Report

2nd Workshop on Carbon Stability of Hydrochar – v2 20/03/2026

Hydrochar Network – 3 March 2026

1. Objective of the Workshop

The workshop aimed to refine the **Draft Protocol for measuring the carbon stability of hydrochar under abiotic storage conditions**. The protocol investigates hydrochar ageing under controlled conditions:

- dry hydrochar
- sealed bottles

The ultimate goal of this initiative is to develop a **standardized methodology** enabling cross-laboratory comparison and the implementation of a future **interlaboratory ring test**.

2. Workshop Structure

Participants were divided into five breakout groups moderated by:

- Silvia Román Suero
- Małgorzata Wilk
- JaeWook Chung/Judy Libra
- Changyoon Jeong
- Fabiano B. Scheufele

Each group discussed **the same set of open points of the Draft Protocol**, following a shared template.

The results were then presented and compared during the plenary discussion.

3. Discussion Outcomes by Protocol Section

3.1 Feedstock Type

Consensus

All groups agreed that the protocol should **not restrict the feedstock type** used for hydrochar production.

Allowing any feedstock ensures that the protocol can be applied broadly across research groups.

However, participants emphasized the importance of **complete reporting of feedstock characteristics**.

Specific proposals from breakout groups

Some groups suggested introducing **reference feedstock categories**, including:

- lignocellulosic residues
- sewage sludge
- manure-derived hydrochars
- commercial hydrochar materials.

One group suggested that **commercial hydrochar products** could serve as useful reference materials for interlaboratory comparisons.

3.2 HTC Process Conditions

Consensus

Participants agreed that the protocol should remain **independent of HTC process conditions**, allowing hydrochars produced under different temperatures and residence times.

However, full documentation of HTC parameters was considered essential.

Specific proposals

Some participants suggested narrowing the initial ring-test dataset to hydrochars produced at:

180–200 °C

This range reflects common HTC operating conditions and may reduce variability in the first interlaboratory comparison.

Additional technical aspects were highlighted by some groups, including the potential influence of heating and cooling rates, post-treatment conditions, pH adjustment, and biomass-to-water ratio. Pressure conditions and reactor scale were also mentioned as factors potentially affecting hydrochar properties and therefore comparability across laboratories.

3.3 Time Between Hydrochar Production and Experiment

Consensus

Most groups supported the approach proposed in the draft protocol:

- hydrochar should ideally be **fresh**
- analysis should begin within **two weeks**
- storage at **<4 °C** before the experiment.

Alternative suggestions

Some participants suggested that **longer storage periods might still be acceptable**, provided that:

- storage conditions are well documented
- ageing prior to the experiment is reported.

Some participants also highlighted the importance of considering sample handling steps such as filtration, residual process water on hydrochar surfaces, and mixing conditions.
Additionally, one group suggested comparing fresh and pre-aged hydrochar samples to better understand the effect of prior ageing on stability measurements.

3.4 Hydrochar Preparation

Hydrochar preparation generated several important suggestions.

Draft protocol proposal

The draft protocol recommends:

- drying at **105 °C**

- particle size **<2 mm**.

Alternative proposals from groups

Several additional suggestions were discussed:

Lower drying temperature

Some participants proposed drying hydrochar at **60 °C** to avoid altering surface chemistry.

Grinding standardization

One group suggested defining a standard grinding method, such as:

- mortar grinding
- ball milling.

Geometry of hydrochar particles

Another suggestion was to maintain a geometry similar to **filter-cake structure after filtration**, in order to better represent industrial hydrochar.

These ideas were not fully agreed upon but were identified as potential areas for future harmonization.

3.5 Incubation Temperatures

Draft protocol

The draft protocol proposes:

- 20 °C
- plus two additional temperatures among 30 °C, 50 °C, or 70 °C.

Suggestions from breakout groups

Several alternative combinations were proposed:

- **10 °C – 20 °C – 50 °C**
- **20 °C – 50 °C – 70 °C**
- **20 °C – 60 °C**

Some participants argued that including **high temperatures (50–70 °C)** may accelerate physicochemical ageing and help detect long-term transformations.

One group explicitly questioned the practicality of operating at temperatures **above 70°C**, suggesting that 20–30–50°C may represent a more realistic and feasible temperature range for most laboratories.

Others suggested that **lower temperatures (10 °C)** might better represent environmental storage conditions.

No final decision was made.

Furthermore, occupying an oven or incubator for one year or more may be challenging for some laboratories, particularly if experiments need to be conducted at multiple temperatures.

3.6 Reference Control Material

Consensus

All groups agreed on the importance of including a **stable reference material**.

Suggested options include:

- high-temperature pyrolysis biochar (>650 °C)
- EBC-certified biochar.

Additional proposals

Some participants suggested including **multiple reference materials**, for example:

- a highly stable biochar
- graphite
- a moderately stable carbon material.

This could allow calibration of the experimental system.

3.7 Minimum Experiment Duration

There was strong consensus that the experiment should last **at least one year**.

This duration was considered necessary to detect slow physicochemical transformations.

Additional suggestions

Some participants suggested extending monitoring beyond one year in future studies.

However, the first standardized protocol should maintain a **365-day minimum duration**.

Although a 365-day duration was widely supported, one group proposed a shorter experimental timeframe (e.g., **6 months**), potentially combined with higher incubation temperatures to accelerate physicochemical ageing processes.

3.8 Analytical Plan

The analytical plan was one of the most extensively discussed topics.

Proposed mandatory analyses

Several analyses were widely considered essential:

- mass change
- elemental composition (CHN)
- proximate analysis
- pH and electrical conductivity
- FTIR spectroscopy.

These parameters allow monitoring changes in both **carbon quantity and chemical structure**.

Optional analyses proposed by groups

Additional techniques proposed include:

- reflectance measurements
- colorimetry (CIELAB coordinates)
- SEM-EDX imaging
- density determination
- leaching tests
- calorimetry.

Participants emphasized the need to distinguish between:

- **minimum mandatory analyses**
- **optional advanced characterization**.

3.9 Gas Sampling and Correction

Gas sampling methodology generated extensive discussion.

Participants identified several possible sources of measurement error:

- pressure changes during sampling
- temperature differences
- gas dilution.

Proposed solutions

Several technical solutions were proposed, including:

- recording temperature and pressure during sampling
- correcting gas volumes to standard conditions
- using **dual-syringe sampling systems** to minimize pressure artifacts
- using Teflon septa to ensure sealing reliability.

Specific procedural suggestions included allowing bottles to cool to room temperature before gas sampling and the use of vacuum vials for gas collection, with subsequent analysis by gas chromatography. In addition to CO_2 and CH_4, N_2O was also mentioned as a relevant gas species in some approaches.

No final standardized method was adopted.

4. Ring Test

The development of the protocol aims to support a **future interlaboratory ring test**.

During breakout discussions, several institutions were mentioned as potential participants, including:

- AGH University (Poland)
- UTFPR – Federal University of Technology Paraná (Brazil)
- MDU – Mälardalen University (Sweden)
- ATB – Leibniz Institute for Agricultural Engineering and Bioeconomy (Germany).

Additionally, Marija Tasic - University of Nis (Serbia) expressed interest in participating following the workshop.

The final list of laboratories will be confirmed after the protocol is finalized.

Considerations

Several additional considerations for the design of the interlaboratory ring test were proposed by participants.

One key suggestion was the use of a **common hydrochar sample distributed to all participating laboratories**, which would allow direct comparison of results across different experimental setups.

However, this approach introduces logistical challenges, particularly related to transport and storage time. Therefore, it was suggested to define:

- a maximum storage time before the experiment
- standardized storage conditions (e.g., below 4°C)
- a common starting point for the experiment after sample reception.

Another important proposal was to structure the protocol into two levels:

- a **minimum protocol**, including essential measurements (e.g., mass loss, gas evolution, elemental composition) to ensure broad participation and comparability
- an **extended protocol**, including advanced analytical techniques (e.g., FTIR, SEM-EDX, TG-MS, reflectance), depending on laboratory capabilities.

Finally, participants emphasized the need to clearly define the number of replicates, including both sample bottles and analytical replicates, as part of standardized reporting requirements.

5. Main Consensus Points

The workshop identified several areas of strong agreement:

- focus on **dry hydrochar ageing in sealed bottles**
- inclusion of a **stable reference char**
- minimum experiment duration of **365 days**
- adoption of a **core analytical package**
- development of a **ring test** to validate the protocol.

6. Remaining Open Questions

Several methodological aspects require further harmonization:

- gas sampling correction methodology
- hydrochar drying temperature
- grinding procedures and particle size
- sample packing density
- final list of mandatory analytical parameters.

These topics will be addressed in the next stage of protocol development.

7. Next Steps

The workshop concluded with the following roadmap:

1. integrate the results of breakout group discussions
2. finalize the experimental protocol
3. define the ring-test design
4. confirm participating laboratories
5. launch the interlaboratory experiment.

In preparation for the ring test, a structured questionnaire will be circulated among participating laboratories to collect information on available facilities, instrumentation, and analytical capabilities. This will support:

- mapping of laboratory capacities
- identification of laboratories able to perform the mandatory analyses
- coordination of tasks across the network
- and potential sharing of infrastructure among partners

This step is considered essential to ensure the effective implementation of both the minimum and extended protocol and to enhance the overall comparability and robustness of the interlaboratory study.

Annex A – Workshop Participants

Moderators

- Gianluigi Farru
- Giovanna Cappai
- Silvia Román Suero (**Group 1**)
- Małgorzata Wilk (**Group 2**)
- Judy Libra (**Group 3**)
- JaeWook Chung (**Group 3**)
- Changyoon Jeong (**Group 4**)
- Fabiano B. Scheufele (**Group 5**)

Participants

Group 1

- Matheus Cavali
- Jeremy Taylor
- Sydnie Bayles

Group 2

- Jim Jian Wang
- Marc Buttmann
- Fritz Keller
- Parisa Endallah

Group 3

- Marija Tasic
- Cordel Bever

Group 4

- Gabriel Gerner
- Gabriel De Freitas Batista
- Stephane Bostyn
- Jewel Das

Group 5

- Zuzanna Prus
- Mona Ghaslani
- Harry Tibbetts
- Joanna Mikusińska

Note: Some participants joined only briefly due to connectivity or scheduling constraints.

- Daniele Pirini
- Luca Musu
- Jaime Guerrero Belza
- Samir Tandon
- Nicole Berge
- Simon Ford
- Rafa Torres Franco
- Christian Aragon Briceño
- Khadija Ajmi