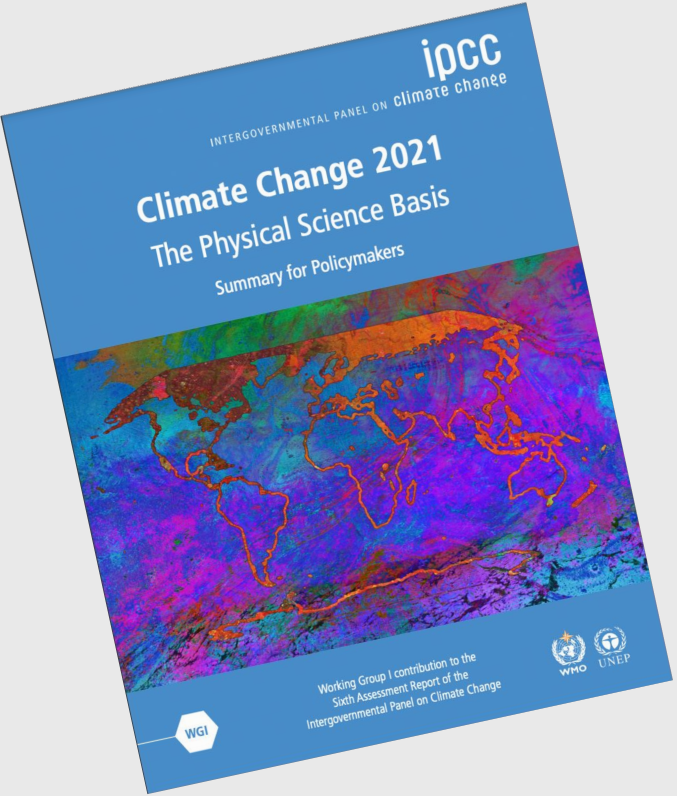
A Sydney man has set an ambitious target to phase out his alcohol consumption within the next 29 years, as part of an impressive plan to improve his health.

The program will see Greg Taylor, 73, continue to drink as normal for the foreseeable future, before reducing consumption in 2049 when he turns 101. He has assured friends it will not affect his drinking plans in the short or medium term.

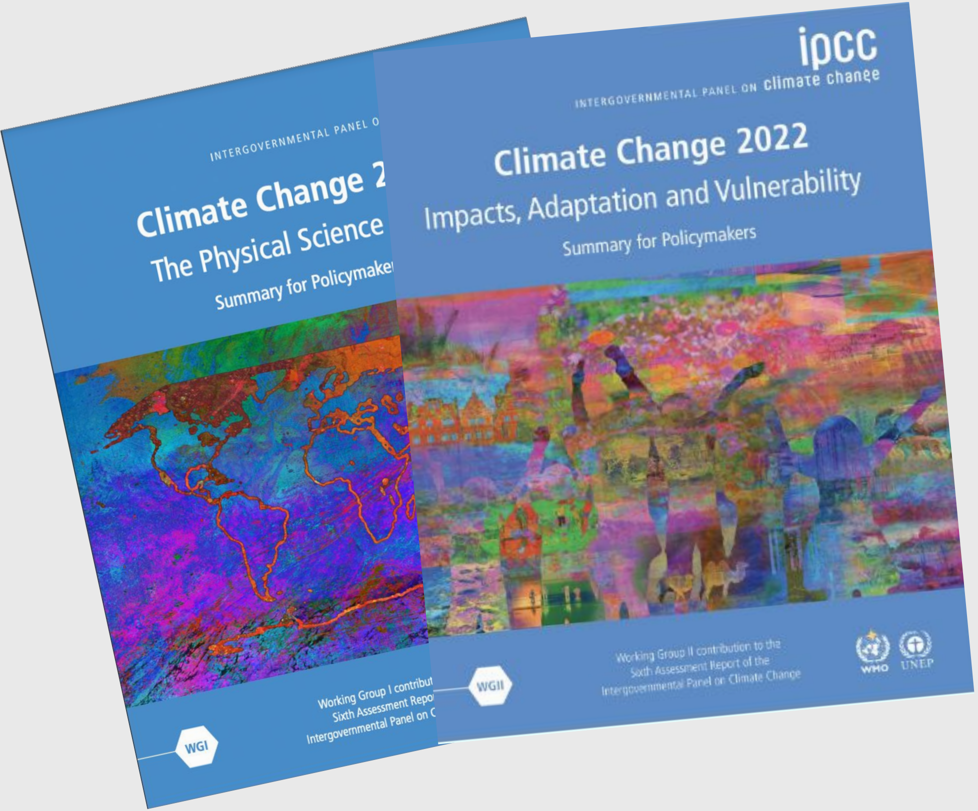
Taylor said it was important not to rush the switch to non-alcoholic beverages. “It’s not realistic to transition to zero alcohol overnight. This requires a steady, phased approach where nothing changes for at least two decades,” he said, adding that he may need to make additional investments in beer consumption in the short term, to make sure no night out is worse off.

Taylor will also be able to bring forward drinking credits earned from the days he hasn’t drunk over the past forty years, meaning the actual end date for consumption may actually be 2060.

“Climate change is widespread, rapid, and intensifying and unequivocally a result of human-induced greenhouse gas emissions”



“All life on earth, from ecosystems to human civilisations, is vulnerable to a changing climate”



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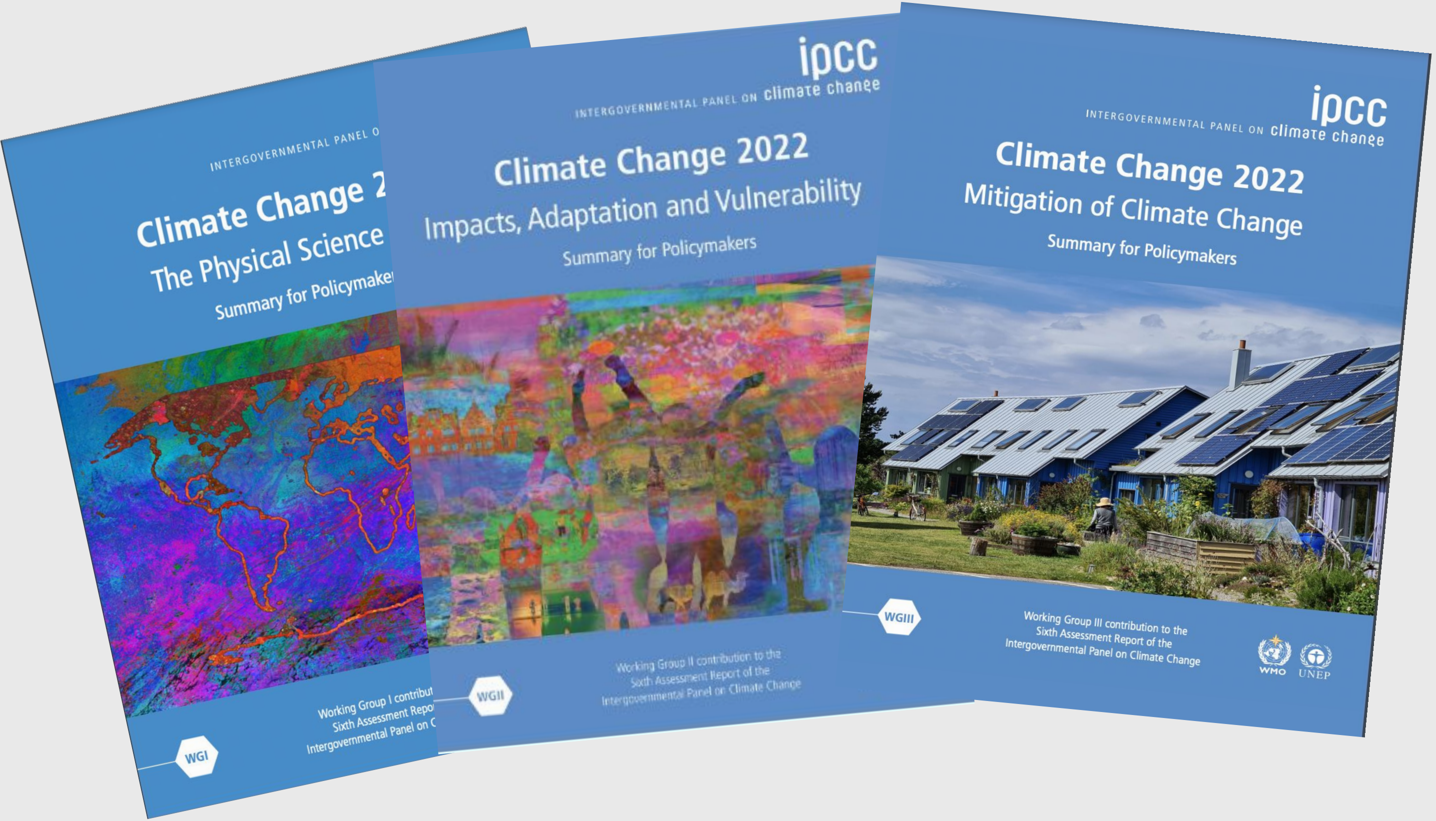
“The deployment of carbon dioxide removal (CDR) to counterbalance hard-to-abate residual emissions is unavoidable to achieve net zero”



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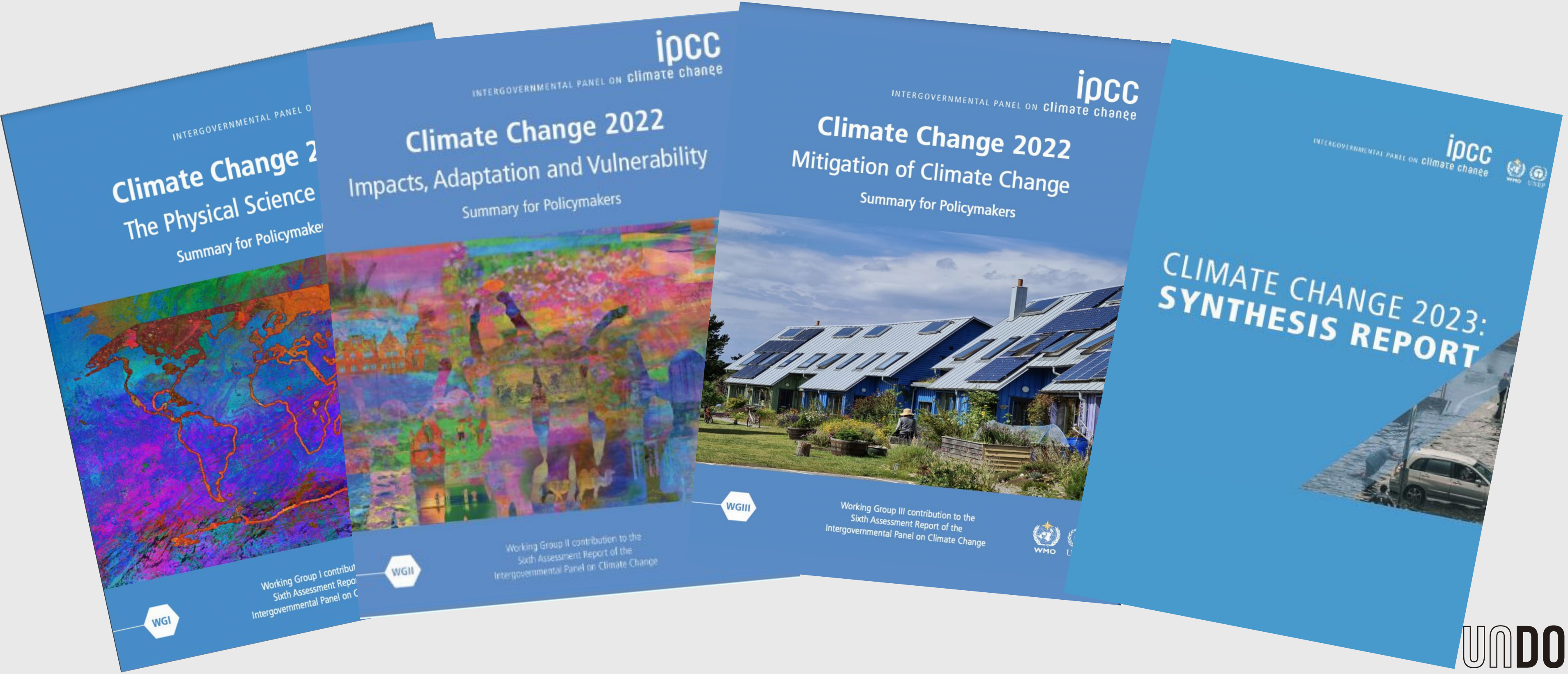
"There is a rapidly closing window of opportunity to secure a liveable and sustainable future for all."



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THE CLIMATE CRISIS WE FACE

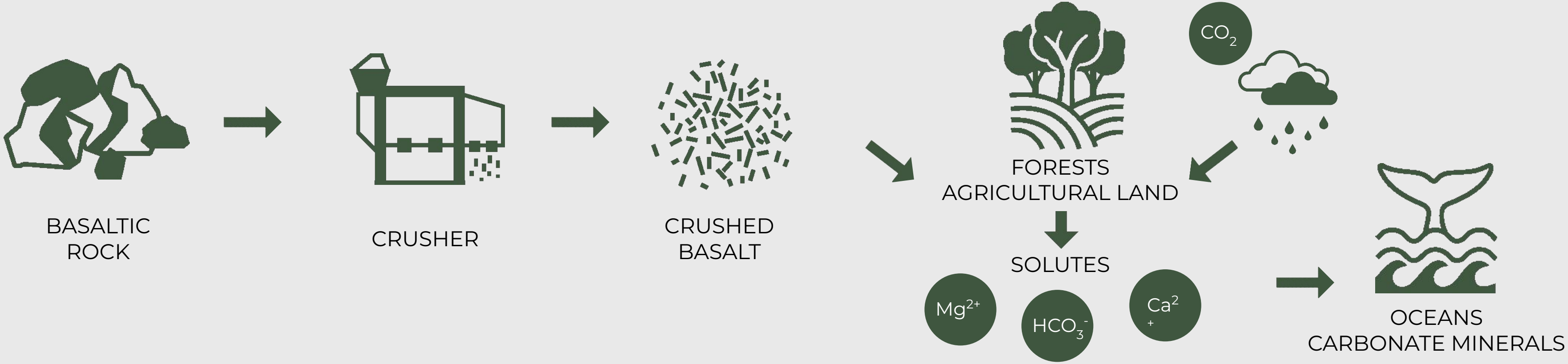
There is a removal need of **10 billion tonnes by 2050 per year** in order to stay within the SBTI goals and achieve net zero by 2050.

Reducing emissions alone isn't enough, we need radical action. We need to undo. And we need to do it at scale.

"**Everything we do at UNDO is designed to maximise the amount of carbon dioxide we can take out of the atmosphere** and optimise the positive impact it has on the environment."

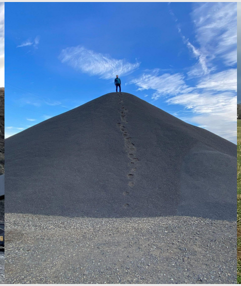
ENHANCED WEATHERING ON ARABLE CROPLANDS

Natural weathering process sped up through the addition of finely crushed, highly reactive basalt to agricultural land.



Giants Causeway

Quarry operations

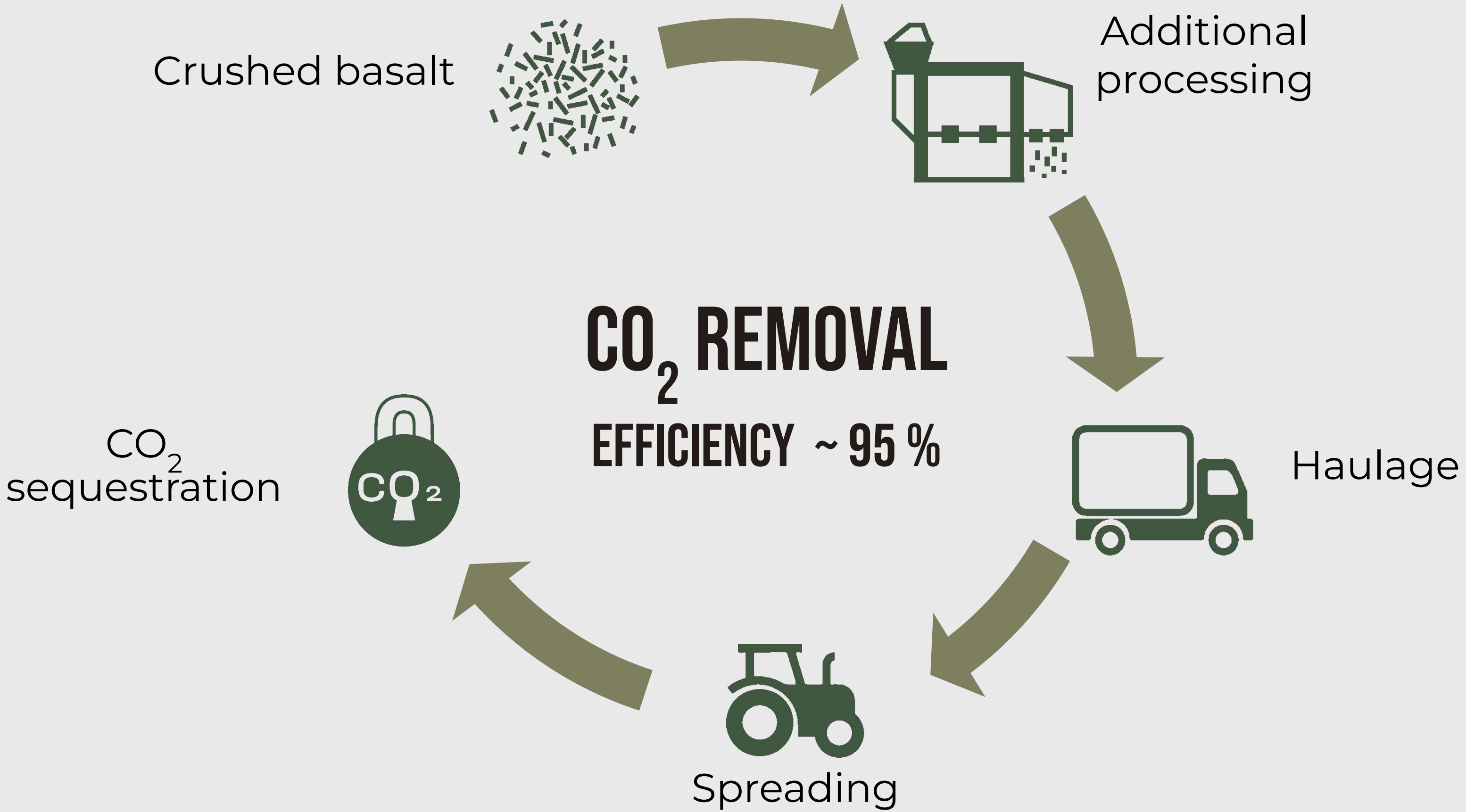


Aggregate by-product

Soil fertility

Møns Klint, Danmark

FACTORING IN THE LCA



"OUR VISION IS TO KEEP THE PLANET FIT FOR FUTURE GENERATIONS".

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"<u>OUR MISSION</u> IS TO PERMANENTLY REMOVE OVER A BILLION TONNES OF CO_2 PER YEAR AND HELP DELIVER SUSTAINABLE & IMPACTFUL SOLUTIONS." JIM MANN CEO

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TEAM OF 60 + UNDOERS, OPERATING LOCALLY BUT SCALING GLOBALLY

UNDO ARE BUILT TO SCALE, AIMING TO REMOVE OUR FIRST BILLION TONNES BY 2030

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Paris Agreement Goal - 1.5°C

- Achieving the Paris Agreement goal of keeping global warming to within 1.5°C above pre-industrial levels by 2100 **requires rapid decarbonisation**

- If countries *only* meet their current nationally determined contributions (NDCs) for 2030, it is likely (with high confidence) that **warming will exceed 1.5°C** during the 21st century

- There is a large gap between 2030 commitments, and the magnitude of emissions reductions needed to limit warming to less than 1.5°C above pre-industrial levels by 2100

- Stabilising global average temperature will require reducing CO_2 emissions to net-zero

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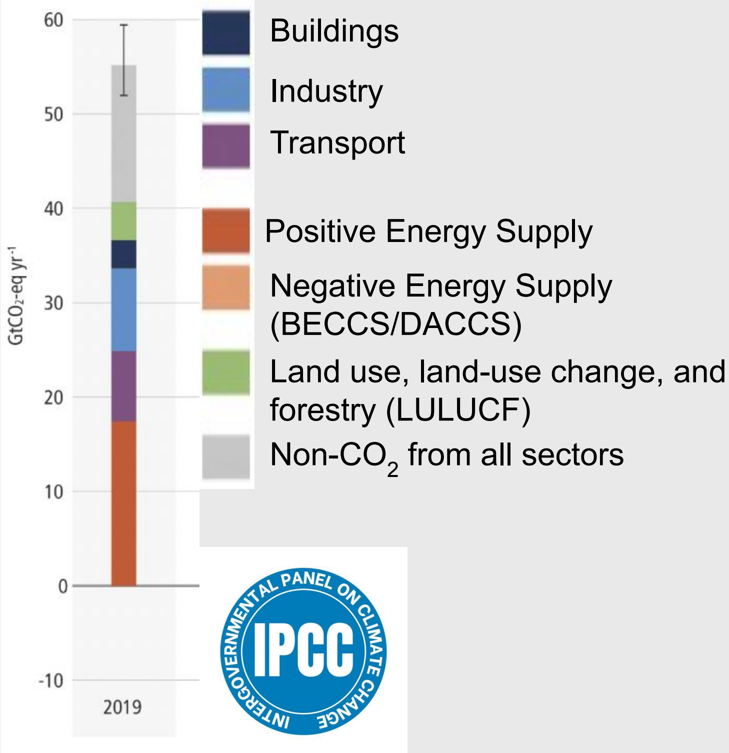
Warming Projections - 2100

- Need to rapidly reduce emissions by 80%
  - Switching power and heating to biomass, wind and solar
  - More energy efficient buildings
  - Improving public transport

- Remaining 20% of emissions
  - Carbon capture and storage (CCS) technology



HIGH PERMANENCE SOLUTION THAT CAN SCALE FAST

Technology	Permanence	Deployment Speed	Does Not Compete For Land	Capex	Co-Benefits
		Scalability			
Enhanced Weathering	H	H	✓	$	✓
Biochar	M	H	✓	$$	✓
Direct Air Capture	H	L	✓	$$$	X
Bioenergy Carbon Capture & Storage (BECCS)	H	M	X	$$$	X
Afforestation	L	L	X	$	✓
Soil Carbon	L	M	✓	$	✓

UNDO MRV VISION:

COMBINE GEOCHEMISTRY MODELING WITH IN-FIELD MEASUREMENTS TO ADVANCE THE SCIENCE WHILST CREATING A GIGATONNE SCALE REMOVAL MRV PATHWAY.

UNDO MRV: MODEL & MEASURE APPROACH

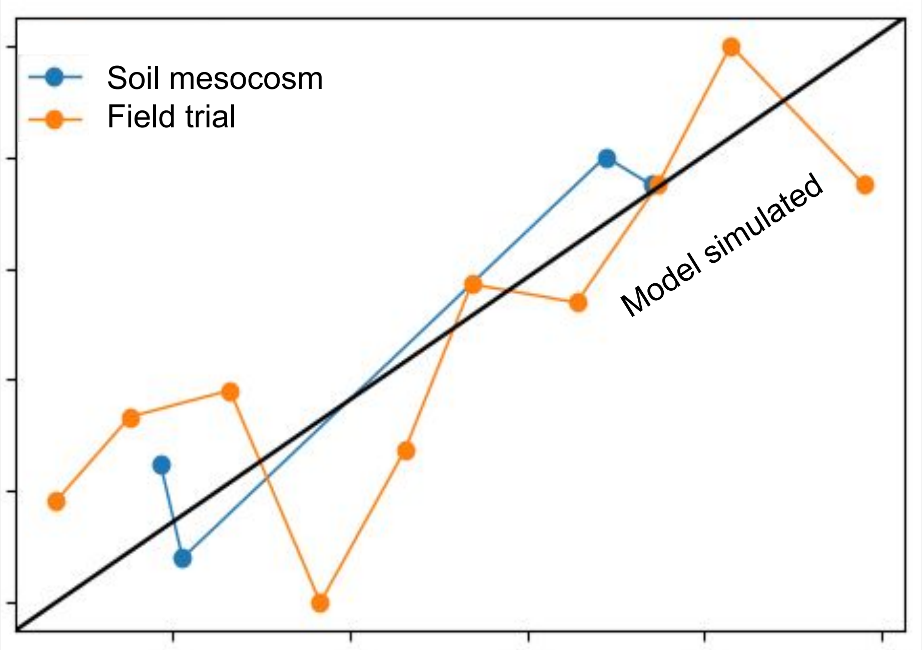
To date, no single method has proven accurate in quantifying the amount of CO_2 sequestered, but, rather, are indications that weathering is taking place. Hence the need for UNDO's model and measure approach.

UNDO uses an **extensively peer-reviewed*** one-dimensional reactive transport model (1D-RTM) with proprietary additions to estimate carbon dioxide removal and mineral weathering over multi-decadal timescales.

The lead developer of this mode is Dr. Peter Wade, who is part of UNDO's geochemistry and modelling team.

Real world published data are used to calibrate and continually improve the model. The team mine existing publications for data used to calibrate model.

MODEL → TRUE UP WITH PUBLISHED AND IN-HOUSE FIELD AND MESOCOSM DATA



*Kelland et al., 2020; Vienne et al., 2022

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OUR GEOCHEMICAL MODEL SO FAR (After Kelland et al. *Glob Chang Biol.*, 2020)

Four key categories of variables used by model:

1. BASALT

- Mineralogy (olivine, plagioclase, pyroxene)
- Mineral dissolution rates
- Particle size and surface area
- Application density

2. CLIMATE

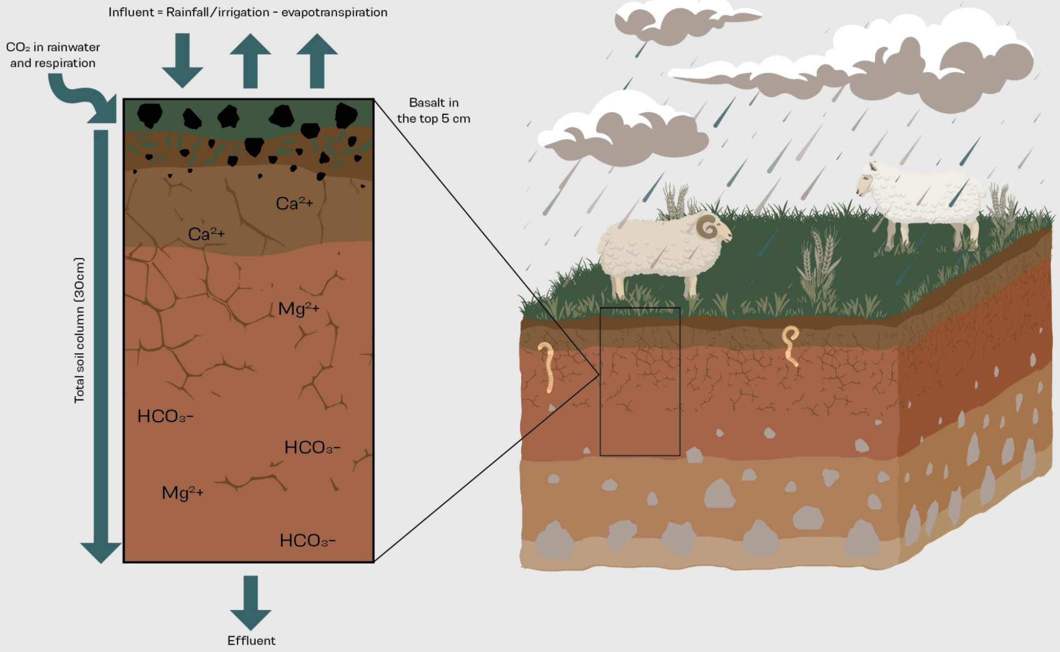
- Temperature
- Precipitation ± irrigation

3. SOIL (PHYSICAL & CHEMICAL) PARAMETERS

- pH
- Texture
- CEC (Cation Exchange Capacity)
- SOC (Soil Organic Carbon)
- Bulk density
- Water filled porosity

4. ATMOSPHERE

- Atmospheric CO_2
- Soil CO_2 partial pressure



Above: From model paper: carbon sequestration is modelled using PHREEQC (Parkhurst and Appelo, 2013), using published experimentally derived kinetic and thermodynamic data (Palandri and Karaka, 2004)

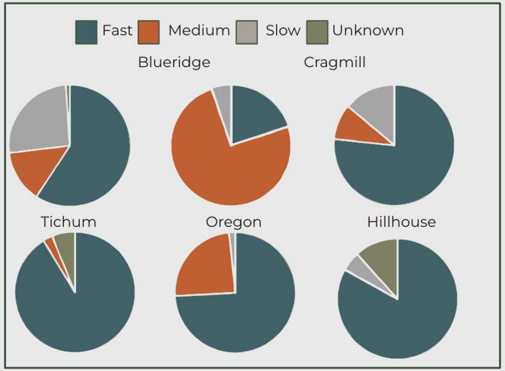
NOTE ON MODEL INPUTS

BASALT WEATHERING VARIATION

(After Lewis et al. *App. Geochemistry, 2021*)

Rate = - surface area • mineral dissolution rate

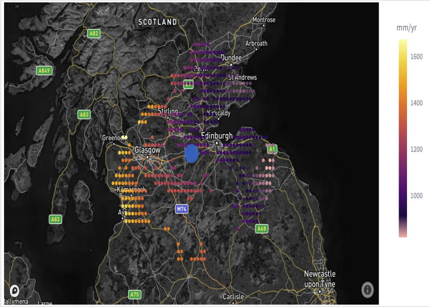
- Under the same soil and climatic conditions, the CO_2 removal potential of different basaltic materials differed by 6.5 times between basalt
- Increasing surface area by a factor of 10 increased CDR by a factor of 2.8
- Mineral dissolution rates range from 19-86% fast weathering minerals



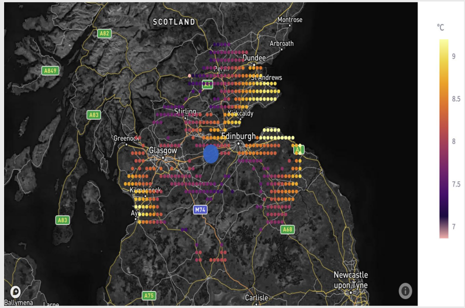
Left: Different rock samples showing variable make up in fast, medium and slow weathering minerals.

SOIL & CLIMATE DATASETS

- Climate and soil data pulled from global datasets for a given radius around a chosen location.
- Averaged values are then calculated taking into consideration the cropland in the area around each data point.
- Harmonised global datasets allow us to get the correct model inputs for any point on Earth



Above: Mean annual precipitation



Above: Mean annual temperature

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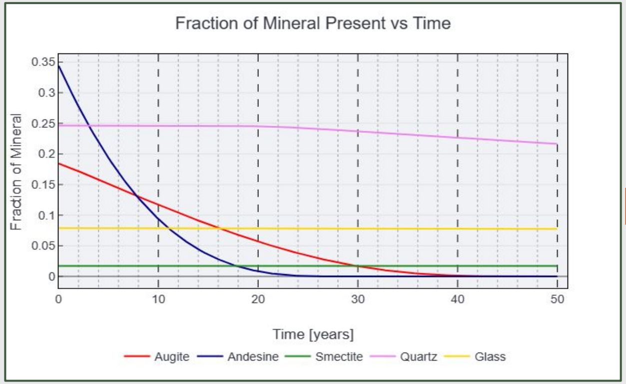
THREE STEPS TO MODELLING CDR

1. Model phased rock weathering rates



Above: Model results of varying weathering rates across five primary rock phases: augite, andesine, smectite, quartz and glass

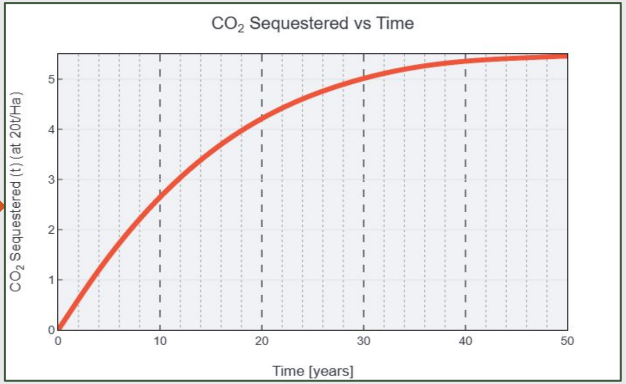
2. Calculate a charge balance

Concentration of Bicarbonate =

2*(Ca+Mg)+Na+K

Above: Calculation required to balance chemical weathering model for CDR.

3. Scale up mol/L to tonnes of CO_2 per ha

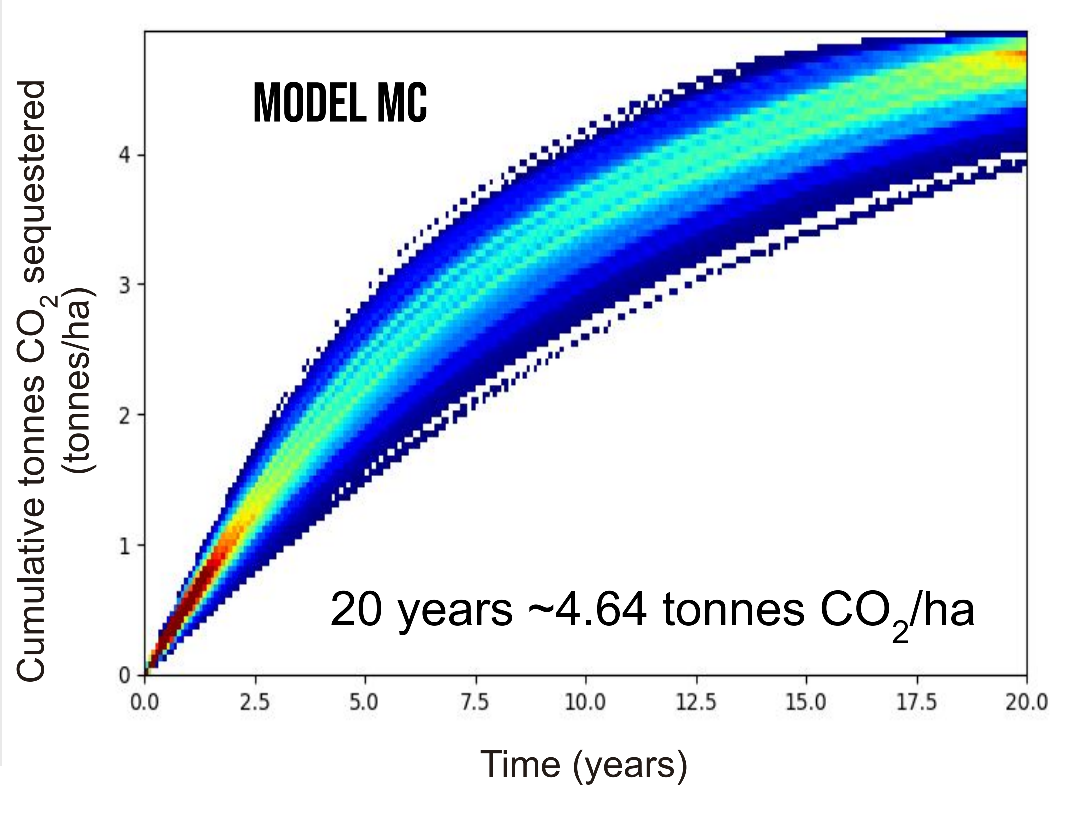


Above: Model output of calculated tCO_2 sequestration per hectare over 50 year time horizon

Model uncertainties:

- **Model predictions**: uncertainties in the input parameters is accounted for using Monte-Carlo simulations, iterating over the probability density function for each input parameter.
- **Dissolution rates**: constants which are used to drive the weathering of basalt mineralogy are being checked using published dissolution rate experiments for each mineral, under controlled laboratory conditions.

UNDO MRV: MODEL & MEASURE APPROACH



Monte Carlo based sensitivity analysis in accordance with the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. The Monte Carlo process includes assigning a probability density function (PDF) - built from a mean value and a standard deviation - for each of the model input parameters. The weathering model is then run (as a job) thousands of times, with the input parameters for each job being pulled randomly from the respective PDFs.

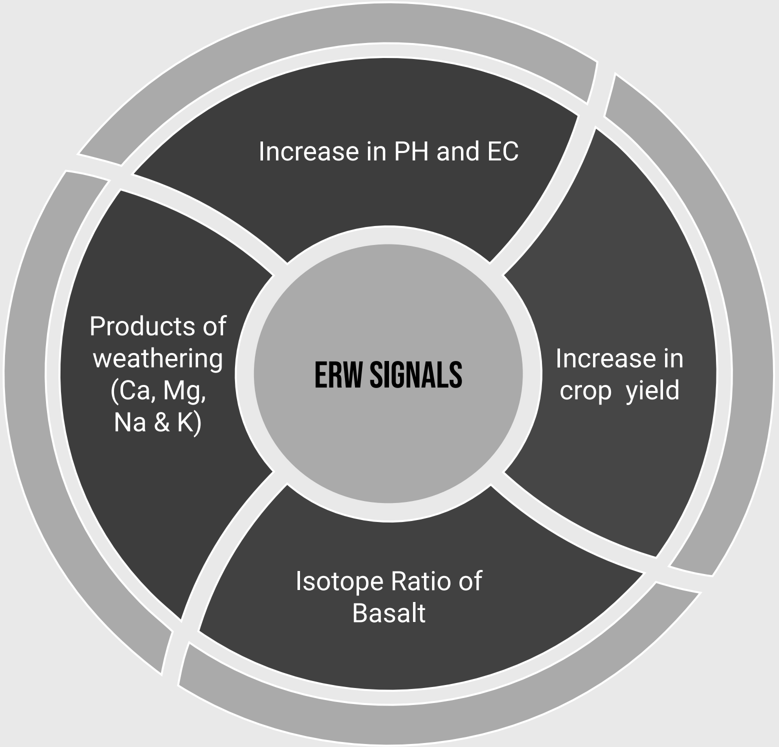
The data from each job is then combined and can be used to form a plot displaying the cumulative CO_2 sequestered vs time for all of the jobs. This forms a probability heat-map, which allows the mean value and standard deviation of each time bin to be determined.

MEASUREMENT OF WEATHERING INDICATORS

- To confirm sequestration for a spreading event, we use measured data and model outputs to **triangulate weathering rate**.

- Our model predicts the evolution in **soil pH**, **electrical conductivity** (EC) and the **release of elements** (base cations and bicarbonate), as result of basalt application.

- We use all known approaches in our field and mesocosm trials, combined with exploring new techniques to **measure indicators** predicted by the model.



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HOW WE MEASURE

We measure weathering indicators multiple ways, primary through our **mesocosm experiments** and **field trials** in selected regions of interest representative of climate and soil conditions (e.g. Scotland).

Indicators measured:

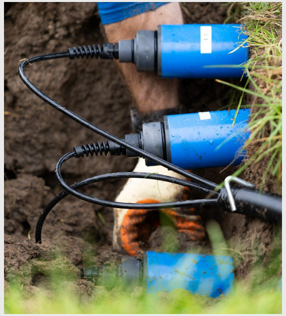
- **In-situ sensors** measure depth- and time-integrated changes in proxy weathering signals (pH, Temperature, soil moisture, electrical conductivity (EC))
- **Soil sampling** measure soil inorganic carbon (SIC) and exchangeable cations
- **Soil pore water sampling** measure pH, alkalinity (HCO_3^-), EC, major cations, anions
- **Sample biomass** for uptake of cations

MESOCOSMS EXPERIMENTS

Soil mesocosms incorporate the complexity of field conditions with added ability to take a wider range of measurements on a higher frequency. More controlled basalt application for ground truthing of the model.

FIELD TRIALS

Combination of small plot trails with high number of replicates combined with large scale operational field trials and agronomy co-benefits trials.



MEASUREMENTS

Field trials

- Installed sensors for in-situ pH and EC measurements
- Extracted poreware for pH, EC and total alkalinity
- Cations and anions
- Ti and rare earth elements and exchangeable ions that are unique to the applied basalt - Cr, Ni, Sr
- HM analysis
- Plant biomass and cation content

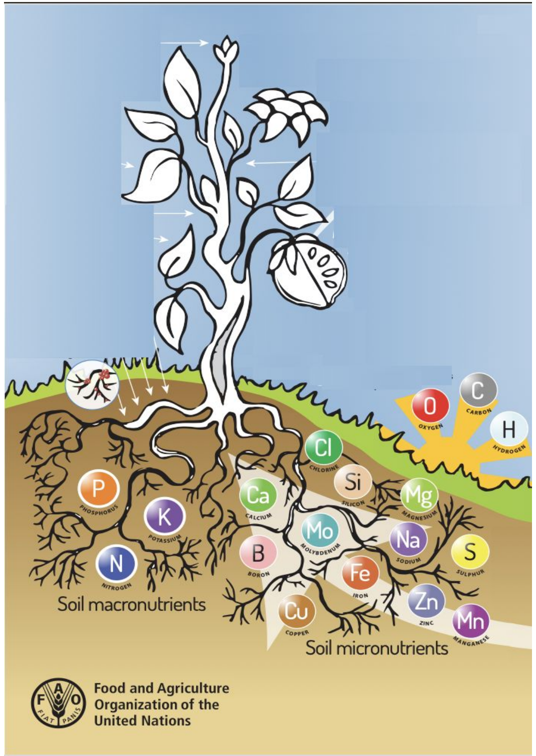
Mesocosm trials

- Poreware for pH, EC, total alkalinity cations and anions
- Leachate for pH, EC, alkalinity, cations and anions
- Plant biomass and cation content

MEASUREMENT	ANALYSIS	MEASUREMENT	ANALYSIS
Porewater EC	Rhizon sample; EC meter	Porewater, pH and total alkalinity	Rhizon sample; auto-titrator
Porewater, cations	Rhizon sample; ICP-MS	Porewater, major anions	Rhizon sample; ion-chromatography
Leachate, pH and alkalinity	Effluent sample; auto-titrator	Leachate, major anions	Effluent sample; ion-chromatography
Leachate, EC	Effluent sample; EC meter	Leachate, cations	Effluent sample; ICP-MS
pH and EC	Soil slurry sample; pH/EC meter	Initial and final soil, cations	Oven-dried soil sequential extraction and ICP-MS
Exchangeable cations	Oven-dried soil extraction and ICP-MS	Integrated soil moisture, timeseries	Laboratory balance
Plant, aboveground and root biomass	Oven-dried sample, balance	Plant, cation content (incl. potentially harmful elements)	Digested sample and ICP-MS

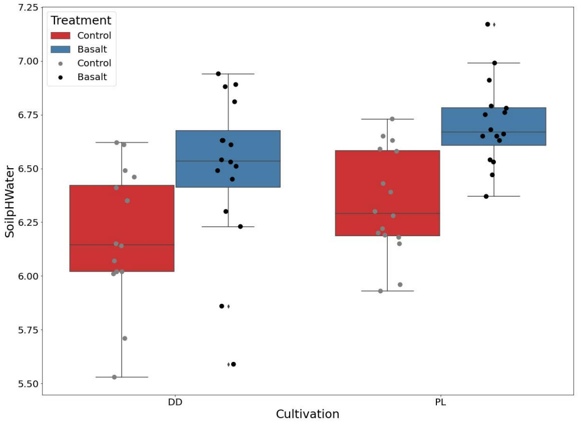
Summary of current measurements and analysis for UNDO MRV.

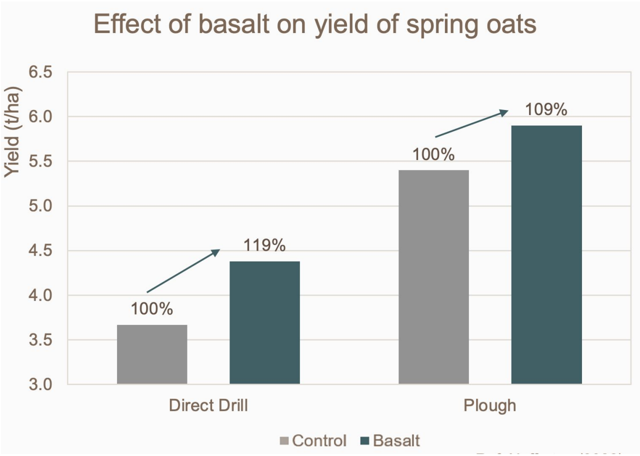
Co-benefits to Soils and Plants



The ERW process raises soil pH making existing nutrients more readily available. Basalt is rich in minerals that release macro- and micro-nutrients, and trace elements, that are essential for plant growth.

Data from first year of basalt application at Nafferton Farm - The University of Newcastle.





BASALT & LAND AVAILABILITY (UK)

- 49 active quarries with suitable byproduct identified
- Currently working with 3 (Breedon being our key partner)
- Approx 300K Hectares of suitable land within 30 miles of the quarries
- Global snapshot below capturing potential areas of expansion

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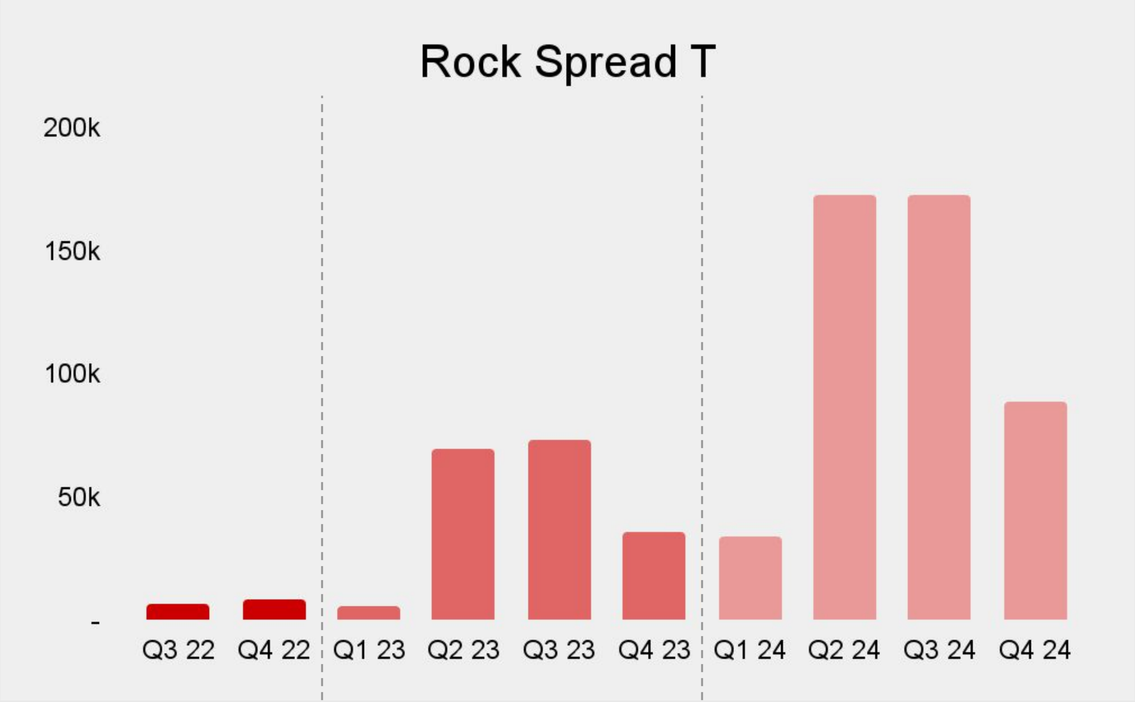
2023 185,000 T ROCK SPREAD = 40,000 T CO2E DELIVERED



FY22 - we spread over 30,000t of Basalt rock which will sequester just over 7k tonnes of CO2e.

FY23 - we plan to ramp that up to 200k tonnes of basalt deployment.

Seasonality drives uneven distribution of spreading

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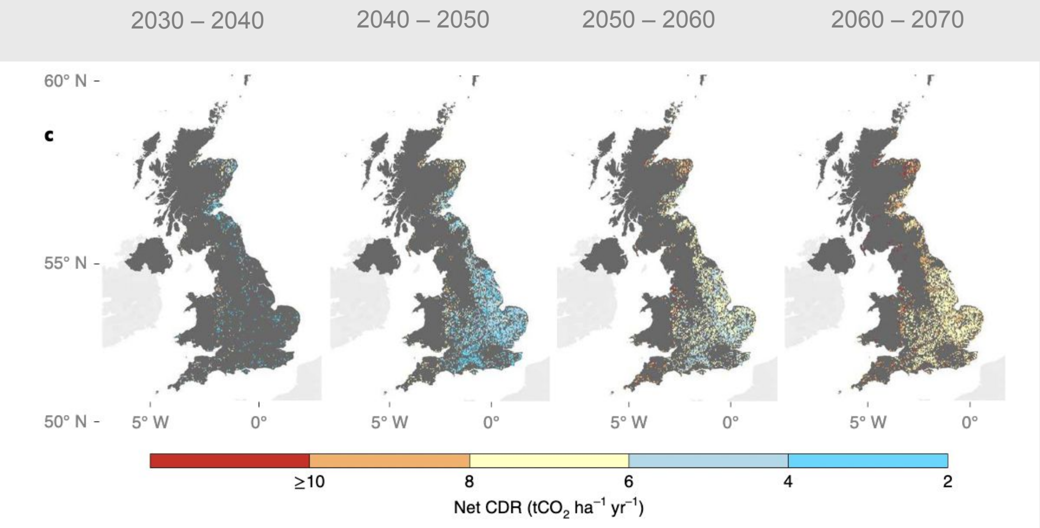
ENHANCED WEATHERING ON UK ARABLE CROPLANDS



Kantzas et al. (2022)

Carbon removal potential
6 – 30 Mt CO_2 per year by 2050

Potential for ~**45 %** of the removals required to meet the UK's net-zero emission targets

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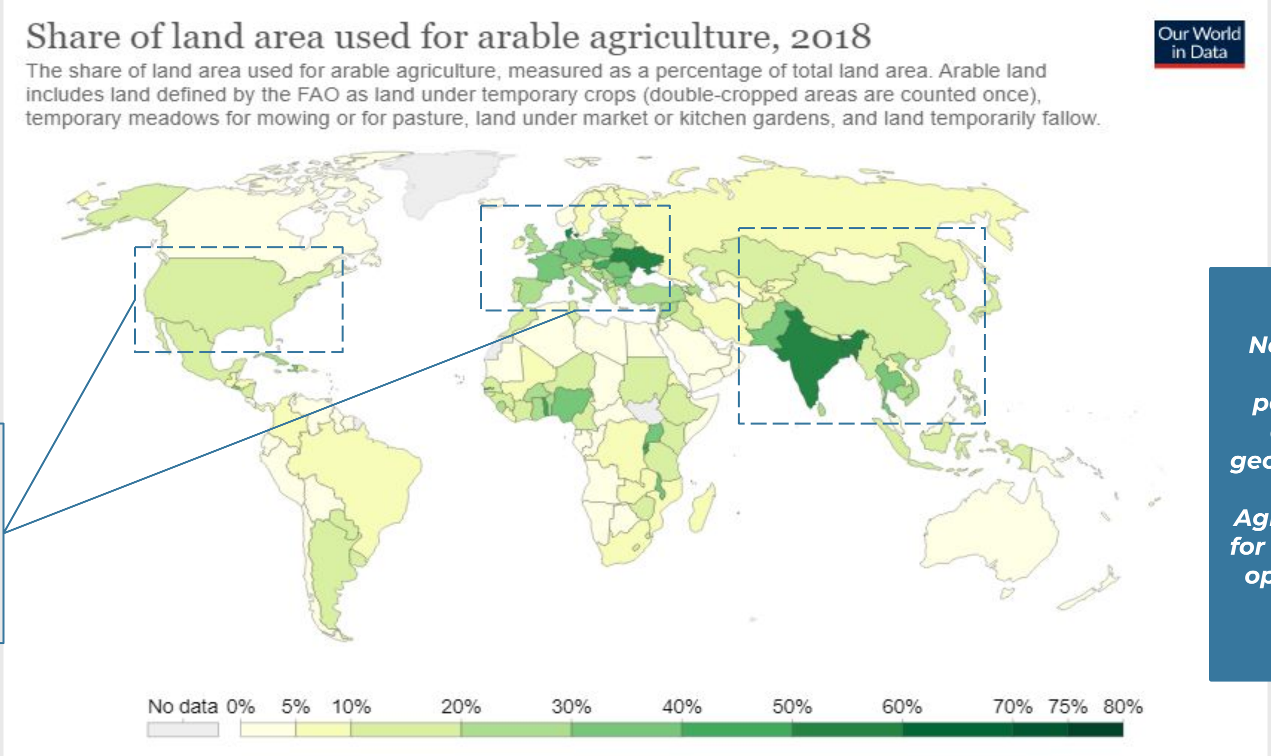
GLOBAL LAND AVAILABILITY



Both the UK, US and rest of Europe have high %'s of land used for agriculture, due to generally favourable climates and soil conditions

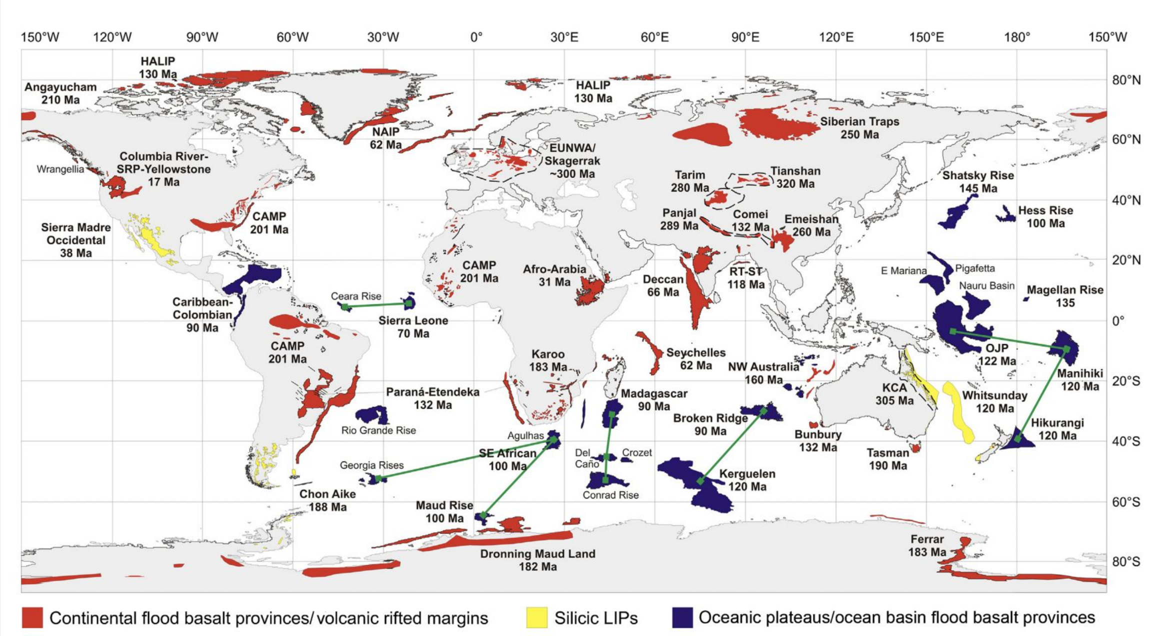
Not all land is suitable for agriculture, particularly cropland, due to climate and geographical constraints

Agricultural land is ideal for rock spreading as it is open land and farmers see co-benefits

GLOBALLY, ALMOST 40% OF LAND IS USED FOR AGRICULTURE

Source: UNDO Research, fao.org

POTENTIAL FOR SCALE - 2025

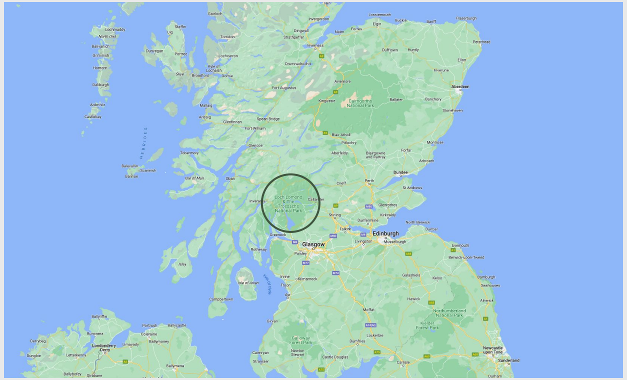


(Self et al. 2015)

BILLIONS OF TONNES OF BASALT GLOBALLY

4MT ROCK

1MT TCO_2E



200K HECTARES

[1]4MT rock @ 20T/HA = 200k Ha = 2000 square km = circle of radius 25.2 km

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OUR PARTNERSHIP MODEL

UNDO's partnership model empowers companies to leverage quarry by-products to remove carbon

UNDO	PARTNERSHIP	UNDO
Identify Rock Type XRD/XRF Testing of Rock Baseline Soil Predictive Model	Source Rock Haul Rock to Destination Spread Rock	Collect Data on Spreading LCA Measure in-Field Input Parameters to Model Carbon Sequestration Modelled Data Submitted & Verified Carbon Marketed Carbon Sold
UNDO establishes operation	Scope of partnership determines carbon share	UNDO verifies in-field weathering data to create & sell approved carbon credits through ISO & Puro (ICROA)

Source Raw Materials → Prepare & Transport → Capture Carbon → Record Data → Verify Carbon → Sell Carbon

TECH & EXPERTISE

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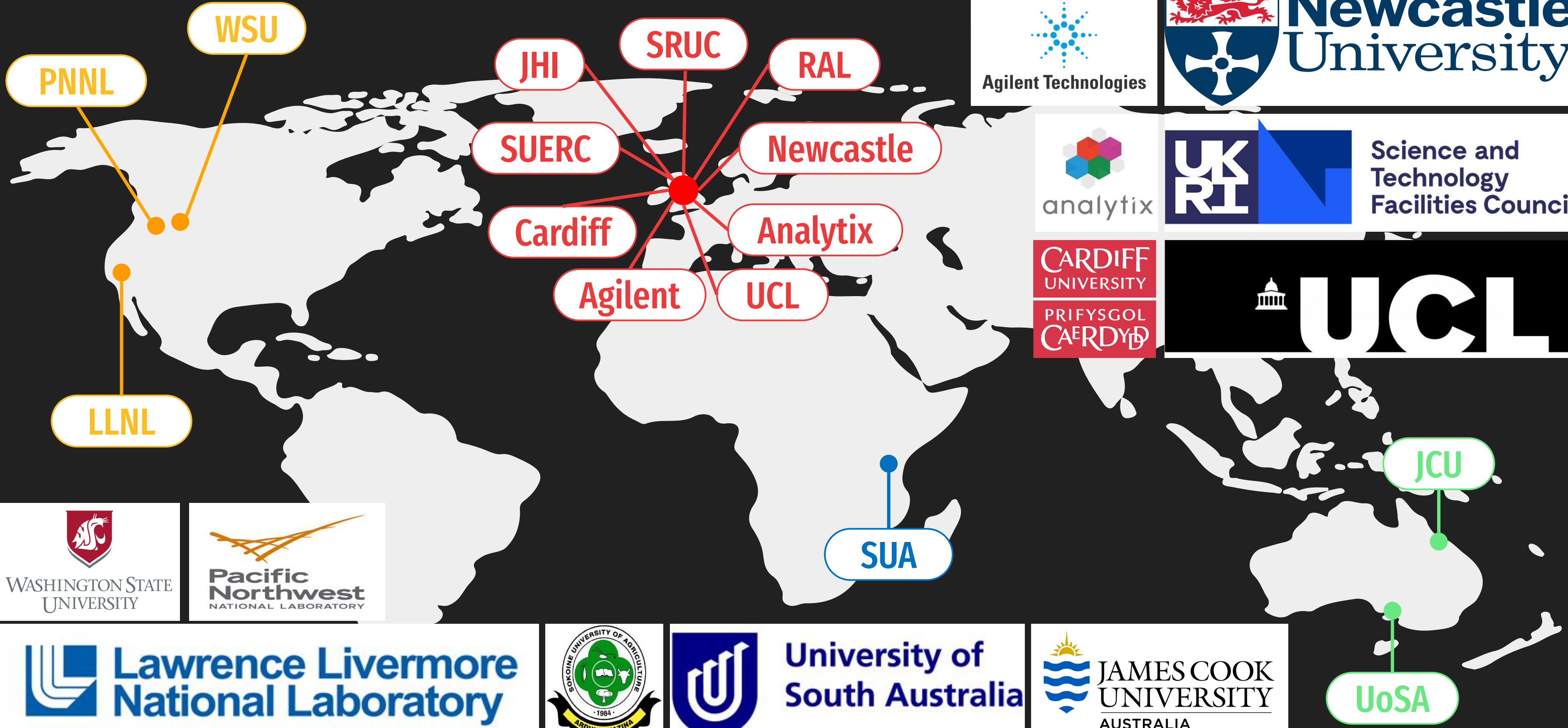
INTERNATIONAL PARTNERS



The James Hutton Institute

SRUC

SUERC Scottish Universities Environmental Research Centre

Agilent Technologies

Newcastle University

analytix

UKRI Science and Technology Facilities Council

Cardiff University Prifysgol Caerdydd

UCL

Washington State University

Pacific Northwest National Laboratory

Lawrence Livermore National Laboratory

Sokoine University of Agriculture · 1984 · Ardhi ni Hazina

University of South Australia

James Cook University Australia


THANK YOU
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