VERIFICATION STATEMENT

In accordance with ISO 14034:2016
Environmental Technology Verification

Technology & Company Information		
Technology Name	**Company**	**Technology Type & Application**
CarbonBuilt Reversa™	CarbonBuilt™ https://carbonbuilt.com	Direct utilization/conversion of carbon dioxide (CO_2) borne in a CO_2-dilute flue gas stream to produce concrete components

Verification Parameter	Verified Performance
Operational Scale	0.34 tonne CO_2/carbonation period (24 hours)
CO_2 Utilization	0.26 tonne CO_2/carbonation period (24 hours)
CO_2 Embedded in Product	19.5 kg CO_2/tonne concrete
CO_2 Conversion Efficiency	75.6 %
Energy Usage	3,704 MJ/batch, 282 MJ/tonne concrete
Water Usage	0.28 m^3/batch, 0.02 m^3/tonne concrete
CMU 28-day Compressive Strength	22.43 MPa

Verifier Information			
Verification Body	**Lead Verifier**	**Verification Body Accrediation**	**Verification ID**
350Solutions, Inc. https://350solutions.com	Bill Chatterton	ANAB Cert. AI-2618 for ISO:IEC 17020-2012 / ISO 14034-2016	VS- CXP-A-01

CarbonBuilt™

Issue Date: April 15, 2021

350 VERIFIED ISO 14034

ANAB ACCREDITED ISO/IEC 17021 INSPECTION BODY

Disclaimer: 350Solutions Name and/or Logo does not imply approval or certification of this product, nor does it make any explicit or implied warranties or guarantees as to product performance. Information on the performance characteristics of the **CarbonBuilt Reversa™ Technology** can be found at **https://350solutions.com.** Contact 350Solutions or CarbonBuilt to obtain a copy of this ETV verification statement.

ENVIRONMENTAL TECHNOLOGY VERIFICATION STATEMENT

CarbonBuilt™

Technology Name:	CarbonBuilt Reversa™
Technology Type:	Direct utilization/conversion of carbon dioxide (CO_2) borne in a CO_2-dilute flue gas stream to produce precast concrete components
Application:	Precast concrete components (e.g., structural, load-bearing concrete masonry unit (CMU), also known as “concrete block”)
Company:	CarbonBuilt™ https://carbonbuilt.com/
Verification Body:	350Solutions, Inc. - ISO/IEC 17020:2012 and ISO 14034 Environmental Technology Verification, Certificate Number AI-2619
Lead Verifier:	Bill Chatterton, 350Solutions, Inc.

TECHNOLOGY DESCRIPTION

The CarbonBuilt Reversa™ technology offers a transformative solution for turning flue gas borne CO_2 into construction components. This technology allows for flexible and adaptable CO_2 processing, and is designed for stack-tap integration into diverse flue gas streams including those associated with power generation, cement and steel production, and the petrochemical industries. This technology requires no pre- or post-treatment (e.g., carbon capture, purification, clean-up, etc.) of the flue gas, operates at ambient pressure/temperature, and enables CO_2 uptake into construction materials and products. A basic summary of the batch process is provided in Figure 1.

CarbonBuilt’s process utilizes flue gas directly; pre-processing for concentration of CO_2 gas is not required. The CarbonBuilt technology embeds CO_2 in a replacement product for traditional Portland cement-based concrete. Concrete mixture formulations feature reduced ordinary portland cement (OPC) contents due to the replacement of OPC by hydrated lime ($Ca(OH)_2$), and coal combustion residues that may include bottom ash and non-compliant fly ashes. After traditional concrete batching, mixing, forming, and curing processes, precast concrete components are placed into a carbonation chamber where CO_2 dilute flue gas is injected. The CO_2 reacts with hydrated lime (portlandite) produced via hydration of calcium oxide, producing calcium carbonate within the product. Calcium carbonate serves as a cementation agent and a CO_2 sequestration agent via mineralization of the CO_2, which enables OPC reduction in concrete mixture formulations.

Image 1: Closed Carbonation Chambers.

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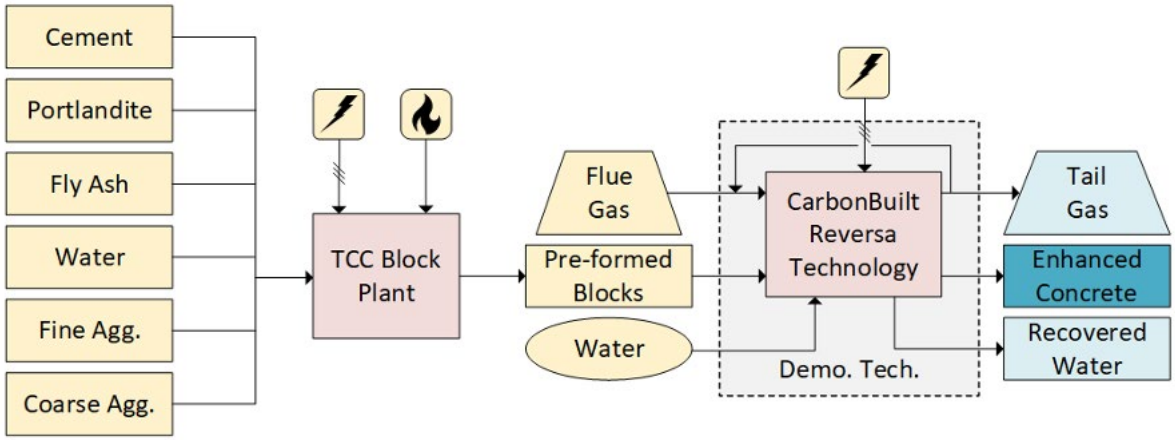

Figure 1. Carbonbuilt Reversa Block Flow Process Summary

The CarbonBuilt process requires no post-processing and produces precast concrete replacement building materials. During the performance demonstration verified here, CarbonBuilt produced standard-size precast concrete masonry units (CMUs) over a series of batches completed during the demonstration period. Each batch was conducted over periods of approximately five days, during which semi-cured blocks were loaded into a curing chamber for sequential processing steps: air-drying, flue gas injection (carbonation/CO_2 mineralization), and finally humid air curing. The cured blocks were then removed from the curing chamber, palletized, and stored. The carbonation periods where CMUs were exposed to flue gas were approximately 24 hours in duration. Each batch generated approximately 13.2 tonnes of concrete block product and embedded roughly 260 kg CO_2. The concrete was shown to be a sellable product by meeting a minimum compressive strength value of 13.79 MPa, as determined by ASTM C90.

Image 2: CarbonBuilt Facility at the Integrated Test Center at the Basin Electric Power Cooperative, Dry Fork Station, Gillette, Wyoming.

The environmental benefit of the technology is its ability to utilize CO_2 from industrial or other processes, reducing and sequestering CO_2 emissions, a major greenhouse gas. Independent lifecycle analysis (not verified) completed on the system indicates that the technology can provide up to 75 % reduction in CO_2 emissions relative to standard CMU production processes. At the current developmental scale, without full system energy optimization and without the use of renewable energy, the relative lifecycle CO_2 emissions compared to traditional CMU production are 29% and 55% lower using Wyoming (CarbonBuilt demonstration site) and South Dakota (concrete block manufacturing plant) electricity grid emission factors, respectively, with respect to CO_2-footprint for U.S. industry-average block manufacturers.

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VERIFICATION DESCRIPTION

The verification process applied here was based on 350Solutions' Standard Operating Procedure (SOP) QSP-350-223-01: "ISO 14034 Environmental Technology Verification", the ISO Technical Committee 207 draft guidance document "Environmental technology verification — E.T.V — Guidance to implement ISO 14034", and a technology specific Verification Plan. The objectives and approaches used for this verification were designed to apply these principles and processes to CarbonBuilt's application for performance verification as presented under the NRG-COSIA Carbon XPRIZE competition. The verification provides CarbonBuilt and potential users of the technology with an independent assessment and verification of performance of the technology.

The verification included four primary tasks including administrative and technical application reviews, development of verification objectives and plans, verification of technology performance claims and reporting. The primary objective of the project was to verify the performance claims made by CarbonBuilt with respect to operation of the technology. CarbonBuilt's performance claims specified in the application for verification include:

Performance Claim 1 – Operational Scale: Operational scale is defined as the average rate of CO_2 fed into the conversion system during the carbonation periods of each batch (nominal 24-hr carbonation periods during 5-day batches) and represents the operational scale during the XPRIZE competition demonstration. Performance results are verified within the range of relevant operating conditions that were evident during this demonstration.

Performance Claims 2 and 3 – CO_2 Utilization and Embedded in Product: CO_2 embedded in product is defined as the utilization of CO_2 input that is converted into useful product – in this case CMUs. Utilization is reported as the average batch rate of CO_2 fed into the conversion system during the carbonation periods of each batch (nominal 24-hr carbonation periods during 5-day batches), that was converted into product. Similarly, CO_2 embedment in product expresses the utilization rate in mass units as kg of CO_2 embedded per tonne of CMUs processed.

Performance Claim 4 –CO_2 Conversion Efficiency: Defined as the fraction of CO_2 converted as the mass ratio of CO_2 input and CO_2 output embedded in the product, expressed as a percentage. The performance claim is presented as the average conversion efficiency during the demonstration, within the operational conditions defined during the period.

Performance Claims 5 and 6 – Energy and Water Usage: For every tonne of concrete with embedded CO_2 that was produced, the conversion system required power and water to complete the conversion process. These inputs were normalized to product output and verified.

Performance Claim 7 – Product Quality: The average compressive strength of CMUs processed by the CarbonBuilt mineralization technology, as MPa. These results are compared to the ASTM C90 standard for CMUs.

Other parameters examined and verified during the demonstration included total system run time and system availability. Both were evaluated by verifying the number of operating hours during the fixed demonstration period and the total number of hours in that period under a set of operational conditions. For the XPRIZE competition demonstration, operating hours could include both productive hours and non-productive hours that are required for the regular operation of the system.

After initial reviews of the technology and following the Verification Plan, performance verification was specified using independent performance data generated during the verification at the Wyoming Integrated Test Center (ITC) in the summer of 2020 during the XPRIZE competition. Using data that was determined to be relevant to the performance claims and of sufficient quality to support verification, 350Solutions assessed the performance of the technology. The verification also statistically examined variability and confidence intervals in the supporting data used to verify performance claims including comparative sample analytical results and analytical variability.

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VERIFICATION OF PERFORMANCE

Table 1 provides a list of the performance claims as they relate specifically to the CarbonBuilt demonstration conducted at ITC. The summary includes the claimed or targeted team performance for each Verification Parameter, and columns for in-field verified values and associated uncertainties.

Table 1 – Carbonbuilt Reversa Verified Performance

Verification Parameter	Verification Value
Operational scale, tonne CO_2/carbonation period	0.34 ± 0.02
CO_2 utilization, tonne CO_2/ carbonation period	0.26 ± 0.04
CO_2 Embedded in Product, kg CO_2/tonne concrete	19.5 ± 2.8
CO_2 conversion efficiency, %	75.6 ± 10.1
Conversion system energy use, MJ/batch, (MJ/tonne concrete)	3,704, (282)
Water Usage, m^3/batch, (m^3/tonne concrete)	0.28 ± 0.13, (0.02 ± 0.01)
CMU 28-day compressive strength, MPa	22.43 ± 1.0

Table 2 presents the non-proprietary operating conditions under which the verification parameters were observed during the demonstration period. These operating conditions have direct correlation to system performance and should be considered in conjunction with the verified performance. The demonstration period included seven consecutive batches - each batch consisted of 828 blocks loaded into the carbonation chamber for a nominal product mass of 13.2 tonne CMU/batch.

Table 2 - Carbonbuilt Reversa Verification Operating Conditions

Operating Parameters	Observed Average Value	Observed Range
Batch duration	138 hrs	122 – 171 hrs
Carbonation period duration	23.7 hrs	21.7 – 24.1 hrs
Carbonation CO_2 input flow rate	14.3 kg/hr	11.1 – 18.5 kg/hr
System inlet flue gas CO_2 concentration	14.5%	12.5 – 15.4%

The basis for the verification was an operational period of 35 days during which data was collected from process operations using on-site datalogging, PLC systems, and manual records. Total system operations and operating characteristics for which data was reviewed and verified are summarized in Table 3.

Table 3 - Carbonbuilt Reversa Verification Operational Period

Verification Period Characteristic	Observed Value
Number of batches	7
Total productive hours operated	771
Total hours of carbonation	166
Continuous process availability concentration	82.6%

The calculation of the performance targets from the measurements that were made on the CarbonBuilt demonstration system are subject to a degree of uncertainty. 350Solutions developed an estimate of the uncertainty of the verification parameters, where appropriate.

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DATA QUALITY

350Solutions, an ANAB accredited ISO/IEC 17020:2012 inspection body for ISO 14034 ETV, was contracted by the NRG-COSIA Carbon XPRIZE to provide independent verification of the CarbonBuilt CO_2 Conversion technology. The verification process applied was based on 350Solutions' Standard Operating Procedure QSP-350-223-01: "ISO 14034 Environmental Technology Verification", the ISO Technical Committee 207 draft guidance document *"Environmental technology verification — E.T.V — Guidance to implement ISO 14034"*, and a technology specific Verification Plan. The objectives and approaches used for this verification were designed to apply these principles and processes, along with the requirements of the NRG-COSIA Carbon XPRIZE competition, to CarbonBuilt's verification of performance claims. Following ISO 14034 guidance, the data quality assessment included:

- Data quality assessment for the specified performance claims;
- Assessment of ancillary data quality (operations, relevance, representativeness);
- Performer competence (testing and analytical providers);
- Sampling and analytical procedures (repeatability, accuracy, measurement equipment calibration and quality checks); and,
- Data management and processing.

Assessment of the quality of data used to verify technology performance was based on three primary components:

- Conformance with the requirements of ISO Standards 14034 and 17025.
- Assessment of the scientific approaches and statistical analyses – specifically, evaluation of measurement uncertainty in laboratory and field demonstration test results, and the statistical analyses of measurement uncertainty.
- The quality of reference field testing and laboratory procedures and results.

In broad terms, the data provided by CarbonBuilt to verify performance with respect to the performance claims were found to be acceptable for verification. Sound scientific approaches and statistical analyses are detailed in the Verification Report and demonstrate that the quality of data and data analyses support verification of the performance claims. Assessment of data quality for the reference laboratory results was verified acceptable based on verification of the following data quality assessments:

- Review and verification of acceptable operating procedures and methods,
- Satisfactory verifier observation of facilities, equipment, and operations,
- Review and observation of performer competence (qualifications and training policies),
- Sampling and analytical procedures (repeatability, accuracy, measurement equipment calibration and quality checks), and
- Satisfactory data management and processing.

All of the findings of the data quality review support verification of the performance claims and conform to the requirements of the standards.

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Detailed results of the verification are presented in the Final Report titled *Environmental Technology Verification Report – CarbonBuilt, VR-CXP-A-01,* (350Solutions 2021). The report can be made available to the interested parties upon request to CarbonBuilt.

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Notice: ETV verifications conducted by 350Solutions are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. 350Solutions makes no expressed or implied warranties as to the performance of the technology and does not certify that a technology will always operate at the levels verified. The end user is solely responsible for complying with any and all applicable Federal, State, and Local requirements.

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