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Soil Carbon Accumulation and Carbon Capture and Sequestration under CORSIA



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- Opening
- Status update on ACT-SAF Programme
- AHG Soil Carbon Accumulation (SCA) in CORSIA
- Carbon Capture and Storage via Geological Sequestration (CCS) in CORSIA
- Q&A
- Closing



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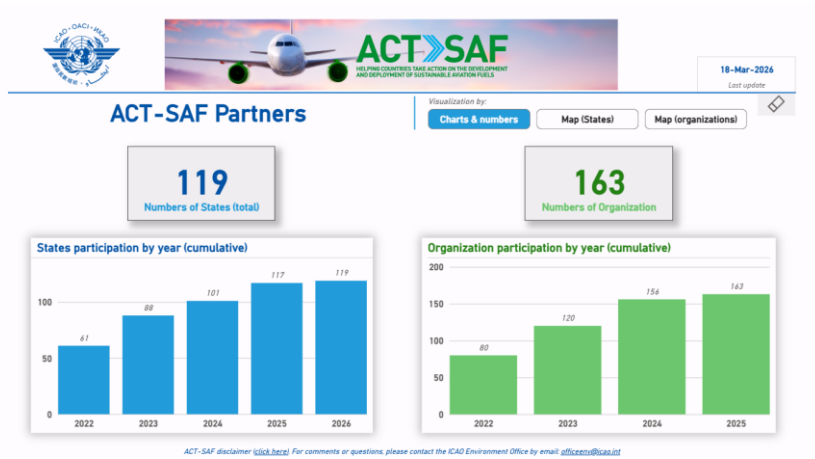


Status update of ACT-SAF Programme



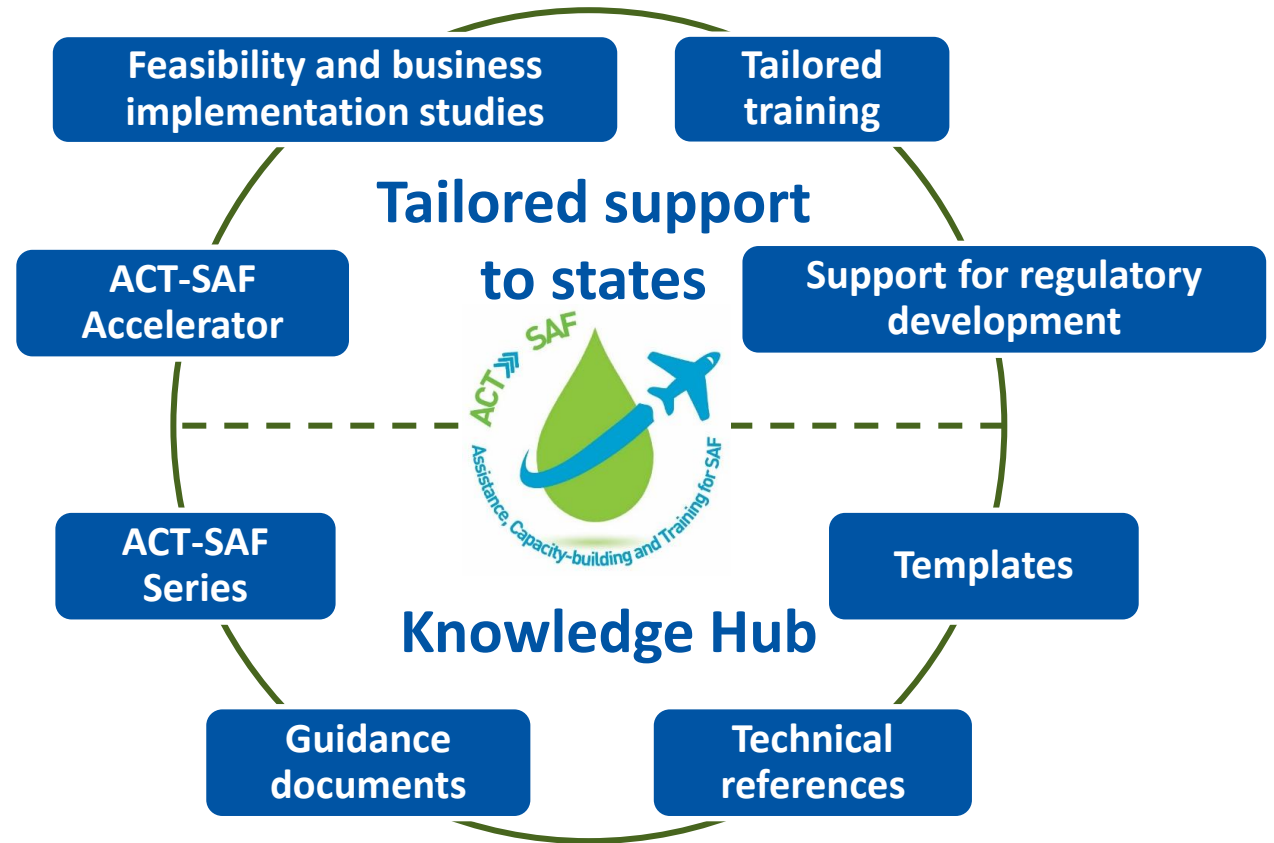


Over 280 ACT-SAF partners



www.icao.int/ACT-SAF

Two streams, eight elements





33 ACT-SAF studies

(17 concluded / 16 ongoing)

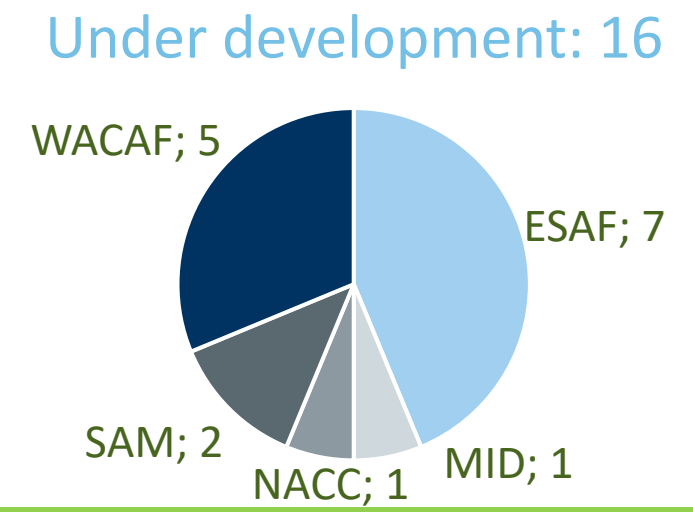
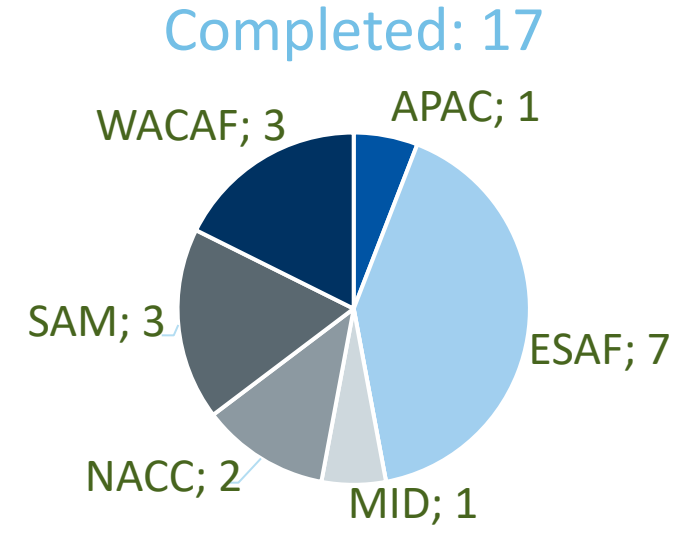
- 8 supporting states/organizations (France, Italy, Netherlands, Switzerland, United Kingdom, EU, Airbus and Volaris)
- 1 co-funded study (Angola/Italy)
- Recent contributions Republic of Korea and Spain will enable additional studies
- Austria and Côte d'Ivoire contributed towards other activities



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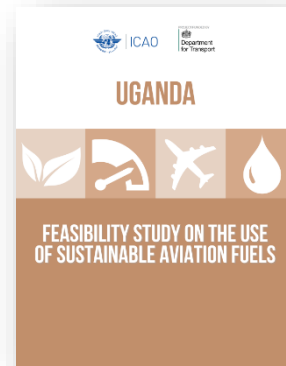


	Feasibility studies	Business implementation studies
Completed	<p>15</p> <p>Burkina Faso, Chile, Côte d'Ivoire, Dominican Republic, Ethiopia, Ghana, India, Jordan, Kenya, Panama, Peru, Rwanda, Trinidad & Tobago, Uganda, Zimbabwe</p>	<p>2</p> <p>Kenya, Rwanda</p>
Under development	<p>11</p> <p>Angola, Argentina, Cameroon, Egypt, Equatorial Guinea, Madagascar, Mauritania, Mexico, Mozambique, Namibia, Senegal</p>	<p>5</p> <p>Chile, Côte d'Ivoire, Ethiopia, South Africa, Zimbabwe</p>





Feasibility studies for Peru & Uganda published



Feasibility studies for Ghana & Panama delivered





AHG Soil Carbon Accumulation (SCA) in CORSIA





- ICAO and Soil Carbon Accumulation (SCA)
- SCA : an Introduction
- Main mechanisms that increase soil carbon accumulation
- Sustainable Agricultural practices and Biochar
- How is SCA considered in CORSIA: methodology
- Measuring SCA

Soil Carbon Accumulation and the ICAO SCA Methodology

- CAEP13: The Methodology was developed
- CAEP14 work is on Implementation

Soil Carbon Accumulation Methodology



CAEP13_FTG08_WP11
9/9/2024
English only

COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)

CAEP/13 FUELS TASK GROUP (FTG)

Eighth Meeting, Montreal, Canada
23 to 27 September 2024

Agenda Item : Core LCA

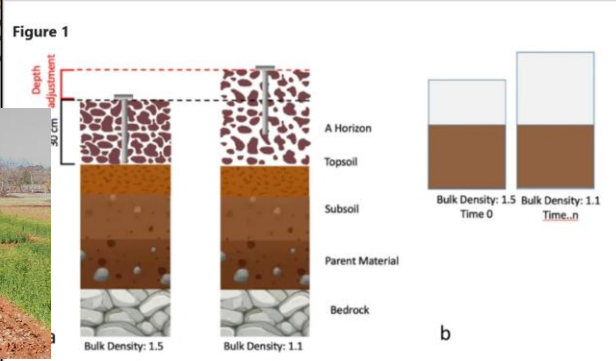
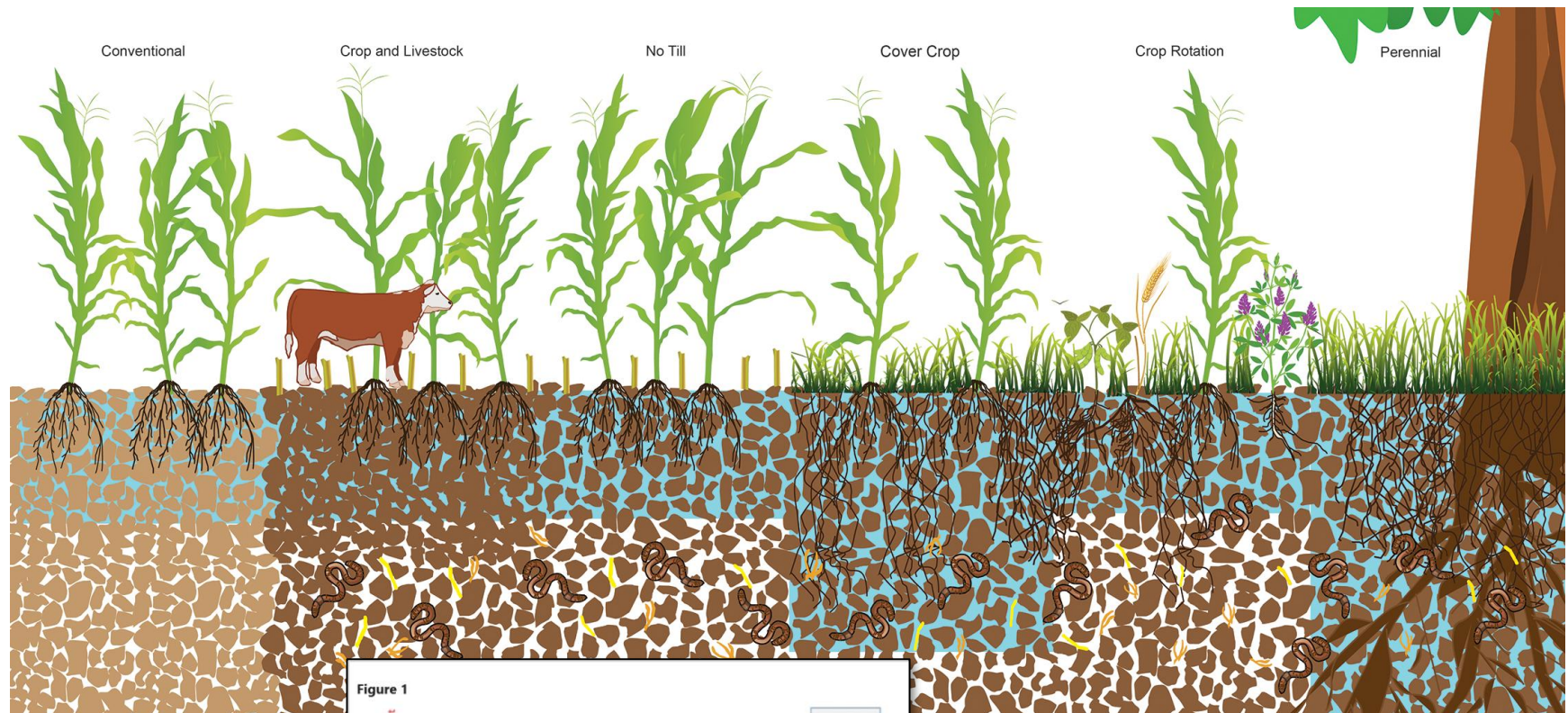
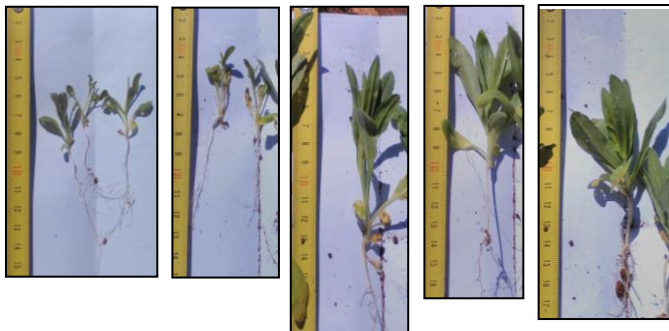
Potential method for inclusion of direct Soil Organic Carbon Accumulation from sustainable agricultural management practices

(Presented by small group on Soil Organic Carbon)

- The Methodology addresses “*fields that were already cultivated before 1st January 2008 (in accordance with the LUC rule established under CORSIA), or feedstocks produced in unused land..*”
- SCA effects related to Land Use Change (LUC) are thus not yet included in this methodology

Bringing organic C back to soil, and promoting soil health and fertility, are key elements for Sustainable Bioeconomy chains as BDR, Climate Positive fuels, Agroforestry, Agroecology, etc. fully aligned with EU Mission and policy on soil, contrast to desertification/erosion, promoting sustainable agriculture

Mineral 100% Biochar+
 No fertilization fertilization Compost Biochar Compost 10%



(a) Example of pedon alteration due to changes in bulk density over time showing the position of the soil sampling device from the soil surface to the same fixed depth. (b) Example of pedon after the correction showing the difference in air space, while the soil mass remains constant.

Comparing infiltration rates in soils managed with conventional and alternative farming methods: A meta-analysis
 Andrea D. Basche Marcia S. DeLonge

Sustainable agricultural practices

- Non-exhaustive exemplary list

- Reduced or zero-tillage.
- Improved crop rotation.
- Use of cover crops.
- Improved management of crop residues.
- Multicropping.
- Forestry-livestock-cropland integration.
- Sugarcane harvesting without burning.
- Use of organic soil improver (e.g. compost, fermented manure, digestates, biochar, etc.).



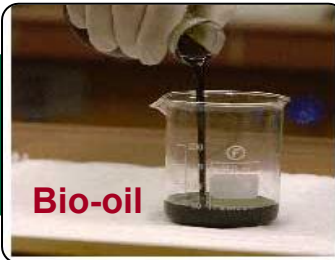
SLOW PYROLYSIS: THERMOCHEMICAL CONVERSION OF ORGANIC MATERIALS THROUGH HEATING IN ANAEROBIC CONDITIONS

PRODUCTS OF THERMOCHEMICAL CONVERSION

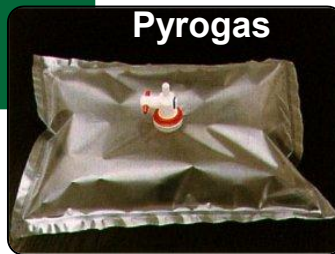
SOLID



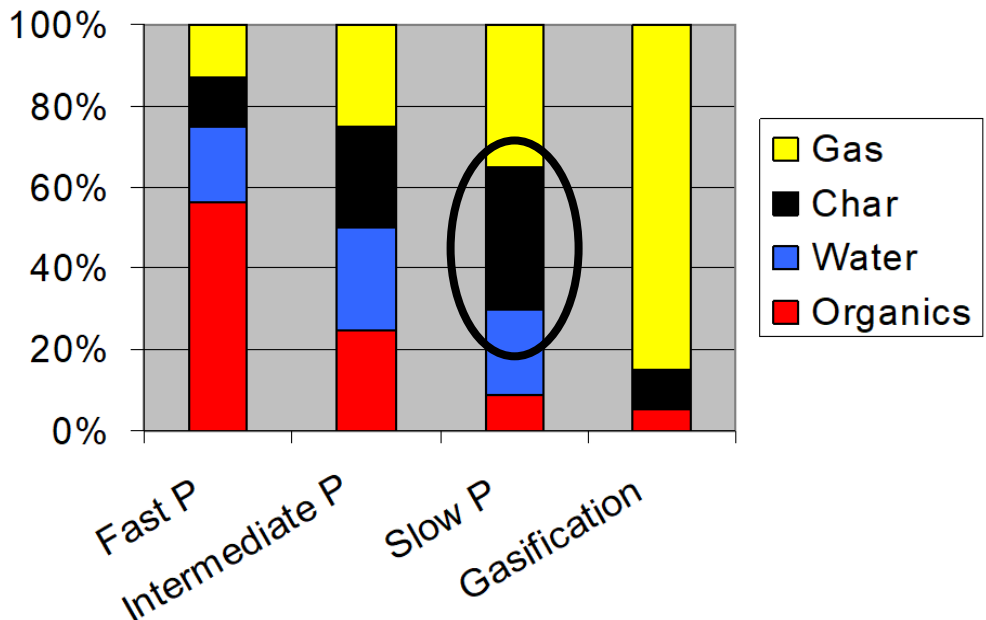
LIQUID



GAS

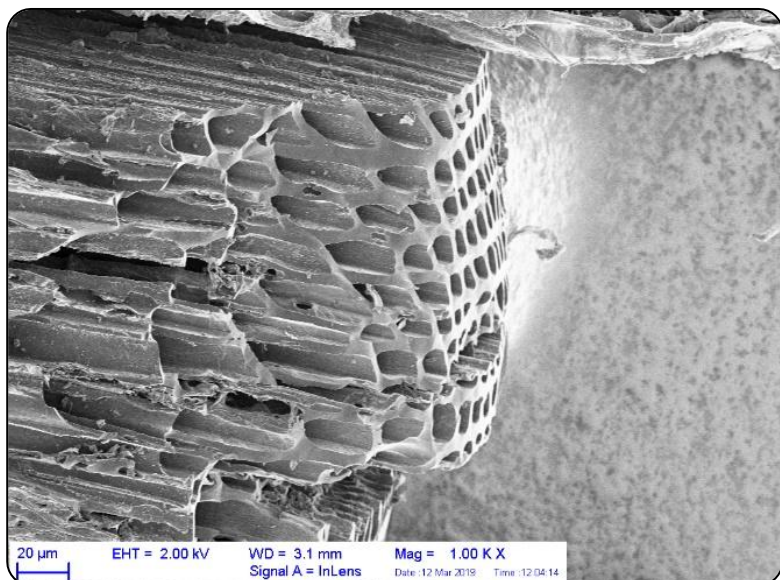


SLOW PYROLYSIS
 TYPICAL PROCESS TEMPERATURE: 400 ÷ 600 °C
 LONG RESIDENCE TIME OF SOLIDS AND VAPORS
 LOW HEATING RATE: 0,1 ÷ 2 °C s⁻¹
 PRODUCTS → CHAR + BIO-OIL + GAS

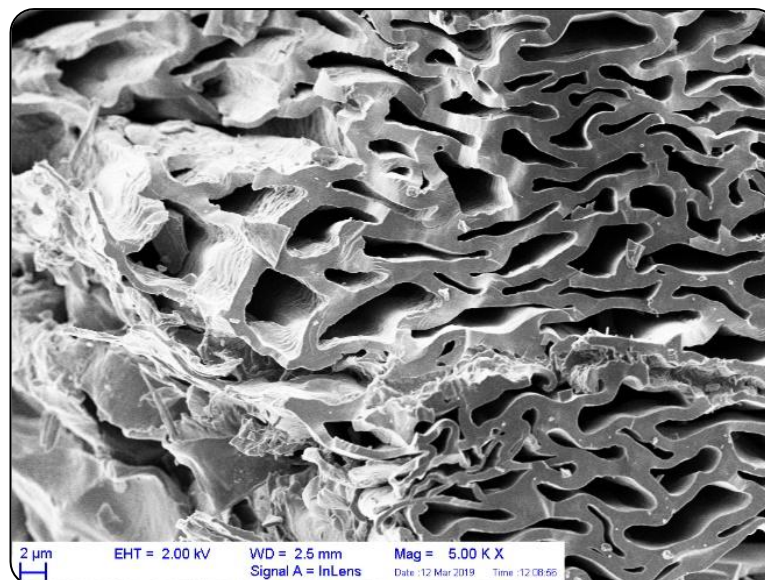


BIOCHAR IS A FORM OF PERMANENT CARBON REMOVAL (EC CRCF DA)

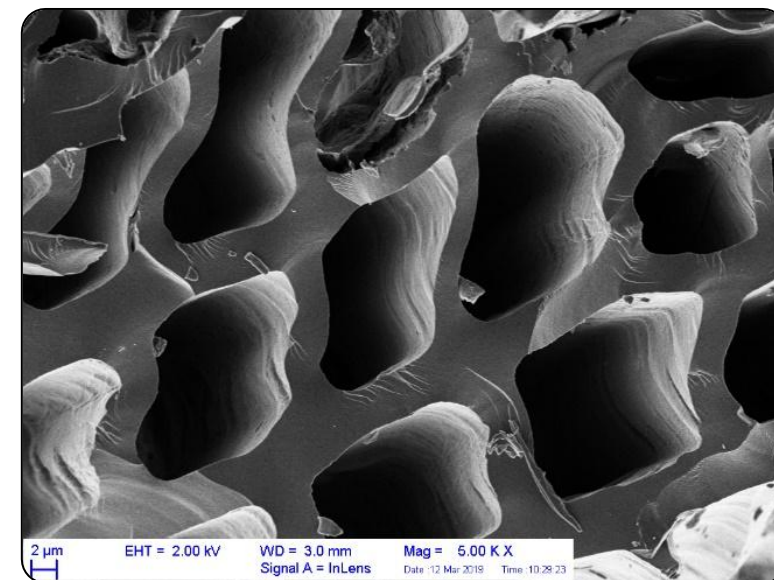
Agronomic characteristics of biochar



SLOW PYROLYSIS OF BLACK PINE – 1000X



SLOW PYROLYSIS OF POPLAR – 5000X



SLOW PYROLYSIS OF POPLAR – 10000X



- **HIGH MOISTURE RETENTION CAPACITY**
- **HIGH POTENTIAL TO LIMIT LEACHING OF NUTRIENTS**
- **SUITABLE HABITAT FOR MICROORGANISM GROWTH**
- **HIGH REACTIVE SURFACE (CEC AND AEC)**

How is SCA considered in CORSIA

- SCA is accounted through a factor named F^{SCA}
- F^{SCA} contributes to improve the GHG performances of the biofuel derived from the feedstock produced in the same field
- Different methods for Biochar and all other agricultural practices

- The annual emission saving claims associated with SCA (F^{SCA}) accounts for the impact of sustainable agricultural management practices on soil carbon stock changes.

- F^{SCA} factor** defined ($\text{g}_{\text{CO}_2\text{eq}}/\text{MJ}_{\text{CEF}}$) →

It is valid for all agricultural practices **except biochar**

- In case the production of SAF results in one or more co-products (fuels), the F^{SCA} value should be proportionally distributed (energy or any other input).

$$F^{SCA} = \sum_j \left[\frac{(CS_j^A - CS_j^R) * 44/12}{D * P_j} \right] \text{wable or any}$$

- Formula for the **Biochar** case:

- Baseline SOC** to be assessed for all sustainable agr (which is entirely considered additional)

$$(CS_j^A - CS_j^R) = 10^6 * \sum_p [BC_p * F_p^C * F_p^{perm}]$$
 - Crop yield assessed every year. SOC reassessed at interval ≤ 5 years

$$F^{SCA} = \sum_j \left[\frac{(CS_j^A - CS_j^R) * 44/12}{D * P_j} \right]$$

- The entire cultivated agricultural area considered for the calculation of a specific application case j must have a similar climate and soil type, as well as similar management history in terms of tillage and carbon input to soil.
- Grouping fields:
 - Those fields that have the same soil and climate characteristics, similar management history in terms of tillage and carbon input to soil, and that will be subject to the same improved management practice may be grouped, including those fields belonging to different farmers. Only fields belonging to the same SAF supply chain can be grouped.
- CS^R and CS^A must be based on measurements of soil carbon stock at farm level
 - Measurements to establish the new soil carbon stock values, CS^A , will then be carried out at regular intervals, no > 5 years. New measurement in case of disturbances (e.g. flooding)
- Biochar excluded from this.

$$F_{\text{SCA}}^{\text{SCA}} = \sum_j \left[\frac{(CS_j^A - CS_j^R) * 44/12}{D * P_j} \right]$$

- Models can also be used to estimate CS^A in the considered period D.
 - Only models calibrated using the latest measured values of CS^A and the latest data on crop yield will be used.
 - The model and its calibration will be validated by the Sustainability Certification Schemes (SCS) during the sustainability certification process.
 - Calibration repeated at each assessment of CS^A and/or crop yield, or following a disturbance event such as fire or flooding (with the exclusion of the case of biochar).
- First validation of SCA models will occur after 5 years from CS^R definition.
- SCS to produce a detailed publicly available report.

- F_p^C is the organic carbon content of biochar for each production type p , measured in tonnes of carbon per tonne of biochar dry matter (t_C/t_{BCdm})
- F_p^{perm} is the durable carbon share, defined as the fraction of biochar carbon for each production type p remaining after 100 years, measured in tonnes of sequestered carbon per tonne of carbon content in biochar; dry matter ($t_{seqC}/t_{C,BC,dm}$)
- F_p^C can be directly measured from representative samples of biochar, while F_p^{perm} can be estimated based on the ratio of hydrogen to organic carbon (H/C_{org}), or the fixed Carbon, or techniques as Random Reflectance (Ro%), or a combination of these, all directly measured from representative collected samples of biochar.
- Eligible biochar will be limited to biochar produced from biogenic feedstocks and biogenic residues generated from the same field that is producing the feedstock for SAF, as well as biochar from organic wastes.
- Soil sampling not required, being not representative for biochar (unsuited for quantitative assessment of a concentrated form of Carbon)
- The chemical-physical characteristics of biochar before use will be verified according to existing standards, and the biochar application mode and level in soil will be third-party audited during its deployment.

$$(CS_j^A - CS_j^R) = 10^6 * \sum_p [BC_p * F_p^C * F_p^{perm}]$$

$$(CS_j^A - CS_j^R) = 10^6 * \sum_p [BC_p * F_p^C * F_p^{perm}]$$

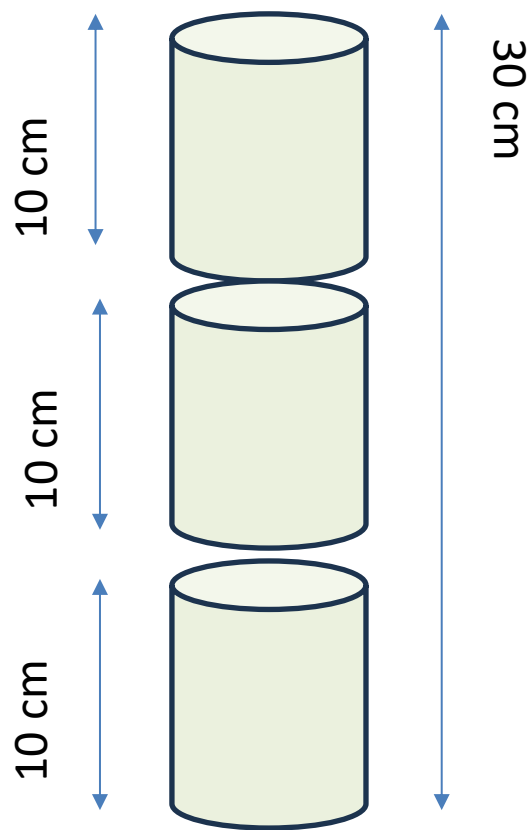
- The chemical-physical characteristics of biochar before use will be verified according to existing standards, and the biochar application mode and level in soil will be third-party audited during its deployment.
- Also, in order to prevent albedo effects, dispersion of the finest biochar particles in the atmosphere or spreading in the environment by flooding, biochar will have to be deployed in the soil and not above it. This will also maximize the agronomic effects (co-benefits) and ensure against risks of reversal through fires.

- Sustainable agricultural practices will be applied recurrently over every cultivation cycle (recurrent application of the practice), allowing that different sustainable agricultural practices may be applied to different crops within the same crop rotation, and generate SCA homogeneously distributed in agricultural land.
- The SCA variation will be accounted through soil sampling or the use of validated soil modelling, over the considered period D, with the exception of certified and in-soil deployed biochar.
- Biochar application can be carried out less frequently, and ideally only once at the beginning of the considered period D (so to reduce soil microbiota disturbances), or in combination with other operations on agricultural soil necessary in farming. However, the same considered period D will be used to evaluate the effect in terms of CEF emission reductions.

CCF – Carbon Correction Factor

- In order to consider the possibility of partly underperforming SCA projects, and reduce the impacts from modelling errors, a Conservative Correction Factor CCF of 15% reduction will be applied to the obtained value of F^{SCA} .
 - This will be matter of analysis in the current SCA AHG during CAEP 14
- The economic operator will recalibrate the CCF if actual testing carried out at time no longer than 5 years shows the over performance/under performance of the F^{SCA} .
- The CCF will not be considered in the case of biochar amendment use in soil, since the F_p^C and the F_p^{perm} factors already consider the fraction of carbon expected to remain sequestered in the soil.

- SOIL SAMPLING → **UNDISTURBED (INTACT) CORE METHOD: METAL RING** PRESSED IN THE GROUND (*JRC, 2018*).
- **3 CONSECUTIVE SUB-SAMPLES** COLLECTED AT THE **SAME SAMPLING POINT: 0–10 CM, 10–20 CM, AND 20–30 CM**.
- IMMEDIATELY AFTER EXTRACTION, THE THREE SAMPLES WERE PLACED TOGETHER IN THE SAME LABELED PLASTIC BAG.



THREE SUB-SAMPLES IN THE SAME BAG.



BULK DENSITY DETERMINED ON THE RAW SOIL MATERIAL AS COLLECTED IN THE FIELD (ISO 11272:2017):

- **SOIL VOLUME** = SUM OF THE 3 CYLINDER VOLUMES
- **SOIL WEIGHT** (INCLUDING STONES AND PARTICLES HIGHER THAN 2 MM) TAKEN AFTER DRYING THE SOIL SAMPLE

Soil sampling

- Soil sampling procedures and methods for both soil carbon content measurement and determination of soil dry bulk density will be defined by guidelines, best practices, or protocols as required in the jurisdiction that at minimum, observes the approach for collecting statistically representative soil samples as specified below; changes in bulk density over time will be considered. Soil samples will be dried, sieved, and grinded to measure their carbon content.

A statistically representative soil sampling method will:

- a) be applied to each field of the application case;
- b) consider a suitable number of samples per hectare, to be grouped, homogenized and used for measurement;
- c) consider sampling to take place in the first 30 cm of the soil or in different soil depth, considering the variation of soil bulk density due to the implementation of the sustainable agricultural practice;
- d) consider an appropriate time for sampling (i.e. before soil cultivation and fertilization or well after harvest), to be maintained for successive measurements, in order to have them under identical condition (i.e. soil moisture);
- e) provide thorough documentation of the process used.

- ✓ *The methodology to define a statistically representative soil sampling will be defined by the Sustainability working group, in close collaboration with the certification bodies and Sustainable Certification Schemes, and reported in the SCS.*
- ✓ *Soil sampling after deployment in soil will not be necessary for the case of biochar, given the long-lasting nature of its recalcitrant Carbon fraction share F_{perm}*

Other elements

- Energy allocation methods will be used to allocate the share of emission savings from SCA to all products and co-products, in proportion to their contribution to the total energy content (measured as LHV, Low Heating Value).
- Emission will not be allocated to wastes, residues and by-products that result from the CEF supply chain of interest.
- The LCA methodology considers the nature and the process emission of all the feedstock and components used in the agronomic phase.

Some examples of open issues

- How to update the list of sustainable agricultural practices: how to apply, how to decide?
- How to determine the baseline?
- Use of models and their validation



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Carbon Capture and Storage via Geological Sequestration (CCS) in CORSIA



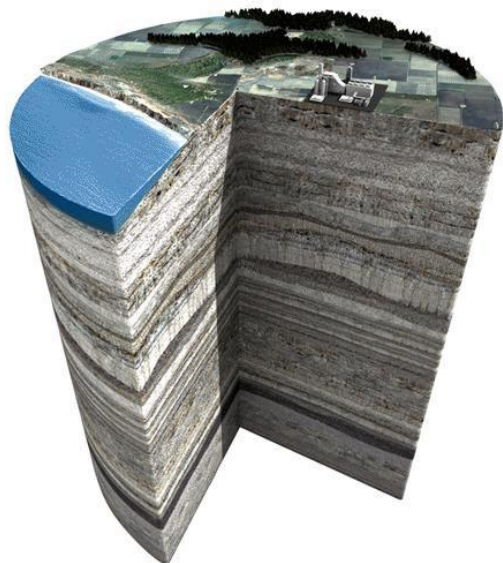
GEOLOGICAL CCS BASICS

FUNDAMENTALS OF CO₂ STORAGE

FINAL TECHNOLOGICAL STEP IN CCS – ISOLATING CO₂ FROM THE ATMOSPHERE

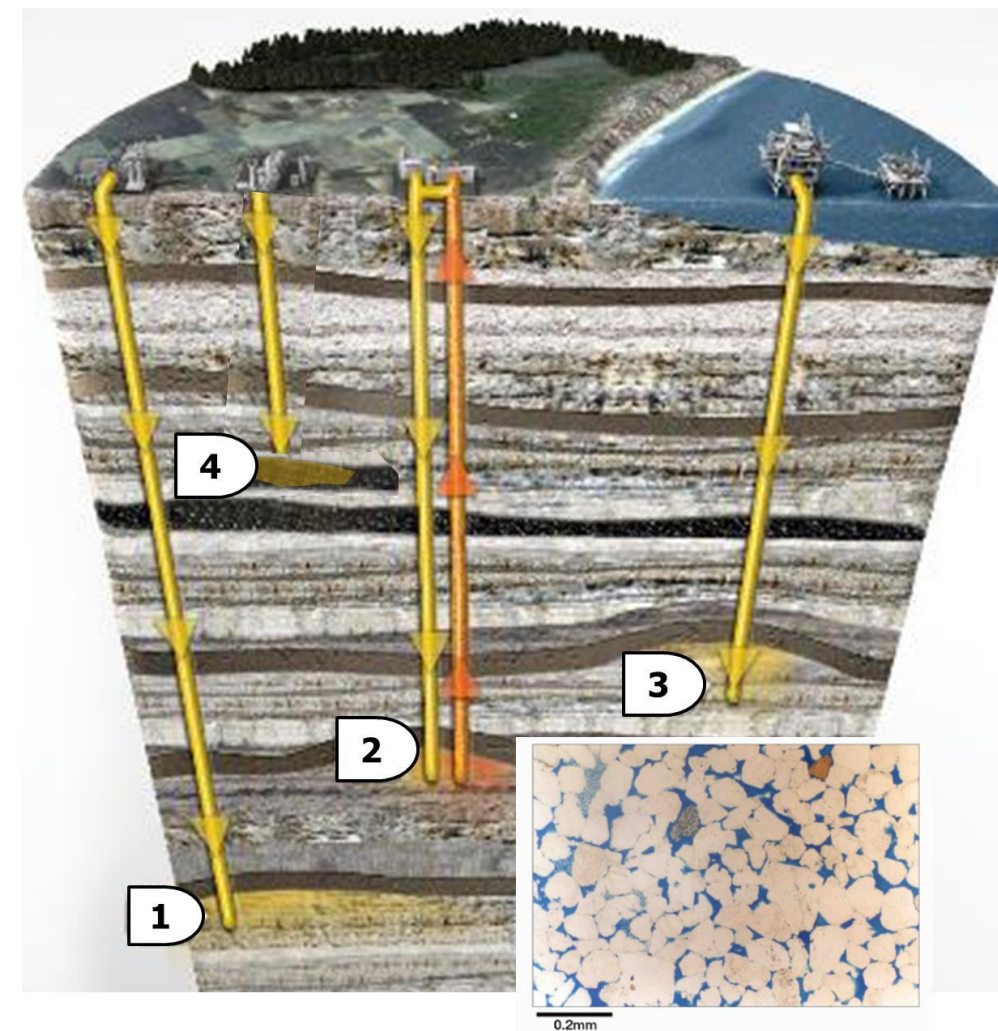
Requirements

1. GEOLOGICAL COMPLEX
 - Reservoir, seal, and trap
2. CAPACITY AND INJECTIVITY
 - Ability to inject CO₂ at required rate
 - Permanently store all required CO₂
3. DEPTH
 - Greater than 800 m*
4. ACCESSIBLE

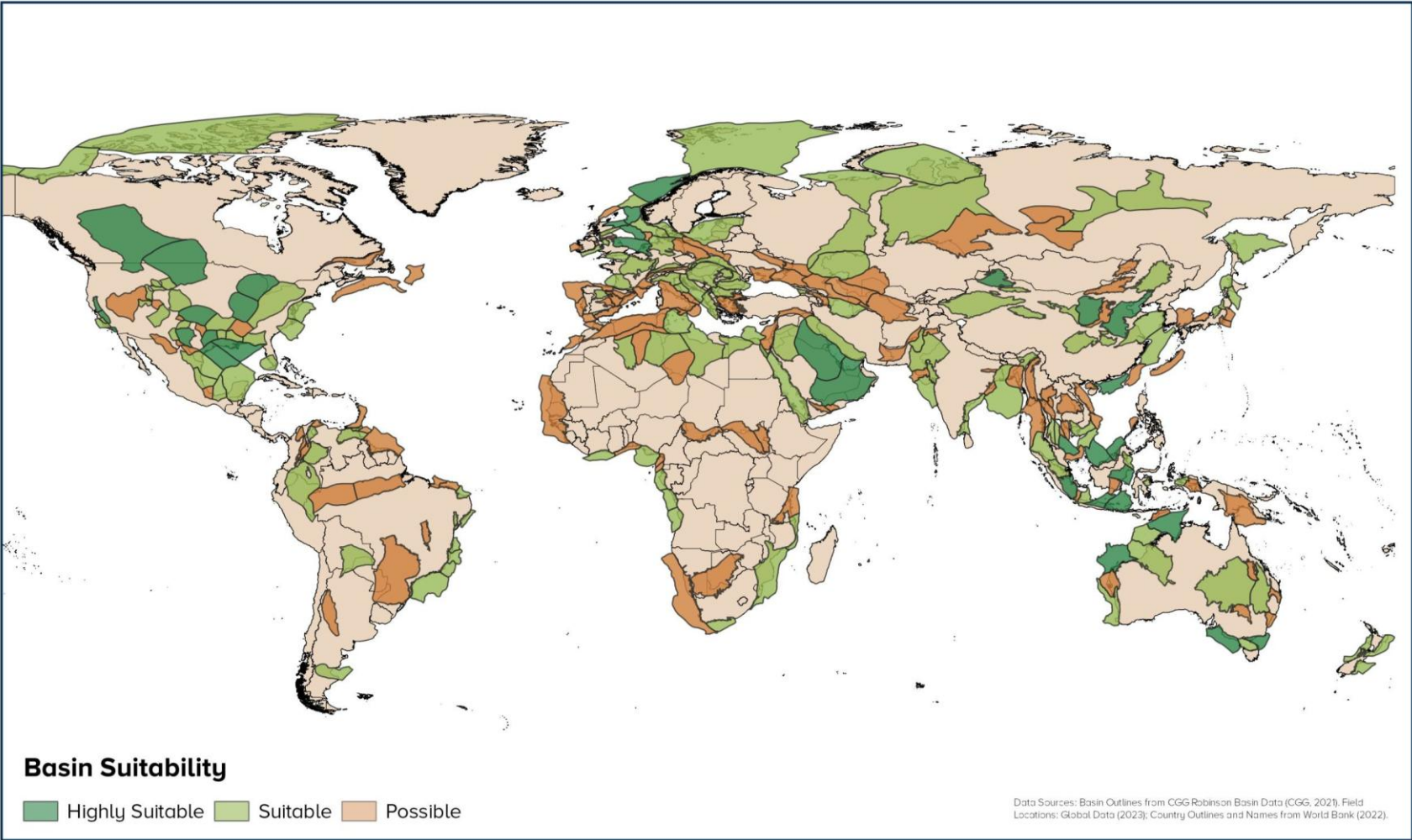


CO₂ STORAGE TARGETS

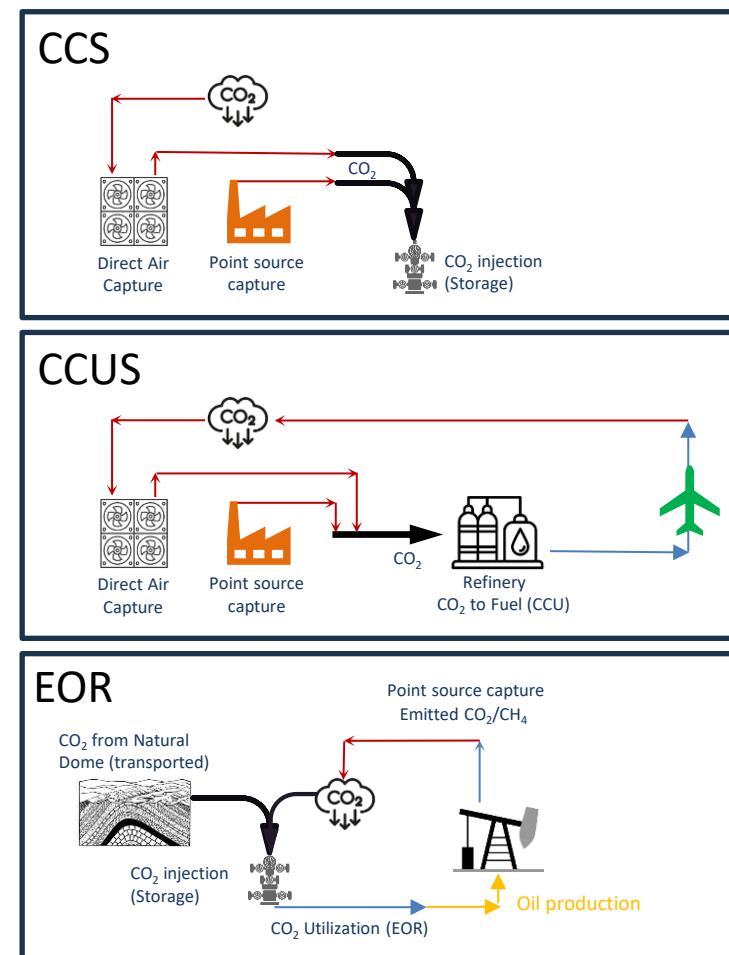
1. DEEP SALINE FORMATIONS
2. ENHANCED OIL RECOVERY
3. DEPLETED OIL AND GAS FIELDS
4. MINERAL CARBONATION



SUITABLE GEOLOGY IS GLOBALLY DISTRIBUTED

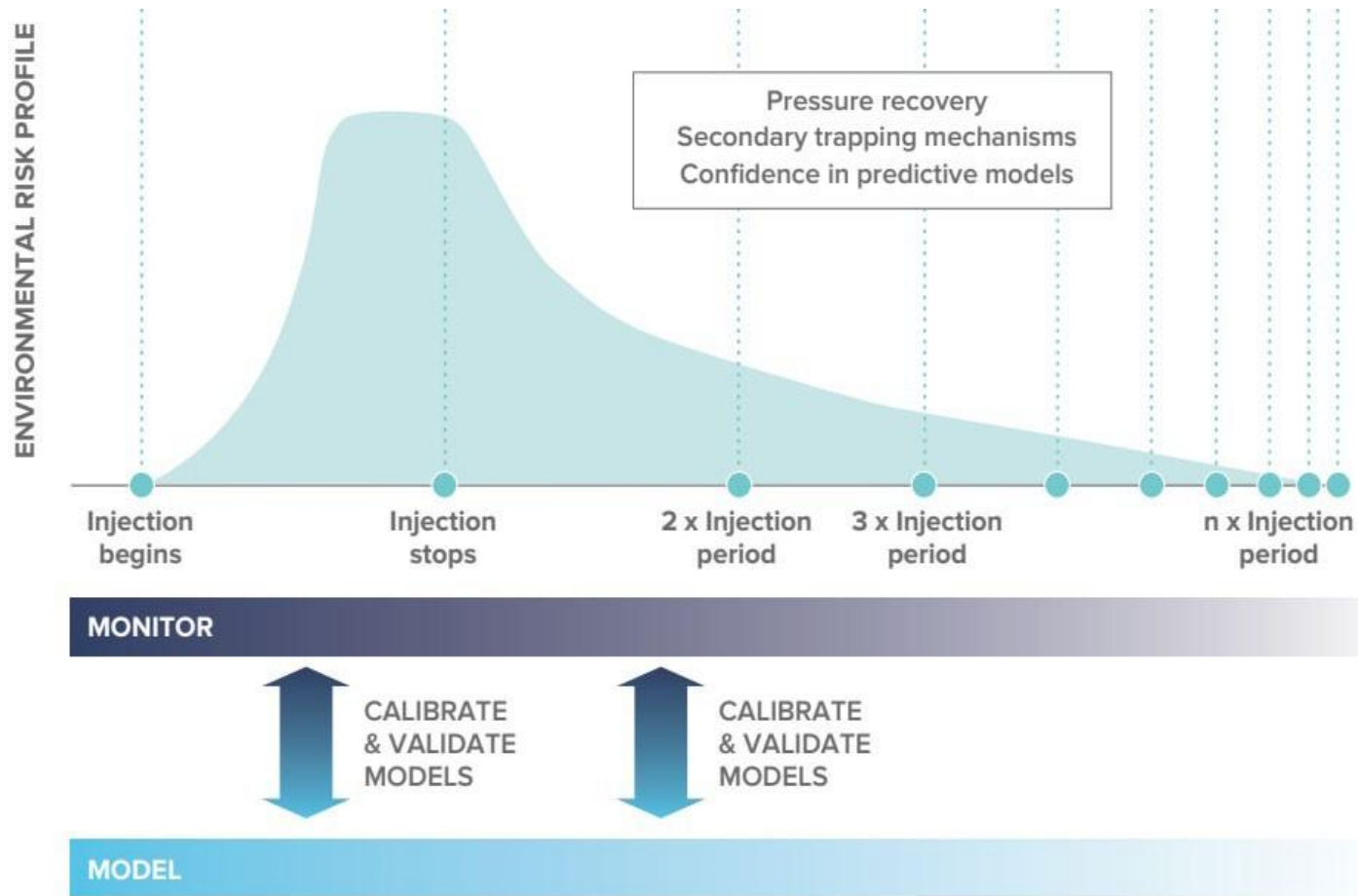


- Carbon capture and sequestration (or storage) – CCS
 - Current focus is geological storage of CO₂
 - Involves injection into deep underground formations, treating CO₂ as a waste to be kept out of the atmosphere forever
- Carbon capture and utilization/sequestration (or storage) – CCUS
 - Captured CO₂ is used for a commercial product (utilized)
- Enhanced oil recovery – EOR
 - Captured CO₂ is injected into aging oil reservoirs to lower the viscosity of oil and increase petroleum production, leaving some gas trapped underground



Current CORSIA requirements ONLY allow credit for geological CCS

Life-cycle risk profile for CO₂ storage



CO₂ leakage poses a risk to:

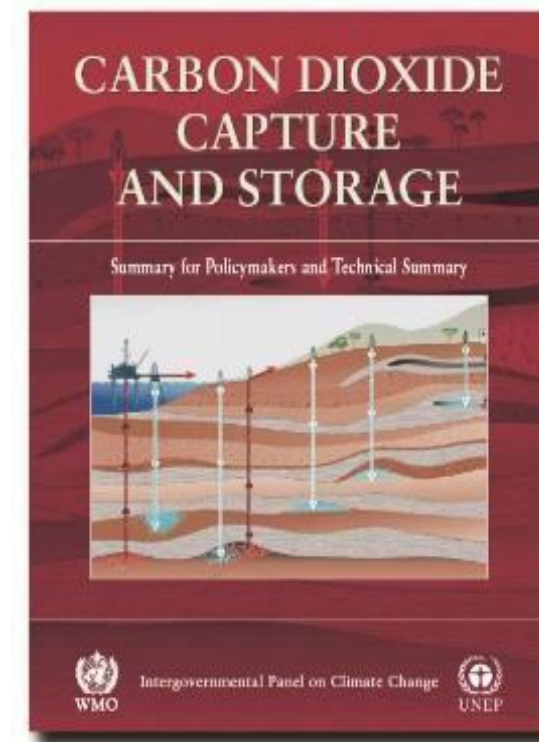
- the technologies position as a credible mitigation solution;
- maintaining a high standard of protection for the environment / human health;
- financial exposure if CO₂ leakage takes place under a carbon crediting scheme.

Evolution of leakage risk

- The lifecycle risk model highlights the level of CO₂ leakage risk over the course of a CCS project lifecycle.
- The risk of leakage rises throughout projects injection phase, before reducing considerably as pressure in the storage site reaches its maximum when injection stops and site closure.
- This lifecycle approach and risk allocation has informed many of the existing CCS regulatory models to date.

IPCC Special Report on CCS (2005)

- “Observations from engineered and natural analogues as well as models suggest that the fraction retained in appropriately selected and managed geological reservoirs is very likely to exceed 99% over 100 years and is likely to exceed 99% over 1,000 years. ”
- “For well-selected, designed and managed sites, the vast majority of the CO₂ will gradually be immobilized by various trapping mechanisms and, in that case, could be retained for up to millions of years. Storage could become more secure over longer timescales. ”



GEOLOGICAL CCS REQUIREMENTS UNDER CORSIA

Key Principles

- Emission reduction (LCA)
- System boundaries
- Permanence
- Site characterization
- Sustainability

Geological CCS Requirements are in the CORSIA Methodology for Calculating Actual Life Cycle Emissions Values



- Section 2.2.2 – System boundary, expected leakage estimation
- Section 3.1 – Site-specific data requirements for processors, expected leakage, sustainability certification requirement
- Section 11 – Requirements for a robust regulatory regime, reserve inventory account, reserve deposit amount, and verifiable reversal

Section 2.2.2 - Carbon capture and sequestration of CO₂ emissions



- **System boundary –**
 - “Emissions must be captured directly from the lifecycle stages of CEF production to be considered for such reductions.”
- **The processing facilities of carbon capture and storage include the capture unit (incl. purification, and compression), transportation (incl. transfer stations and CO₂ pipelines), injection, and the storage site.**

Section 2.2.2 - Carbon capture and sequestration of CO₂ emissions



- **Expected leakage estimation subtracted from the storage benefit for LCA value.**
 - At a minimum, the following must be considered in this calculation:
 - (1) Risk of leakage occurrence: geological uncertainties, seismic activity, man-made activities, storage activities, storage management and monitoring, ground movement (incl. uplift and subsidence), ground water contamination;
 - (2) magnitude of leakage; and
 - (3) leakage pathways: geological, man-made, injection-related.
 - Expected leakage from the storage reservoir can be reduced according to the expected success of mitigation activities, although the emissions of material and energy inputs associated with such measures must be accounted for.

Section 3.1.i – Additional relevant data to be reported to ICAO



- 1) Point of capture, capture technology, capture efficiency, quantity of CO₂ captured, location of the storage reservoir, and transportation processes
- 2) Site-specific details on the assessment of leakage risks over a 100-year period, including:
 - 1) Site-specific characterization of reservoir
 - 2) CO₂ plume modeling of both extent and predicted movement
 - 3) Secondary effects of CO₂ sequestration
 - 4) Measures to manage, monitor, and minimize leakage risks
- 3) Expected leakage re-assessed at least every 5 years
- 4) CCS processing facilities subject to full sustainability certification - in addition, the restrictions on land use and land use conversion in Sustainability Criteria 2.1, 5.1, and 7.1 will apply to CCS processing facilities in addition to the feedstocks.

Approved CCS requirements addressing sustainability



Eligibility Framework

- Economic operator definition:

Economic operator. Economic operators include feedstock producers, **processing facilities**, and traders upstream of and including the blending point.

CORSIA Economic Operator

An entity required to be certified according to CORSIA Sustainability Criteria



LCA Methodology Document

- Section 2.2.2) The **processing facilities** of carbon capture and storage include the capture unit (incl. purification, and compression), transportation (incl. transfer stations and CO2 pipelines), injection, and the storage site.
- Section 3.1.i) CCS **processing facilities** are subject to full certification to the CORSIA Sustainability Criteria, and in addition, **the restrictions on land use and land use conversion in Sustainability Criteria 2.1, 5.1, and 7.1 will apply to CCS processing facilities in addition to the feedstocks.**



Specific Sustainability Criterion for Emissions Reduction Permanence



3. Greenhouse gas Emissions Reduction Permanence

Principle: Emissions reductions attributed to CORSIA SAF should be permanent.

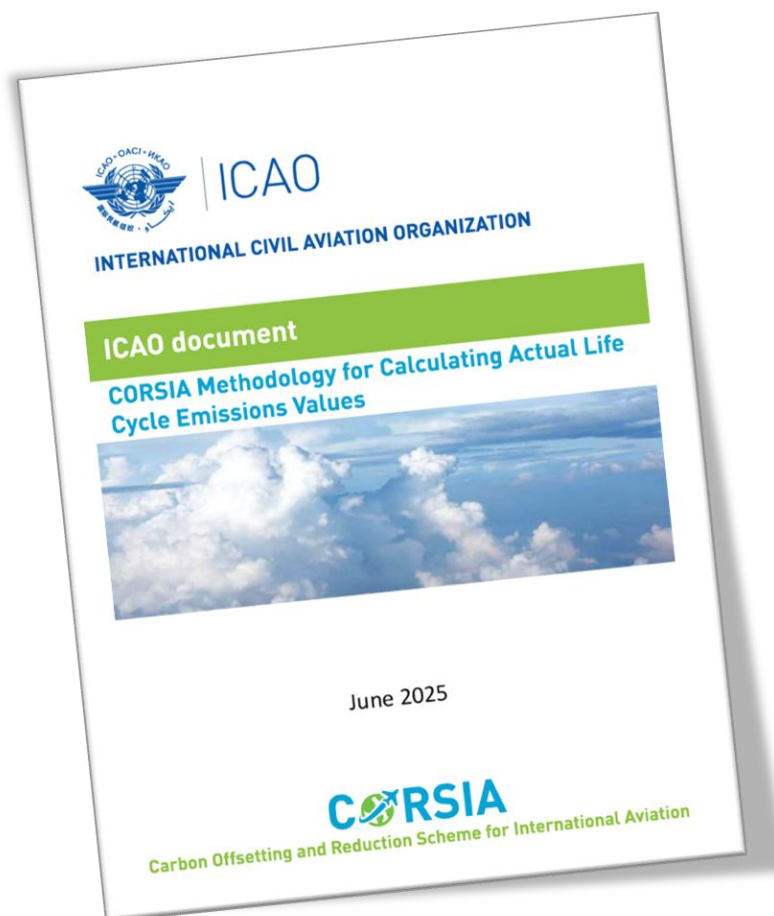
Criterion 3.1: Operational practices will be implemented to monitor, mitigate and compensate any material incidence of non-permanence resulting from carbon capture and sequestration (CCS) activities.

Section 11 – Requirements for Geological CCS monitoring, mitigation, and compensation of impermanence



- **Section 11 – Requirements for Geological CCS monitoring, mitigation, and compensation of impermanence**
 - 11.1 Regulatory Scheme CORSIA Eligibility Requirements – will demonstrate compliance with a regulatory scheme that meets the eligibility requirements outlined.
 - 11.2 Reserve inventory account (RIA) – covers potential estimated net leakage

Section 11.1 Regulatory Scheme CORSIA Eligibility Requirements for CCS Geological Sequestration Projects



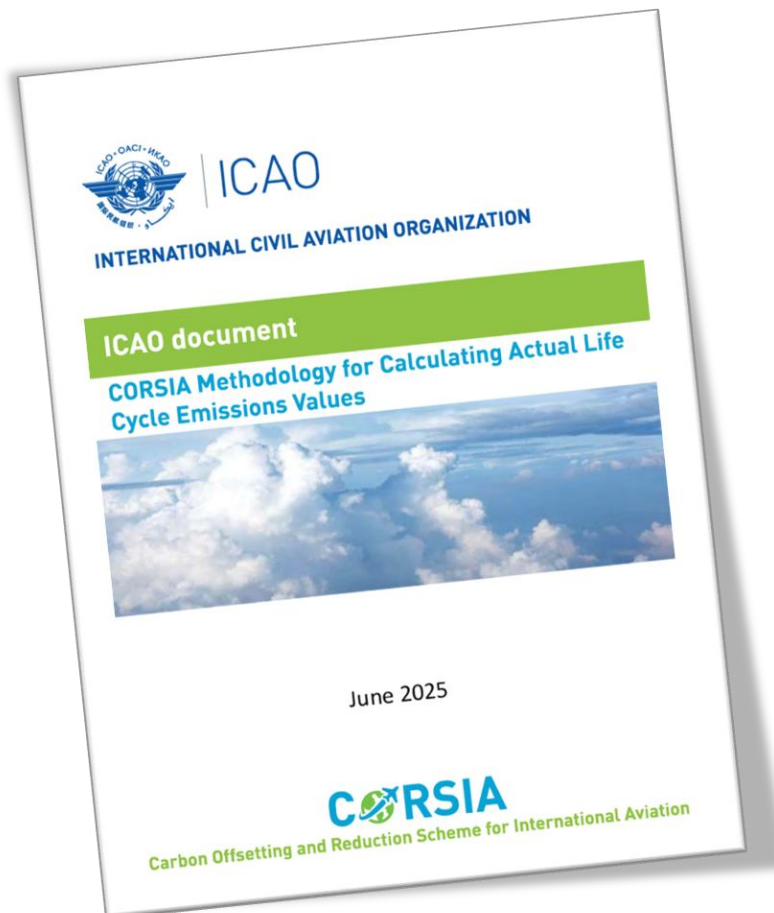
- Proposed requirements based on existing studies of comprehensive CCS regulatory frameworks
- Example regulatory frameworks that meet or exceed the requirements are listed
- Projects complying with an Eligible Regulatory Scheme meet the first requirement
- Other regulatory frameworks can be assessed by SCSs and/or can be added to example list over time

LCA Methodology document: <https://www.icao.int/CORSIA/corsia-eligible-fuels>

Elements of Eligible Regulatory Schemes

- 1. Carbon Dioxide Stream Characterization*
- 2. Site Selection and Characterization*
- 3. Storage unit Adequacy*
- 4. Demonstration/Verification of Secure Storage*
- 5. Area of Review (AoR) Delineation and Modeling*
- 6. Leakage Pathway Assessment*
- 7. Well Construction and Completion*
- 8. Well Operation*
- 9. Testing and Monitoring Plan*
- 10. Emergency and Remedial Response Plan*
- 11. Post-Injection Site Care (PISC)*
- 12. Injection Well Plugging*
- 13. Site Closure*
- 14. Financial Assurance*
- 15. Safety and Environmental Protection*
- 16. Induced Seismicity*

11.2 Complementary measures to monitor, mitigate, and compensate: Reserve Inventory Account



- Additional carbon is stored beyond that required to achieve the calculated emissions reductions
- Based on Core LCA calculation of expected net leakage
- In the event of a verifiable reversal, the corresponding amount of reserved carbon will be retired from the Reserve Inventory Account to compensate for the leakage, leaving CORSIA CEF claims unaffected.

CCS sustainability in CORSIA to date

- Ensures full sustainability certification of all economic operators engaged in CCS.
- Additional requirements for application of robust regulatory elements provides further assurance of proper site preparation, injection execution, and management.
- Permanence buffer in form of LCA requirements (i.e., prediction of leakage and crediting only for anticipated permanent storage) and RIA.
- Further work ongoing to ensure long-term permanence.





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