Final Outcomes Report
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SOLIDIA CONCRETE - A SUSTAINABLE METHOD FOR CEMENT PRODUCTION AND CO_2 UTILIZATION

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Converting Greenhouse Gases into Valuable Carbon-Based Products

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3. Executive Summary

The objective of the CCEMC Grand Challenge Round 1 (CCEMC) program entitled “Solidia Concrete – A Sustainable Method for Cement Production and CO_2 Utilization” is to roll out an innovative technology that will generate a new line of cement and concrete products while offering equivalent cost, superior performance and unprecedented reduction in CO_2 emissions. To accomplish this goal, Solidia Technologies and LafargeHolcim have joined forces to accelerate the development and commercialization these newly developed products. Hereafter referred to as Solidia Cement™ and Solidia Concrete™, they offer the potential to reduce the CO_2 footprint of cement and concrete manufacturing by over 1 million tonnes per year in Alberta alone. This CO_2 savings is realized by reducing the CO_2 emitted at cement plants in Alberta by up to 600,000 tonnes per year, and by sequestering more than 400,000 tonnes per year of CO_2 during the curing of concrete products made with this new cement.

This program will make an immediate, positive impact on the Alberta building and infrastructure industry.

The future of this new technology hinges on the demonstration that Solidia Cement can be manufactured in conventional cement kilns, and that Solidia Concrete can be CO_2-cured in conventional concrete plants. Solidia Cement has been successfully produced by LafargeHolcim in two separate manufacturing campaigns. The first campaign, conducted at a cement facility in Whaiutehall, PA in March 2014, produced 5,000 tonnes of Solidia Cement. The second campaign, run at a cement facility in Pecs, Austria in June 2015, produced an additional 6,000 tonnes. Both campaigns proved the basic sustainability metrics predicted for Solidia Cement; that the CO_2 emitted during cement production was reduced by 30% vis-à-vis Portland cement manufacturing. The output of these campaigns provides the cement supply that drives the commercial development of Solidia Concrete in North America and Europe respectively.

The demonstration that Solidia Concrete, made with Solidia Cement, can set and harden via a reaction with CO_2 on an industrial scale is the subject of this CCEMC Gand Challenge Round 1 program.

In the course the program, commercial-ready CO_2-curing processes were developed for a variety of precast concrete parts, including pavers, blocks, hollow core slabs, and architechtural panels. These processes were then successfully demonstrated on-site at eight different Canada-based precast concrete product manufacturers, three of which are located in Alberta. Finally, curing systems at two different precast concrete manufacturers (a paver manufacturer in the U.S. and a hollow core slab manufacturer in Alberta), were sucessfully retrofitted so that a portion of the manufacturer’s capacity could be converted to Solidia Concrete.

The output from these precast concrete manufacturing demonstrations proved that Solidia Concrete can meet basic CSA standards, provide excellent environmental durability when compared to conventional concrete, improve concrete manufacturing efficiencies, and reduce concrete manufacturing costs while providing the sustainability metrics stated above.

Solidia Technologies, partnered with LafargeHolcim, is now poised to provide Solidia Cement and Solidia Concrete technology to the precast concrete marketplace so that the product performance, process economic, and sustainability attributes can be realized.

If granted a CCEMC Grand Challenge Round 2 award, Solidia Technologies will use the funding to begin Solidia Cement manufacturing in Alberta, develop the provincial precast Solidia Concrete market, and develop process technology to allow entry into the cast-in-place concrete market.

4. Project Description

Technology Description and Program Goals

The objective of the CCEMC Grand Challenge Round 1 (CCEMC) program is to roll out an innovative technology that will generate a new line of cement and concrete products while offering equivalent cost, superior performance and unprecedented reduction in CO_2 emissions. This program will make an immediate, positive impact on the Alberta building and infrastructure industry. To accomplish this goal, Solidia Technologies and LafargeHolcim have joined forces to accelerate the development and commercialization of newly developed cement and concrete products. These new products, hereafter referred to as Solidia Cement™ and Solidia Concrete™, offer the potential to reduce the CO_2 footprint of cement and concrete manufacturing by over 1 million tonnes per year in Alberta alone. This CO_2 savings is realized by reducing the CO_2 emitted at cement plants in Alberta by up to 600,000 tonnes per year, and by sequestering more than 400,000 tonnes per year of CO_2 during the curing of concrete products made with this new cement.

Two major technological acheivements are at the core of this outstanding green technology; 1) Solidia Cement is manufactured with conventional cement ingredients in conventional cement kilns, at temperatures 250˚C lower and using substantially less $CaCO_3$ than for Portland cement. These factors reduce both energy consumption and CO_2 emissions associated with cement production, each by 30%. 2) Solidia Concrete, made with Solidia Cement, sets and hardens because it consumes CO_2 to produce cementitious calcium carbonate-based bonds, thereby permanently and safely sequestering up to 300 kg of CO_2 per tonne of cement used in the concrete.

The means to commercialize this technology by 2020 entails participation in all three rounds of the CCEMC Grand Challenge program. In *Round 1* (2014-2016), Solidia Technologies and LafargeHolcim are partnering to demonstrate pilot scale Solidia Concrete production in non-structural precast applications such as commercial masonry products. *Round 1* will culiminate with the commercial production and sale of Solidia Cement, and the use of that cement in commercial Solidia Concrete applications. *Round 2* (2016-2018) will continue to address the precast concrete market, extending the reach of Solidia Concrete into structural applications. In addition, Solidia Technologies and LafargeHolcim will partner to begin the development of cast-in-place CO_2-curing technologies. *Round 3* (2018-2020) will complete the penetration of Solidia Concrete into precast markets, complete the development of cast-in-place curing technologies, and begin the market penetration of Solidia Concrete in cast-in-place applications.

Project Goals: CCEMC Grand Challenge Round 1 Work Plan

The main objectives of Round 1 are to identify relevant precast concrete applications in Alberta that are suitable for conversion to Solidia Concrete, to develop time-, energy-, and CO_2-efficient pilot scale curing processes for at least four of these precast applications, to transfer this technology to at least one Alberta-based precast concrete manufacturer, and to position Solidia Technologies and LafargeHolcim for a broad penetration of the precast concrete market. The work plan has four key milestones and corresponding tasks associated with each milestone.

The key deliverables at the end of CCEMC Grand Challenge Round 1 include the following:

a) A market study of the Alberta concrete market with focus on at least 4 precast applications that will be identified through the market study. The market study involves understanding of the target applications and their economics.
b) A description of the different curing methods for the 4 precast applications, the equipment needed and how Solidia's technology can be integrated into the Alberta precast market.
c) A description of the pilot implementations of precast applications, and a description of the monetary value that the conversion to Solidia's technology will bring to the manufacturing process
d) An accumulation of concrete property data obtained from testing of precast products manufactured using Solidia's technology
e) A scale-up and commercialization timeline of the target precast applications in Alberta market.

A detailed description of the Milestones and Tasks that comprise CCEMC Grand Challenge Round 1 is offered in **Table 1**.

Table 1: CCEMC Grand Challenge Round 1 Program Milestones, Tasks, Schedule and Budget

Milestone 1: IDENTIFY 8 PRECAST APPLICATIONS IN ALBERTA	**Start Date**	**End Date**	**Funding from Applicants**	**Funding from CCEMC**	**Total Cost**
Task 1: Conduct market research of precast market in Alberta	04/01/14	06/30/14	$35,100	$15,900	$51,000
Task 2: Develop target list of Alberta precast manufacturers	04/01/14	06/30/14	$33,800	$15,200	$49,000
Task 3: Understand precast plant and product economics	04/01/14	06/30/14	$33,800	$15,200	$49,000
Task 4:Build customer value proposition for 8 applications	04/01/14	06/30/14	$33,800	$15,200	$49,000
Milestone 2: DEVELOP PILOT SCALE CURING PROCESSES FOR 4 APPLICATIONS	**Start Date**	**End Date**	**$ from Applicants**	**$ from CCEMC**	
Task 1: Research different curing methodologies	04/01/14	06/30/14	$34,400	$15,600	$50,000
Task 2: Build lab-scale curing reactors for different applications	04/01/14	06/30/14	$155,000	$70,000	$225,000
Task 3: Optimize curing processes	07/01/14	09/30/14	$147,400	$66,600	$214,000
Task 4: Identify modifications required for customer curing equipment	04/01/14	09/30/14	$35,100	$15,900	$51,000
Milestone 3: PILOT SCALE IMPLEMENTATION OF AT LEAST 1 PRECAST APPLICATION AT AN INDUSTRIAL PRECAST FACILITY	**Start Date**	**End Date**	**$ from Applicants**	**$ from CCEMC**	
Task 1: Identify customers for pilot implementations	04/01/14	12/31/14	$35,100	$15,900	$51,000
Task 2: Understand customer plant economics	06/30/14	12/31/14	$35,100	$15,900	$51,000
Task 3: Demonstrate pilot production	01/01/15	03/31/15	$203,300	$91,700	$295,000
Task 4: Conduct extensive 3rd party testing	03/31/15	06/30/15	$52,400	$23,600	$76,000
Task 5: Identify additional customers	01/01/15	06/30/15	$68,200	$30,800	$99,000
Milestone 4: MARKET LAUNCH PLAN READY FOR LEAST 1 PRECAST APPLICATION	**Start Date**	**End Date**	**$ from Applicants**	**$ from CCEMC**	
Task 1: Optimize products based on test results	07/01/15	09/30/15	$33,800	$15,200	$49,000
Task 2: Secure CO2 supply arrangements	04/01/15	06/30/15	$34,500	$15,500	$50,000
Task 3: Retrofit curing equipment at target precast plant	04/01/15	06/30/15	$34,500	$15,500	$50,000
Task 4: Begin marketing campaigns in collaboration with Lafarge and precasters	06/30/15	09/30/15	$102,700	$46,300	$149,000
CCEMC GRAND CHALLENGE ROUND 1 PROJECT TOTALS			$1,109,000	$500,000	$1,609,000

Work Scope Overview

In this report we describe our progress toward meeting the first three milestones enumerated in Table 1 above. Each milestone is discussed within a separate section immediately below. For each individual task within each milestone, the completed work and the work that is still in progress will be described in detail.

Milestone 1: Identify 8 Precast Applications in Alberta is discussed in Section 5.1. This section goes into detail about the market research Solidia conducted to identify potential customers and the process to develop a targeted list for Solidia's technology. It describes the process Solidia used to understand the economics of precast plants, and in turn develop value propositions for potential applications.

Milestone 2: Develop Pilot Scale Curing Processes for 4 Applications is reviewed in Section 5.2. The research conducted to explore different curing methodologies for each application is outlined, which leads to describing how the lab-scale reactors were developed. This section covers the optimization of the curing process and identifies the modifications necessary for customer curing equipment to adapt the Solidia CO_2-Curing technology.

Milestone 3: Pilot Scale Implementation of at Least 1 Precast Application at an Industrial Precast Facility will be described in Section 5.3. This section will discuss the identified customers for the pilot scale implementation trials using the customers plant economics. It also goes into the demonstration of the technology during the pilot production trials and summarizes the 3rd party testing performed on the products produced. This section covers the identification of additional customers for future pilot scale implementations.

Milestone 4: Market Launch Plan Ready for at Least 1 Precast Application will be reviewed in Section 5.4. This section will briefly summarize the optimization work for the hollow core slab product. Much of that optimization effort is described in Section 5.3. This section will also contain an update on securing a CO_2 supply, and retrofitting the curing equipment for industrial scale CO_2-curing adoption at one U.S.-based customer site and at one Alberta-based customer site. Finally, it will contain descriptions of both a market study and a marketing campaign to translate of this work into Alberta.

5. Outcomes and Learnings

5.1 Milestone 1: Identify 8 Precast Applications in Alberta

5.1.1 Milestone 1 Task 1: Conduct Market Research of Precast Manufacturers

Initially, Solidia focused on two generic precast applications in Alberta: pavers and masonry (described below as Category 1 applications) and semi-structural products (described below as Category 2 applications). **Table 2.a** offers a view of the expected adoption rate of Solidia's technology per producer category. Category 1 producers are averaged to have a cement consumption of 10,000 tonnes and Category 2 producers to have 20,000 tonnes annually. Solidia does not expect the producers to convert 100% of their production immediately to the new technology, but to convert in increments shown in Table **2.a**, with each producer spending 12 months at each conversion stage. **Table 2.b** offers a description of the estimated CO_2 savings per product category and per year. This table takes into account the CO_2 avoided by the production of Solidia Cement instead of Portland Cement, and the CO_2 captured during the curing process.

Table 2.a:	Total Expected Number of Producers and Conversion % by year							
Conversion %	2017		2018		2019		2020	
	Cat. 1	Cat. 2	Cat. 1	Cat. 2	Cat. 1	Cat. 2	Cat. 1	Cat. 2
10%	1	1	3	1	3	1	3	0
30%	0	0	1	1	3	1	3	1
50%	0	0	0	0	1	1	3	1
Full Conversion (100%)	0	0	0	0	0	0	1	1

Table 2.b: Estimated CO_2 Reduction Realized from Solidia Concrete (tonnes of CO_2, Relative to Concrete Made with Portland Cement)				
	2017	**2018**	**2019**	**2020**
Category 1 (Pavers and Masonry)	550	3,300	9,350	20,350
Category 2 (Semi-Structural)	1100	4,400	9,900	19,800
Total Savings	**1,650**	**7,700**	**19,250**	**40,150**

Through Solidia's partnership with LafargeHolcim, the project has gained a powerful marketing tool to target applications that would be a good fit for the implementation of Solidia Concrete technology. LafargeHolcim and Solidia partnered to identify potential precast manufactures in Alberta, and the surrounding provinces. Market research was conducted and focused on a few key indicators to identify ideal candidates for this technology. The key indicators used really focused on the precast application compatibility, ease of conversion and willingness to implement Solidia's technology.

Solidia and LafargeHolcim will focus on two different categories of products in the scope of this agreement, which are defined below.

The first category (*Category 1*) of applications includes products that have low to no regulatory barriers, and product geometries that Solidia has experience curing efficiently. These applications include concrete pavers, concrete blocks (also known as concrete masonry units or CMU), and roof tiles.

The second category (*Category 2*) of applications have higher regulatory barriers (typically semi-structural applications), and longer market entry times. These applications can vary in geometry based on customer application, but are generally larger and more complex than the previous category of applications. These applications include products such as extruded hollow core, architectural precast panels and concrete pipe.

In order to achieve a more broad understanding and penetration of the Canadian concrete market, Solidia and LafargeHolcim have expanded the area of focus to include identification of markets outside of Alberta. This effort has focused on eastern Canada, primarily in Ontario. With this strategy, Solidia and LafargeHolcim are seeking to increase the demand for Solidia Concrete across the entire Canadian marketplace.

5.1.2 Milestone 1 Task 2: Develop Target List of Precast Manufacturers

Building off the market research study, Solidia and LafargeHolcim were able to develop a target list of precast manufacturers that were identified as ideal candidates for the implementation of the technology. These target precast manufacturers were chosen because they met all of the key indicators described in Task 1.

From the list of precast manufacturers collected in Task 1, Solidia and LafargeHolcim chose specific candidates for future implementation, based on the precast application compatibility, ease of conversion and willingness to implement Solidia's technology. These candidates covered ten selected applications; four types of concrete blocks, three types of pavers, hollow core slabs, architectural precast panels and concrete pipes. Pilot scale curing processes were developed for nine of these ten, either with CCEMC funding or in Solidia funded work that preceded the commencement of this CCEMC program. These will be described in more detail in subsequent sections of this report.

Additionally, Solidia and LafargeHolcim selected candidates for pilot-scale implementation. These implementations, hereafter referred to as Phase 1 trials, will be described in Section 3.3 (Milestone 3). To date, Phase 1 trials have been conducted for six applications (architectural precast panels and concrete pipe are still to be demonstrated) at six different companies/locations in Alberta and Ontario. The specific precast applications are listed in **Table 3** below.

Table 3: Identified precast applications for Phase 1 trials

Application	Category	Pilot Scale Trial Date	Trial Location
Concrete Block Customer #1	1	4/15/14	Alberta, Canada
Concrete Block Customer #2	1	2/13/15	Ontario, Canada
Concrete Block Customer #3	1	2/17/15	Ontario, Canada
Concrete Block Customer #4 **Paver Customer #1**	1	2/21/15	Ontario, Canada
Paver Customer #2	1	7/20/15	Quebec, Canada
Paver Customer #3	1	TBD	Quebec, Canada
Hollow Core Slab Cutomer	2	5/9/16	Alberta, Canada
Architectural Precast Panel Customer	2	TBD	Same as for Hollow Core Slab
Concrete Pipe Customer	2	TBD	Alberta, Canada

Note that five of the precast concrete plants referenced in **Table 3** are owned and operated by LafargeHolcim in Alberta. This gives the Solidia and LafargeHolcim marketing teams access to market and plant operations data that would not be accessible for the trials conducted at privately owned precast operations.

5.1.3 Milestone 1 Task 3: Understand Precast Plant and Product Economics

Solidia and LafargeHolcim have identified precast manufacturers in Alberta and Ontario that meet the criteria for ease of adoption and provide the smoothest transition for Solidia's technology into the market. Large manufacturers (approximately 10,000 tonnes or greater of cement consumption per year) of architectural and structural products have been the primary focus. It is believed that these manufacturers will be able to maximize the benefits inherent to Solidia's CO_2-curing technology.

A. Capital Investment Needed for CO_2-Curing of Solidia Concrete

The adoption of CO_2-curing at a precast concrete manufacturing facility will require a certain level of capital investment. The Solidia Technologies approach to this challenge attempts to minimize this investment. The bulk of the concrete manufacturer's processing equipment, including raw materials storage and conveyance, concrete mixing, concrete forming, and concrete product handling, will remain unchanged after conversion to CO_2-curing. The capital investment necessary to enable CO_2-curing is concentrated at the concrete curing chamber. Here, the capital investment can be divided into two distinct sections;

- The gas conditioning system, which manages the temperature, humidity and CO_2 concentration within the curing chamber, and;
- Mechanical modifications to the existing curing chamber or the building of a new chamber.

The specific components of the gas conditioning system and modifications to the curing chamber are described in detail in Sections 5.2, 5.3 and 5.4 (Milestones 2, 3 and 4). It is projected that the conversion of a standard concrete paver and/or block manufacturing facility in this manner will require a capital investment of approximately $2,000,000. This cost is accounted for in the value models developed for the two customers profiled in Section 5.1.4.

B. Identification of Value-Added Attributes of Solidia Concrete

A detailed list of the potential value adding attributes of Solidia Concrete and Solidia Cement are laid out in **Tables 4** and **5** below.

Table 4 describes the general benefits associated with the adoption of Solidia Cement and Solidia Concrete technology. The benefits have been divided into product, process and sustainability categories to indicate the broad impact that Solidia's CO_2-curing technology can have on a manufacture's existing process. This table shows that the non-hydraulic nature of Solidia Cement has an added advantage, not just for the sustainability side, but also for the concrete product and the concrete manufacturing process. These latter categories offer significant opportunity to reduce manufacturing costs, reduce inventory costs, and improve field performance.

Table 4: Benefit summary of Solidia Concrete

Solidia Concrete™
Benefit Summary

	Product	Process	Sustainability
Cures w/ CO_2 (not H_2O)	• No $Ca(OH)_2$ = improved durability • No calcium hydroxide based efflorescence	• Ability to recycle fresh concrete waste. • Non-hydraulic cement = faster clean-up times = increased production time • Increased production flexibility	• ~3% of final products mass is permanently stored recycled CO_2 • CO_2 converted to stable calcium carbonate • Process water can be recycled, it is not chemically consumed
28-day strength in 24 hrs	▪ Improved quality control	▪ Potential for improved inventory management, ready-to-ship production	▪ No added water during curing, steam curing not required
Additional	• Similar mix designs • Same aggregates • Light cement color	▪ Same mixing / forming ▪ Minimal process modifications	▪ Local raw materials ▪ Potential carbon credit

Table 5 includes the potential value proposition that Solidia and LafargeHolcim have identified when the technology is adopted for specific applications. The potential value proposition for each application has been determined through data collected from prior pilot trials at customer locations in the US. The value potential has not yet been validated on larger, production scale implementation, but once larger scale trials are run these items will be validated. Each of the value proposition attributes have been identified in the left hand column of **Table 5**, and the specific product to which the attribute pertains is marked with an 'X'.

The LafargeHolcim marketing and sales teams in Western and Eastern Canada have developed lists of customers inside and outside of the LafargeHolcim network for Phase 1 trials and for discussions on adoption of the technology. A target list has been developed that includes nine precast manufacturers identified in Canada, in addition to the Phase 1 demonstrations that have been conducted to date. Four of these, Hollow Core Slab Customer, Architectural Precast Panel Customer, Concrete Block Customer #1, and Concrete Pipe Customer, are located in Alberta.

Additional details on the marketing plan, the end-user target market and market launch details can be found in Section 5.4.4

Table 5: Potential value-adding attributes of Solidia's Cement and Concrete Technologies

VALUE PROPOSITION ATTRIBUTES PRECAST CUSTOMER MATERIAL SAVINGS OR PRODUCT IMPROVEMENTS	Normal and Lightweight Block	Architectural Block	Paver Products	Hollow Core	Architectural Precast Panels	Roof Tiles
High Early Strength	X	X	X	X	X	X
Better Durability Properties	X	X	X	X	X	X
No Primary Efflorescence		X	X		X	X
Lighter Colour		X	X		X	X
Better Pigmentation		X	X		X	X
Cement Content Reduction	X	X	X	X	X	X
Admixture Reduction / Elimination	X	X	X	X	X	X
Less Concrete Waste	X	X	X	X	X	X
Curing Energy Savings						
Water Savings	X	X	X	X	X	X
Alternate Production Materials	X	X	X	X	X	X
Lower pH (No Alkali Reactivity; Potentially More Corrosive Environment for Reinforcement)	X	X	X	X	X	X
Shorten Production Cycle Time	X	X	X	X	X	X
Potential For Just-In-Time Production	X	X	X	X	X	X
Improved Inventory Management / Cash Flow	X	X	X	X	X	X
Faster Clean-Up	X	X	X	X	X	X
Streamline Post-Curing Processes		X	X			X
Smaller Curing Area / Racks / Boards / Pallets	X	X	X			X
Extended Production Season		X	X	X	X	X
Reduced Equipment Maintenance	X	X	X	X	X	X

5.1.4 Milestone 1 Task 4: Build End-User Value Proposition for at Least 4 Applications

Solidia and LafargeHolcim have conducted value workshops to outline the economic impact of the novel cement and curing technologies on the concrete producers current operations. The result of this workshop is a comprehensive economic analysis detailing the impacts in different areas of a precast plants operations.

Solidia and LafargeHolcim have completed this economic analysis for two of the producers listed in **Table 3**. The output from each of these workshops is a pro forma income statement that outlines the impact of a complete plant conversion to Solidia's concrete system. It compares the current OPC production with water/steam curing to the Solidia system operation with CO_2 curing. Analyses for a concrete block and paver customer and for a concrete block customer have been completed. The results are shown below in **Tables 6** and **7** with an explanation of where the additional value is created in the process. These income statements and analyses will become a template for evaluating the value created by Solidia's system for each customer moving forward.

As illustrated in **Table 6**, the concrete block and paver customer shows an increase in revenue of ~ \$1.7MM was calculated for their production. This increase in revenue is due to extra capacity provided by reductions in cleaning time inside of the plant. This increase in revenue can be realized because the producer is at greater than 80% capacity.

The most significant impact of Solidia's CO_2-curing approach on a producer's business is reflected in a meaningful reduction in the cost of goods sold ("COGS"). Select product and process enhancements, as described in the table above, produce a \$1.5MM reduction in COGS. From a product enhancement perspective, COGS savings are realized in a reduction in certain admixtures required to achieve certain mechanical and chemical properties, reductions in color pigments, reductions in costs associated with in-field efflorescence management, and the reduction in white cement usage due in part to Solidia Cement's light color. From a process enhancement perspective, COGS savings are realized in faster equipment clean-up, less process material waste, and reductions in both work-in-process and finished goods inventories. These projected enhancements reflect the field experience gained during the Phase 1 trial.

The Solidia Cement system delivers a 35% gross margin increase, from \$8,847 million to \$12,066 million, over the incumbent Portland cement system. The pro forma assumes no change in selling, general, and administrative (SG&A) costs.

Producers should also expect an increase in depreciation due to capital costs associated with the installation of new CO_2 gas handling equipment and curing chamber retrofit, in this case, an increase of 200,000, effectively improving earnings before interest and taxes (EBIT). The pro forma holds tax rates constant for both systems resulting in an increase in net profit of \$1.97MM.

An important factor to mention is that the pro forma assumes no value for any carbon tax savings. Solidia Technologies believes favorable economics related to forthcoming carbon tax programs will add substantial value to its value positioning.

Table 6: Pro Forma Income Statement for the Concrete Block and Paver Customer (in 000's)

Per plant / year	Current Product Line	After SOLIDIA Conversion	SOLIDIA Value Added
Revenue	$21,010	$22,679	$1,669
Cost of Goods Sold	$12,163	$10,613	($1,550)
Gross Margin	$8,847	$12,066	$3,219
%	42%	53%	
SG&A	$1,261	$1,261	$0
EBITDA	$7,586	$10,805	$3,219
%	36%	48%	12%
Depreciation/Cost of Equipment	$780	$1,104	$324
EBIT	$6,806	$9,701	$2,895
%	32%	43%	10%
Interest	$369	$229	($140)
EBT	$6,437	$9,473	$3,035
Tax rate	35%	35%	
Net Profit	$4,184	$6,157	$1,973
%	20%	29%	9%

For the concrete block customer, the pro forma income statement in **Table 7** shows no increase in revenue, due in part to the fact that the plant is running below 80% capacity. This is a conservative estimate, as it assumes no additional sales or revenue streams over their current sales due to price premiums or market share gains for green, sustainable products.

As seen by the revenue numbers, concrete block customer is a smaller operation than the concrete block and paver customer. But Solidia's technology still has a major impact on the operation. The customers COGs are reduced by 4%. The production savings come from the same items outlined in the previous income statement, but since the concrete block market is a lower margin industry, they have less of an effect on overall bottom line of the producer.

With all of these factors taken into account, the Solidia Cement / Solidia Concrete technologies are still able to increase the overall net profit of the operation by 1.5%. The capital investment is covered for the producer in the value model as well.

These analyses indicate that a significant financial incentive exists for their adoption, without the need for environmental subsidies.

Table 7: Pro Forma Income Statement from the Concrete Block Customer (in 000's):

Per plant / year	Current Product Line	After SOLIDIA Conversion	SOLIDIA Value Added
Revenue	$5,558	$5,558	$0
Cost of Goods Sold	$3,213	$3,107	($106)
Gross Margin	$2,345	$2,451	$106
%	42%	44%	
SG&A	$333	$333	$0
EBITDA	$2,012	$2,117	$106
%	36%	38%	1.9%
Depreciation/Cost of Equipment	$780	$805	$25
EBIT	$1,232	$1,312	$81
%	22%	24%	1%
Interest	$135	$86	($49)
EBT	$1,096	$1,226	$130
Tax rate	35%	35%	
Net Profit	$713	$797	$84
%	13%	14%	1.5%

5.2 Milestone 2: Develop Pilot Scale Curing Processes for 4 Applications

This section will address Milestone 2: Develop Pilot Scale Curing Processes for Applications. CO_2-curing process development focused on generating products that met the customer specification while trying to keep the overall cost to a minimum.

Each of the following subsections will focus on the development of the Solidia Cement and curing technologies vis-a-vis a specific application. Each section will provide the reader with a brief description of the designated application and the progress on each task associated with Milestone 2.

> **Task 1: Research of different curing methodologies** will be addressed in the ***Fundamental Research Findings*** section. This section will describe the main developments for each application's mix design, CO_2-curing and flow design characterization.
>
> **Task 2: Build lab-scale curing reactors for different applications** will be summarized in the ***Curing Chamber Fabrication/Modification*** section, which reviews the fabrications and modifications performed based on the research findings.
>
> **Task 3: Optimize curing processes** will be addressed in the ***Process Optimization/Repeatability*** section. Process optimization was performed after the chambers had been fabricated and modified, and focused on the CO_2-curing of each application.
>
> Finally, **Task 4: Identify modifications required for customer curing equipment** will be discussed in the ***Potential Customer*** section.

It should be noted that, immediately prior to the commencement of the CCEMC project, Solidia had developed first and second iterations of CO_2-curing chambers. The first iteration chamber attempted to incorporate all aspects of CO_2-curing atmosphere control within the chamber. This included control of the atmosphere temperature, humidity, CO_2 content, flow rates, and flow direction. No attention was paid to the uniformity of these parameters throughout the chamber.

The second iteration chamber separated the chamber itself from the gas conditioning equipment. A CO_2-curing atmosphere distribution system was built within the chamber in the form of a plenum. These two attributes dramatically improved control of overall CO_2-curing, and the flexibility in adapting the chamber and gas conditioning system to the specific application.

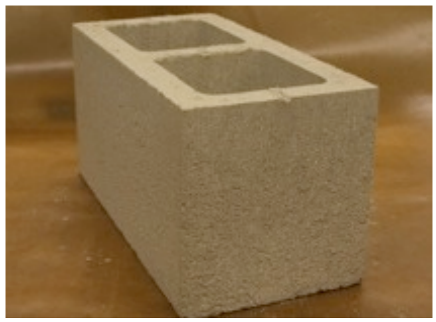
For each of the applications discussed below, Solidia received mix designs from prospective customers. At Solidia, work with the application mix designs consisted of mimicking the proportions, while taking into account the different grading of locally sourced raw materials. On occasion, a prospective customer would provide Solidia with a limited amount of their raw materials, but most of the optimization focus was on the application CO_2-curing development.

5.2.1 CONCRETE BLOCKS (CONCRETE MASONRY UNITS, CMU'S)

A Concrete block is a rectangular block used in construction. Concrete blocks have two "hollow cores" per block to reduce the amount of material in a block and hence to reduce weight and associated costs. Blocks come mainly in two varieties: standard and lightweight. The lightweight variety differs in the concrete mix design by the use of lightweight aggregate rather than natural stone. Another difference is that the lightweight variety uses less sand in its formulation. **Figure 1** below shows a concrete block formed with Solidia Cement and cured with Solidia's CO_2-curing technology.

Note that the fundamental research, curing chamber fabrication, optimization and repeatability research work for this application was performed prior to the commencement of the CCEMC-funded program. This work was not charged to CCEMC.

Figure 1. Concrete block formed with Solidia Cement



Development Items	
Product Description	Concrete Block
Forming	Raw concrete is vibro-compacted using a Columbia press
CO_2-Curing	Concrete blocks are CO_2-cured in an enclosed chamber utilizing an external gas conditioning system
Development Stage	Optimization/Scale up stage

Research Schedule

Activity	Date	Status
Fundamental research	November 2013	➻
Curing chamber fabrication	February 2014	➻
Optimization	March 2014	➻
Repeatability	March 2014	➻
Pilot-scale implementation trials (Phase 1)	April 2014 – December 2015	➻
Scale up	On going	■

➻= Completed ■ = Not yet complete

Milestone 2 Task 1: Concrete Block Curing Methodologies

Concrete blocks are formed using vibratory compaction and require a certain amount of forming water, dependent on the mix, to form and evenly disperse Solidia Cement throughout the product. The required amount of water for forming the block is higher than the water requirement necessary to convert calcium silicate to calcium carbonate during CO_2-curing. The drying process and curing process are directly related; hence one of the main objectives during the CO_2-curing process is the removal of water from the product in a controlled manner.

Non-uniform gas distribution within a chamber will cause varied drying rates (as well as reaction rates during CO_2-curing) dependent on the location of the blocks in the chamber. For this reason, maintaining a uniform gas composition inside the chamber has proven critical to producing concrete blocks with consistent performance.

Because concrete blocks have a high surface-area-to-volume ratio and relatively thin walls, attention must be given to the relative humidity profile used, especially during the early stages of CO_2-curing. Aggressive drying of blocks during these early stages of CO_2-curing results in weak and crumbling block corners, which are most prone to rapid drying.

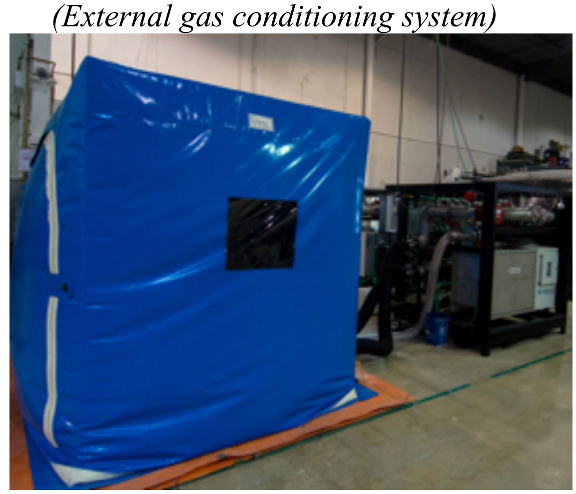
Based on these considerations, and the fact that most block manufactures are interested in cycling block through their curing chambers in approximately 20 hours, the prevailing curing strategy for blocks has been to gradually remove moisture from the blocks during CO_2-curing in a controlled manner via manipulation of gas temperature, relative humidity, and flow rate.

<u>Milestone 2 Task 2: Build Lab-Scale Curing Reactors for Concrete Blocks</u>

The first iteration of CO_2-curing chambers was used for the initial concrete block research. This chamber had a gas conditioning system that was contained inside of the chamber (**Figure 2**). Thus, gas temperature control and humidity control were performed inside the chamber by internal heating elements and cooling coils. Modifications were made to move the gas conditioning system outside of the chamber to provide better control over the gas temperature, humidity and flow (**Figure 3**). Moving this gas conditioning system outside of the chamber and using a blower to recirculate the gas yielded smaller temperature and humidity gradients to which the concrete blocks are exposed. This transition improved CO_2-curing uniformity, subsequently narrowing the range of product performance.

Figure 2. First iteration of CO_2-curing chamber (*Internal gas conditioning system*)

Figure 3. Updated CO_2-curing chamber *(External gas conditioning system)*



The first iteration chamber's flow distribution yielded poor uniformity throughout the chamber. A flow design model suggested that the addition of a plenum would provide a more uniform temperature and relative humidity profile throughout the chamber. The plenum was fabricated based on design suggestions from a computational fluid dynamics (CFD) flow design model. These modifications to the first iteration CO_2-curing chamber led to the development of the second iteration of CO_2-curing chambers. **Figures 4** and **5** illustrate a block based CFD model and the second iteration of CO_2-curing chambers with a gas distribution plenum.

Figure 4. CFD model of a block curing system

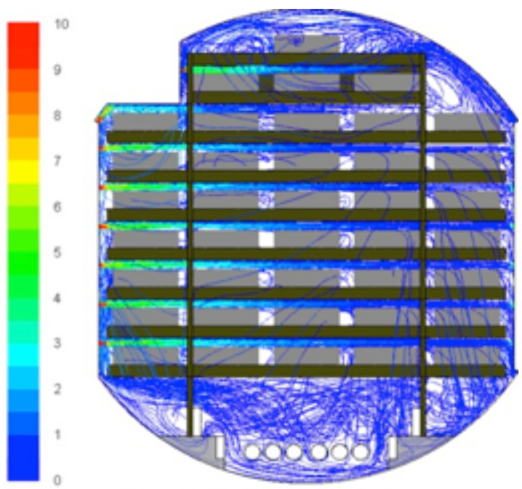


Figure 5. Solidia Concrete blocks on rack with plenum

<u>Milestone 2 Task 3: Optimized Concrete Block Curing Processes</u>

A statistical approach was taken to determine the range of conditions that would yield an acceptably cured block, acceptable referring to a product that meets all CSA (Canadian Standards) specifications. Varying both the temperature and relative humidity during experimentation in a controlled manner determined the statistical variation of the process and provided a set of operating conditions that would yield acceptable product.

Once the range of conditions that yielded an acceptable product was defined, optimization of the total CO_2-curing duration required and the associated energy consumption came into focus.

<u>Milestone 2 Task 4: Identify Modifications Required for Customer Curing Equipment</u>

Customer	Curing Chamber Assessment for Milestone 3 and Beyond
Concrete Block Customer 1	• Chamber Assessment: Garage style curing chamber, concrete construction that is manually loaded via fork lift, steam cured • Necessary modifications: o Seal (internal gas proofing) o Door (addition of gas tight door) o Gas distribution system added (plenum) o Gas conditioning system

Concrete Block Customer 2	• Chamber Assessment: “High rise” style curing chamber, steel construction, automated loading via finger cart, steam cured • Necessary modifications: o Sealing - internal gas proofing o Addition of gas tight door that is automated o Gas distribution system added (plenum) o Gas conditioning system
Concrete Block Customer 3	• Chamber Assessment: Autoclave curing chamber, steel construction, automated loading, steam cured • Necessary modifications: o Gas distribution system added (plenum) o Gas conditioning system
Concrete Block Customer 4	• Chamber Assessment: “High rise” style curing chamber, steel construction, automated loading via finger cart, steam cured • Necessary modifications: o Sealing - internal gas proofing o Addition of gas tight door that is automated o Gas distribution system added (plenum) o Gas conditioning system
Concrete Block Customer 5	• Chamber Assessment: Autoclave curing chamber, steel construction, automated loading, steam cured • Necessary modifications: o Gas distribution system added (plenum) • Gas conditioning system

5.2.2 CONCRETE PAVERS

Concrete pavers are brick-like pieces of concrete that are commonly used in outdoor applications, such as walkways, patios, platforms or driveways. Pavers come in various shapes, from rectangular to square, and in various sizes.

There are two main types of pavers: through-body, which is the one "layer" of concrete throughout the entire paver, and face pavers, which have two "layers" of concrete with the surface face containing no large aggregate to give a smooth finish on the face of the paver. **Figure 6** below shows through-body pavers being formed using Solidia Cement during a customer trial.

Note that the fundamental research, curing chamber fabrication, optimization and repeatability research work for this application was performed prior to the commencement of the CCEMC-funded program. This work was not charged to CCEMC.

Figure 6. Through-body rectangular pavers produced with Solidia Cement

Product Description	Concrete pavers
Forming	Raw concrete is vibro-compacted using a Columbia press
CO_2-Curing	Concrete pavers are CO_2-cured in an enclosed chamber utilizing an external gas conditioning system
Development Stage	Optimization /Scale up

Research Schedule

Activity	Date	Status
Fundamental research	February 2014	➻
Curing chamber fabrication	February 2014	➻
Optimization	March 2014	➻
Repeatability	March 2014	➻
Pilot-scale implementation trials (Phase 1)	April 2014 – May 2016	➻
Scale up	On going	■

➻= Completed ■ = Not yet complete

Milestone 2 Task 1: Paver Curing Methodologies

Concrete pavers are formed using vibratory compaction and require a certain amount of forming water, dependent on the mix, to form the product and to evenly disperse Solidia Cement throughout the product. Much like concrete blocks, concrete pavers are made with a “dry-cast” concrete mix. Meaning the concrete mixture has no slump and will not consolidate without vibration and/or compaction. The required amount of water for forming the paver is higher than the water requirement necessary to convert calcium silicate to calcium carbonate during CO_2-curing. The drying process and curing process are, therefore, directly related; hence one of the main objectives during the CO_2-curing process is the removal of water from the product.

Non-uniform gas distribution within a chamber will cause varied drying rates (as well as reaction rates during the CO_2-curing) dependent on the location of the pavers in the chamber. Curing pavers in an environment that allowed them to dry evenly allows for better reaction throughout the paver. **Figure 7** shows a humidity probe attached to a paver surface.

Figure 7. A probe monitors the temperature, relative humidity at paver surface during CO_2 curing

Pavers are produced in a multitude of sizes, shapes (bullnose, square, rectangular) and finishes. Curing research demonstrated that the geometry and densities will affect the curing parameters and the required curing duration to achieve a complete cure.

The aesthetic properties of concrete pavers are a critical consideration for producers. A wide range pigment combinations are used to achieve a broad spectrum of colors. In light of this, special attention was given to the impact that a given CO_2 curing profile may have on a paver’s final color.

Milestone 2 Task 2: Build Lab-Scale Curing Reactors for Pavers

The first iteration of CO_2-curing chambers was used for the initial concrete paver research. This chamber had the gas conditioning system contained inside of the chamber. Thus, gas temperature control and humidity control were performed inside the chamber. Modifications were made to move the gas conditioning system outside of the chamber to provide better control of the gas temperature and relative humidity, as well as increasing uniformity and decreasing energy consumption.

As in the case of concrete blocks, first iteration chamber's flow distribution yielded poor paver uniformity throughout the chamber. A flow model suggested that the addition of a plenum would provide a more uniform temperature and relative humidity profile throughout the chamber. The plenum was fabricated based off design suggestions from the flow model. These modifications to the first iteration CO_2-curing chamber led to the development of the second iteration of CO_2-curing chambers. **Figure 8** shows the results of a CFD model for gas flow inside a theoretical second iteration, paver curing chamber. **Figure 9** is a photograph of the curing chamber built to the specifications of the CFD model.

Figure 8. CFD model of a paver curing system

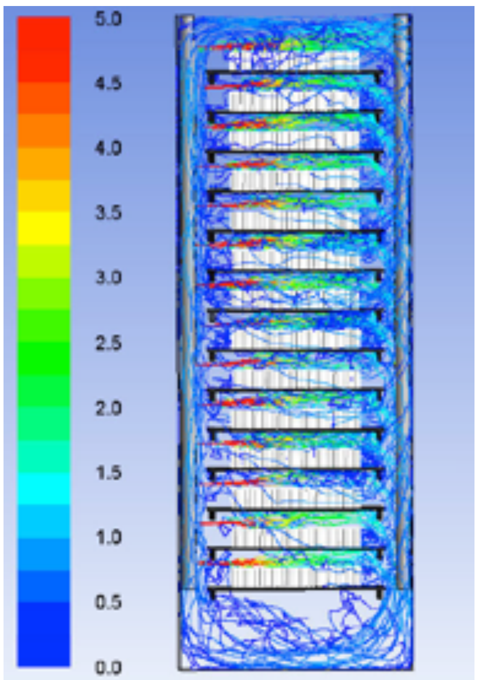
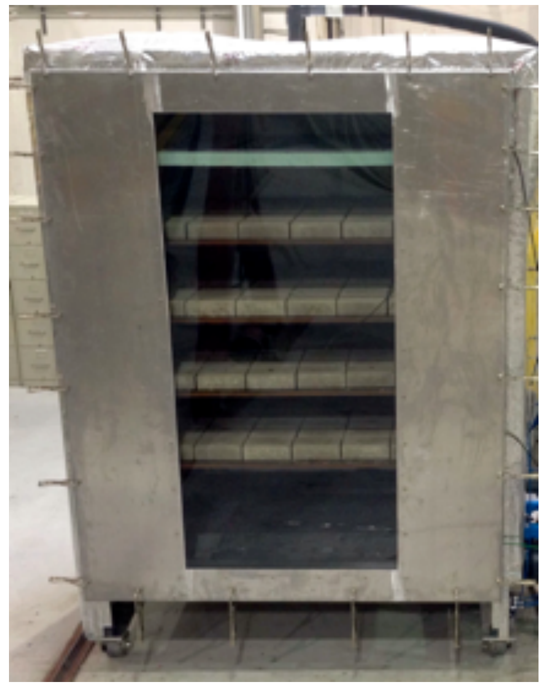


Figure 9. Mock-up curing system with plenum



Milestone 2 Task 3: Optimize Curing Processes

A statistical approach was taken for determining the range of conditions that would yield an acceptably cured paver, acceptable referring to a product that meets all CSA (Canadian Standards) specifications. Varying both temperature and relative humidity during experimentation in a controlled manner determined the statistical variation of the process and provided a set of operating conditions that would yield acceptable performance in products of varying size.

Once the range of conditions that yielded an acceptable product was defined, optimization of the total CO_2-curing duration required and associated energy consumption came into focus.

Milestone 2 Task 4: Identify Modifications Required for Customer Curing Equipment

Customer	**Curing Chamber Assessment for Milestone 3 and Beyond**
Paver Customer 1	• Chamber Assessment: "High rise" style curing chamber, steel construction, automated loading via finger cart, steam cured • Necessary modifications: o Sealing - internal gas proofing o Addition of gas tight door that is automated o Gas distribution system added (plenum) o Gas conditioning system
Paver Customer 2	• Chamber Assessment: "High rise" style curing chamber, steel construction, automated loading via finger cart, steam cured • Necessary modifications: o Sealing - internal gas proofing o Addition of gas tight door that is automated o Gas distribution system added (plenum) • Gas conditioning system
Paver Customer 3	• Chamber Assessment: "High rise" style curing chamber, steel construction, automated loading via finger cart, steam cured • Necessary modifications: o Sealing - internal gas proofing o Addition of gas tight door that is automated o Gas distribution system added (plenum) • Gas conditioning system

5.2.3 HOLLOW CORE SLABS

Hollow core slabs are large, pre-stressed, precast building elements widely used in the construction of floors in multistory apartment and retail buildings and other large structures such as sports stadia. Hollow core slabs are an example of a Category 2 application described in Section 5.1.1.

The slabs are extruded to lengths of about 120 meters, around pre-stressed steel cables, at a variety of thicknesses between 20 and 30 centimeters on 150 meter long heated steel beds. The extrusions contain 4 to 8 large circular or oval axial voids (the cores) along their lengths, which greatly reduce the amount of material in the slab, minimizing its weight and reducing its cost. **Figure 10** provides a visualization of a 20 cm thick hollow core slab produced with Solidia Cement. The long slabs are cut to the smaller lengths that are specified by in the building design.

Note: *The fundamental research work on this application described below was performed prior to the commencement of the CCEMC-funded program. This work was not charged to CCEMC.*

Curing chamber fabrication, optimization, repeatability and scale up work were all performed under the CCEMC-funded program. To this end, Solidia is developing a process for fabrication of precast hollow core slabs to serve the need for building construction in Alberta.

Figure 10. Hollow core slab formed with Solidia Cement

Product Description	Hollow Core Slab
Forming	Concrete is extruded/formed via vibro-compaction using an Elematic machine
CO_2-Curing	Hollow core slab is cast onto a heated bed. The CO_2-curing chamber is two plenums placed on either end of the slab with a tarp sealed to the plenums and the heated bed. An external gas conditioning system is used.
Development Stage	Product Development

Research Schedule

Activity	Date	Status
Fundamental research	December 2014	➻
Curing chamber fabrication	July 2014	➻
Optimization	February 2015	➻
Repeatability	October 2015	➻
Scale up	May 2015	➻

➻= Completed ■ = Not yet complete

Milestone 2 Task 1: Hollow Core Slab Curing Methodologies

Hollow core slabs are formed using an extruder, via vibratory compaction. This process requires a certain amount of forming water, dependent on the mix, to extrude the hollow core slab properly and evenly disperse Solidia Cement throughout the product. The required amount of water for forming the hollow core slab is higher than the water requirement necessary to convert calcium silicate to calcium carbonate during CO_2-curing.

The drying process and curing process are directly related; hence one of the main objectives during the CO_2-curing process is the removal of water from the product. Even removal of the excess forming water from the product is desired to maintain an even carbonation reaction along the length of the hollow core slab. Non-uniform gas distribution along the length of the hollow core will result in varied drying rates (as well as reaction rates during the CO_2-curing) yielding uneven curing over the length of the hollow core slab.

Computational fluid dynamic (CFD) flow models were used to simulate different mechanisms for the gas flow for the hollow core CO_2-curing process. This model was used to model the current state of the hollow core CO_2-curing process as well as provide feedback on modifications that could be made to the equipment to provide more uniformity over the length. The model also helped to predict the longest section that could be thoroughly cured using the existing equipment.

Milestone 2 Task 2: Build Lab-Scale Curing Reactors for Hollow Core Slabs

With the help of the CFD flow models, modifications to the plenums were implemented to yield a more uniform flow and atmosphere (temperature and relative humidity) over the length of the hollow core slab. The plenum was fabricated based off the suggestions from the model.

The CO_2 conditioning unit form the second iteration CO_2-curing chamber was used with the hollow core tarp chamber. Modifications to the system were made to accurately monitor the CO_2 concentration, relative humidity and temperature. Sensors were upgraded to ensure fidelity of the data. Pressure control and gas relief valves were added to the plenums to improve system control and process safety.

A gas tight sealing system was designed around the existing hollow core bed to create a gas tight tarp seal for the curing chamber.

A series of internal sensors was prepared and used to collect curing profiles as a function of time and length on the slab.

Curing profiles were developed for 6 meter sections of hollow core. Parameters such as gas flow, relative humidity and temperature along the length were manipulated to determine the conditions that would yield a uniformly cured hollow core slab.

A temperature increase of the casting bed improves the uniformity of the drying profile over the length of the product, in turn improving the CO_2-curing profile. This improvement in uniformity is because the heat being supplied from the bed is more uniform along the length of the slab.

The CFD simulations were compared with in house experiments for the process optimization. The CFD model predicted a flow pattern of a specific plenum design, after the plenum was fabricated and connected to the CO_2-curing system; the blower capacity was adjusted to maintain a consistent gas velocity. The resulting product verified the CFD predictions. To improve uniform gas distribution perforated PVC hoses were plugged into the inlet plenum and inserted into the cores of the hollow core slab. This resulted in an evenly cured hollow core slab and gave the potential for an additional option for scaling the process up to longer hollow core sections.

Note: *The curing methodology to develop homogeneous curing profiles in chambers through use secondary flow enhancers located inside the curing chamber, which is described in the following section and again in section 5.4.1 and section 5.4.3.C, was developed under a separate research program. As a result, this work was not charged to this program. However, the application and optimization of this concept, as applied to the hollow core application described below, was conducted under the scope of this program.*

Milestone 2 Task 3: Optimized Hollow Core Slab Curing Processes

Based on the work done in process optimization for CO_2 curing a 6 meter section of hollow core, curing profiles were developed for 16 meter sections of hollow core. A set-up was devised to enable the flow of the CO_2 curing gas through the cores of the hollow core slab and obviate the need for the perforated PVC hoses that were inserted into the cores of the 6 meter hollow core slabs used in the earlier 6 meter configuration.

This set-up includes forming holes from the top of the hollow core slab to access the cores of the hollow core slab at three points along the length of the hollow core slab. Specifically, these holes were located at the beginning, the center and at the end of the 16 meter hollow core section. These holes were formed using a plenum base as show in **Figure 11** below. As seen in **Figure 11**, the plenum base was left in the holes at the beginning and end of the 16 meter hollow core slab.

Figure 11. A plenum base used to punch holes from the top of the hollow core slab to access the cores and a heating unit placed on top of the plenum base

On one end of the hollow core slab, which would be distal to the gas inlet into the gas tight sealed tarp chamber, a heating unit was placed on top of the plenum prior to mounting the fan on top of the plenum. **Figure 11** also shows the placement of the heating unit on the plenum base. The heating unit was provided to compensate for the heat losses that occur during the gas transport across the length of the hollow core slab. On the other end of the hollow core slab, which would be proximal to the gas inlet, the plenum was placed on the plenum base without the heating unit and the fan was mounted on top of the plenum. The assembly of the plenum with the fan mounted on top of it is shown in **Figure 12**.

Figure 12. A plenum assembly with the fan mounted on top of the plenum sitting on top of the plenum base

The fan on the plenum with the heating unit inside it was oriented to suck gas out of the hollow core. In contrast, the fan was oriented to blow the gas into the hollow core for the second fan and plenum assembly which did not have the heating unit included inside it. Additionally, when the gas tight sealed tarp chamber was set-up, it was ensured that the gas inlet and outlet from the gas conditioning system was located at the end where the plenum assembly without the heating unit inside was situated.

The final set-up is schematically shown in **Figure 13**. This orientation was critical in achieving the desired gas flow to get a uniformly cured hollow slab.

Figure 13. Schematic showing hollow core bed with two plenum assemblies inside a gas tight tarp sealed chamber

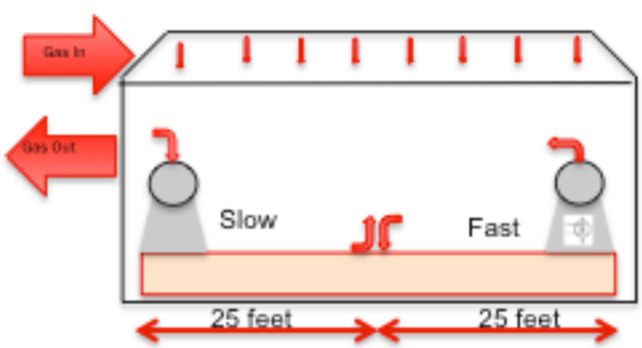


Figure 14 shows the actual assembly of a gas tight tarp sealed chamber housing a hollow core inside it and connected to the gas conditioning system. The hose on the top in **Figure 14** acts as the gas inlet transporting gas into the gas tight sealed tarp chamber from the gas conditioning system, while the hose on the bottom of **Figure 14** acts as the gas outlet transporting gas out of the gas tight sealed tarp chamber to the gas conditioning unit.

Figure 14. The actual assembly of a gas tight tarp sealed chamber housing a hollow core inside it and connected to the gas conditioning system

Using the above described set-up parameters such as gas flow, relative humidity and temperature along the length were manipulated to match the parameters observed and recorded for 6 meter sections of hollow core that yielded a uniformly cured hollow core slab. The uniform curing of the hollow core slab was established by coring samples at various locations along the length and width of the hollow core and evaluating them for compressive strength. The compressive strength target was 30-40 MPa.

In attempts to attain the compressive strength target and demonstrate uniform cure, it was identified that the fan on the plenum closer to the end plate having inlet and outlet hoses that transport the conditioned gas from the gas conditioning system needs to operate a speed slower than the fan at the other end of the hollow core slab. This optimization ultimately resulted in a uniformly cured 16 meter section of hollow core slab. In this instance too, consistent with the earlier runs of a 6 meter section of hollow core, temperature increase of the casting bed was seen to improve the uniformity of the drying profile over the length of the product, in turn improving the CO_2-curing profile.

A seminal advantage of this system is the ability to be expand the capabilities of the system to facilitate the cure of longer hollow core slabs by repeating the set-up back-to-back, thereby elongating the length of the hollow core slab that is possible to be cured using this methodology. Care needs to be taken to scale-up the CO_2 gas conditioning system simultaneously to support the scaled-up process while implementing this expansion.

The CFD simulations were compared with in house experiments for the process optimization. The CFD model predicted a flow pattern of a specific plenum design, after the plenum was fabricated and connected to the CO_2-curing system; the blower capacity was adjusted to maintain a consistent gas velocity. The resulting product verified the CFD predictions.

<u>Milestone 2 Task 4: Identify Modifications Required for Customer Curing Equipment</u>

Customer	**Curing Chamber Assessment for Milestone 3 and Beyond**
Hollow Core Customer, Alberta	• Chamber Assessment: heated base, tarp covering product • Necessary modifications: o Gas distribution system o Gas conditioning system o Tarp sealing system o Heated base modification to reach elevated temperature

5.2.4 ARCHITECTURAL PRECAST PANELS

Architectural precast panels are construction products produced by casting raw concrete into a reusable mold of the desired product dimensions. The product can be pre-stressed or post-stressed. Precast panels are an example of the second category of product that requires longer lead times to market. While precast panels can have a diverse set of applications, this study will focus primarily on building walls.

Solidia Technologies is currently focusing on wall panel applications that vary in length and height dimensions, but are held between 7 and 18 cm thick. **Figure 15** is an image of an architectural precast panel that will be a building wall.

It is anticipated that a Research and Development trial will be conducted at Architectural Precast Panel Customer in 2016.

Figure 15. Architectural Precast Panel

Product Description	Architectural Precast Panel (wetcast)
Forming	Raw concrete is poured into a mold and is self-compacted into the shape (self-compacting concrete, SCC)
CO_2-Curing	Wetcast panels are cured in a chamber with a heated base utilizing an external gas conditioning system
Development Stage	Product development

Research Schedule

Activity	Date	Status
Fundamental research	April 2015	➽
Curing chamber fabrication	March 2016	■
Optimization	Ongoing	■
Repeatability	Ongoing	■
Scale up	Not started	■

➽= Completed ■ = Not yet complete

Milestone 2 Task 1: Architectural Precast Panel Curing Methodologies

Architectural precast panels are formed by pouring raw concrete into molds. The raw concrete self-compacts into the mold form. The amount of forming water necessary to achieve the flow required for a self-compacting concrete is greater than in the other concrete applications reported in this study. Thus, the process of removing water from the concrete to initiate and maintain CO_2-curing poses a major challenge.

As in the case of the hollow core slab, the architectural precast panel will require a heated base to supplement the gas conditioning system in providing energy transfer necessary for uniform water removal from the panel. Additionally, the gas flow over the panel should have a high enough velocity to remove the vaporized water from the headspace of the chamber.

Milestone 2 Task 2: Build Lab-Scale Curing Reactors for Architectural Precast Panels

The gas conditioning system from the second iteration of Solidia curing chambers will be used for the architectural precast work, with no modifications. Initially plenums were designed to provide uniformity of the CO_2 in the headspace of the chamber in the horizontal direction, but not in the vertical direction. This was to create uniform temperature, relative humidity and CO_2 concentration over the length of the plenum.

Subsequently, a new chamber design was identified to cure wet cast concrete parts. **Figure 16** below shows a wet cast, flow through chamber that was developed to CO_2 cure a 10 cm thick wet cast concrete part. The target was to cure the concrete part with 10 cm cross-sectional thickness in 16 hours and achieve a compressive strength of greater than 35 MPa. These process and product requirements for curing duration and strength were provided by the Architectural Precast panel Customer.

Figure 16. A wet cast, flow through chamber used for CO_2 curing a 10 cm thick wet cast concrete part

The wet cast, flow through chamber is characterized by the presence of a heating pad. The mold, in which the wet concrete mix is cast, is placed on top of the heating pad with the metal bottom of the mold in contact with the heating pad. The heating pad provides heat for curing the base of the concrete facilitating a uniform cure of the part including the base. The heated pad used can be seen in **Figure 17**.

Figure 17. A heating pad used for curing the base of a wet cast concrete geometry

Secondary circulation fans were deployed to promote a uniform flow over the surface of the concrete part. The secondary fans used in the wet cast flow through chamber can be seen in **Figure 18**. Also seen in **Figure 18** is the mold placed on top of the heating pad.

Figure 18. Secondary fans used in the wet cast flow through chamber for assisting with the uniformity of gas flow inside the wet cast flow through chamber

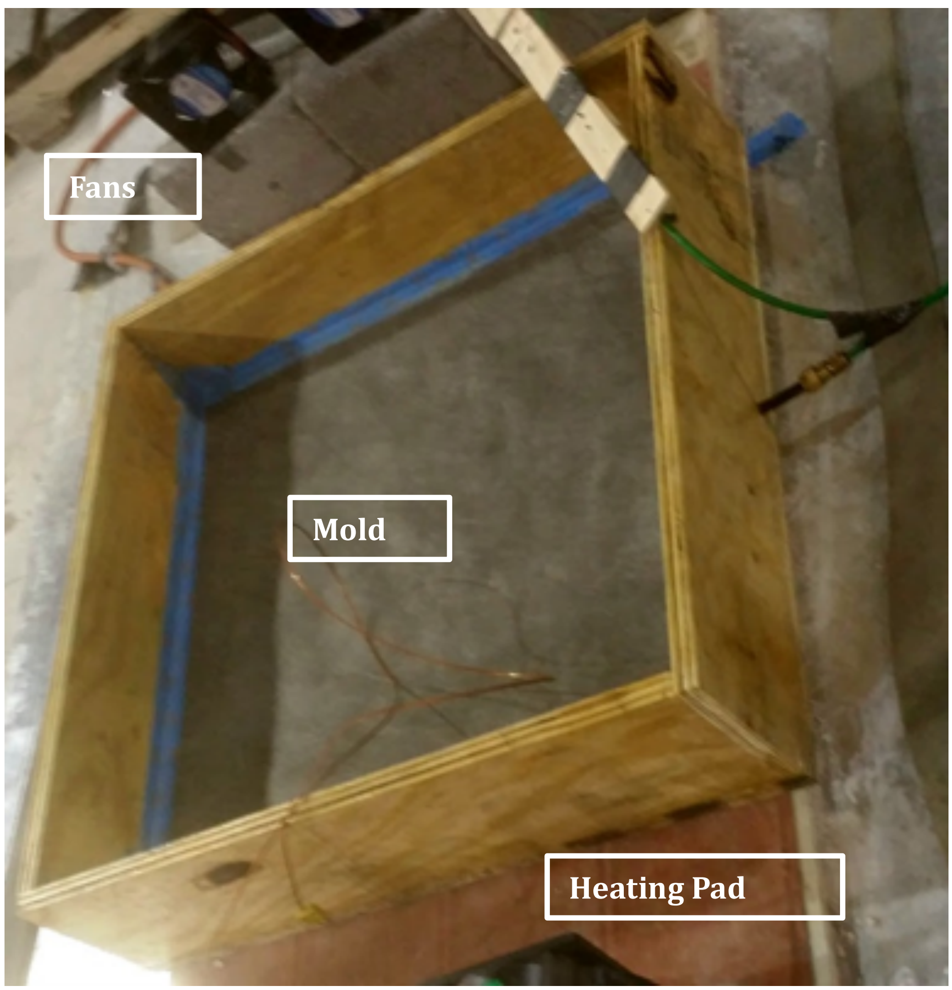
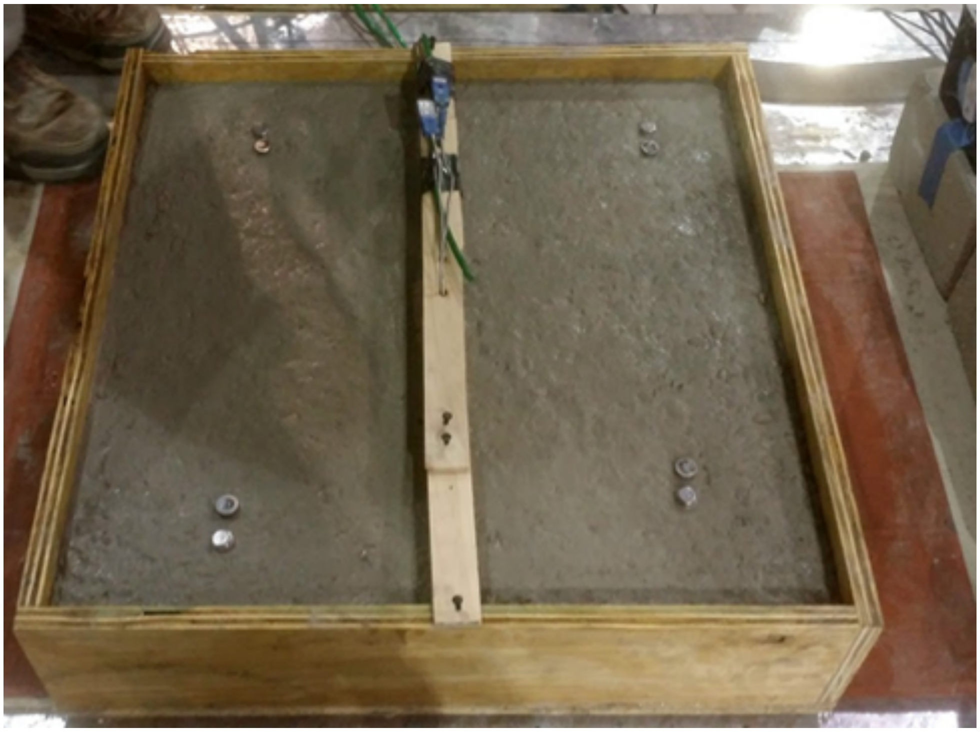


Figure 19 shows the mold filled with wet cast concrete mix ready to be placed inside the wet cast flow through chamber shown in **Figure 16**. The wet cast flow through chamber was connected to a gas conditioning system for CO_2 curing of the wet cast concrete part.

Figure 19. A mold filled with wet cast concrete mix prior to being placed inside the wet cast flow through chamber



Using the wet cast flow through chamber, a 10 cm x 60 cm x 60 cm concrete slab was uniformly cured in-house at Solidia Technologies in 16 hours, as shown in **Figure 20.** The samples cured with the above described methodology resulted in a compressive strength greater than 35 MPa.

Figure 20. A uniformly cured 10 cm x 60 cm x 60 cm concrete slab

Milestone 2 Task 3: Optimized Architectural Precast Panel Curing Processes

Mix design optimizations have been performed in order to minimize the water content in the raw concrete and, thereby, moderate the drying and curing time of the panels. Pre-drying of the panels (prior to CO_2-exposure) is also being evaluated.

As a next step, this effort will continue to scale-up the lab-scale curing process to uniformly cure wider and longer slabs; up to 400 cm wide and 760 cm long.

Milestone 2 Task 4: Identify Modifications Required for Customer Curing Equipment

<table>
<tr><th>Customer</th><th>Curing Chamber Assessment for Milestone 3 and Beyond</th></tr>
<tr><td>Architectural Precast Panel Customer, Alberta</td><td>Chamber Assessment: steel base with either wood or steel mold, tarp covering product
Necessary modifications:
Gas distribution system
Gas conditioning system
Tarp sealing system
Heated base</td></tr>
</table>

5.3 Milestone 3: Pilot Scale Implementation of at Least 1 Precast Application at an Industrial Precast Facility

This section addresses Milestone 3: Pilot Scale Implementation of at least 1 precast application at an industrial precast facility, and the associated tasks. Pilot scale implementation will hereafter be referred to as Phase 1 trials.

Task 1: Identify customers for pilot plant implementations will be addressed in the *Customer Profile* section; this section will describe customer products, cement consumption and location of the customer.

Task 2: Understand customer plant economics will be reported in the *Value Proposition* section, which describes how the implementation of the Solidia CO_2-curing technology will add value and potential savings to the customer's current process.

Tasks 3 & 4: Demonstrate pilot production and conduct extensive 3rd party testing will be summarized in the *Key Objectives, Preliminary Results* and *Customer Assessment* sections. These sections review the objectives of the pilot production demonstration, the results performed by a 3rd party testing facility and the customer's overall assessment of the Solidia CO_2-curing technology.

Task 5: Identify additional customers will be reviewed independently in Section 5.3.9 with a compilation of additional potential customers that have been identified in Canada.

<u>**Phase 1 Trial Description**</u>

The purpose of a Phase 1 trial is to successfully mix, form, and cure selected precast products made with Solidia Cement. In each case, a concrete partner's mixing, forming and related process equipment was used in the partner's manufacturing facility to form a concrete object for curing. Product curing is conducted in the partner's manufacturing facility in a portable CO_2-curing chamber supplied and operated by Solidia. In this manner, the customer is provided with first-hand experience working with Solidia Cement and CO_2-curing.

The products made during the trial are tested in accordance with the partner's testing specifications. The trial objectives are tailored to suit the desired product or value items that the precast concrete partner wants to evaluate. The data generated during Phase 1 trials is used to further the technology implementation process.

Phase 1 trials have been carried out at six different potential customer sites during the period covered by this report. The first trial involved making lightweight concrete blocks; the second trial involved making normal weight concrete blocks; the third trial involved making both lightweight and normal weight concrete blocks; the fourth trial involved making pavers and normal weight concrete blocks; the fifth and sixth trials involved making concrete pavers. A seventh trial is scheduled for July, 2016 at Concrete Block Customer 5.

5.3.1 CONCRETE BLOCK CUSTOMER 1
Alberta, Canada

Phase 1 Field Trial

Trial Type	Product Type
Field trial	Lightweight Block
Trial date	4/07/2014 to 4/16/2014

Customer Profile

Products	Lightweight Block
Cement consumption	~ 10,000 tonnes per year
Location	Alberta
Production process	Vibrocompacted, tall chamber, controlled environment curing

Figure 21. Concrete block produced during Phase 1 Trial performed at Concrete Block Customer 1

Value Proposition

Benefit Summary	Product	Process	Sustainability
Cures with CO_2 (not H_2O)	• No $Ca(OH)_2$ = improved durability • Reduced alkali-silica reactivity • Better resistance to deicing salts • Better resistance to sulfate attack	• Reduced cement waste • Faster clean-up	• 70% reduction CO_2 / ton cement • Can use waste CO_2 • CO_2 stored as stable calcium carbonate
28 day strength in 24hr	• Improved quality control	• Reduced finished concrete waste	• No added water during curing
Additional	• Same mix designs • Same raw materials • Broader choice of raw materials • Lighter cement color • Same strength / hardness	• Same mixing / forming • Minimal process modifications	• Local raw materials • Potential carbon credits

Key Objectives:

Demonstration	• Validate compatibility between Solidia Cement and customers production equipment. Successfully form products on customer's production line. • Demonstrate non-hydraulic properties of Solidia Cement.
Optimization	• Refine mix design and curing duration to meet performance specifications and customer expectations.
Finished Products Assessment	• Produce lightweight block that meet 15 MPa compressive strength specification. • Produce products that can successfully undergo post processing, burnishing

Preliminary Results:

Demonstration	➻ Compatibility seen with process equipment, facilities production team able to produce Solidia Cement based blocks. ➻ Non-Hydraulic nature of Solidia cement demonstrated by storing mixes overnight and observing still-formable mix.
Optimization	➻ Mix design and 16 hour CO_2 curing duration yield products that meet compressive strength criteria.
Finished Products Assessment	➻ Solidia Cement based products tested at 16 MPa on average (at 3rd party lab) ➻ Solidia Cement based products successfully burnished yielding appropriate ascetics

Customer Assessment

- Plant crew expressed that the non-hydraulic nature of Solidia Cement significantly reduced production equipment clean up time.
- Production manager indicated that products made with Solidia Cement had marketable color, and increased pigmenting options.
- Production manager felt Solidia Cement based products could potentially increase their market share.

Next Steps

Activity	Date	Status
Finished product assessment	4/18/2014	➻
Detailed trial summary	4/30/2014	➻
Trial report	4/25/2014	➻
Post-trial review	5/7/2014	➻
Implement P3* system	12/1/2016	■

*P3 refers to "Phase 3" implementation, described in Section 5.4.3. ➻= Completed ■ = Not yet complete

Potential CO_2 Impact

	Plant Information:	Formula	Masonry: Block (current)	Masonry: Block (future)
A	Plant Cement Consumption (tons/year)		10000	10000
B	CO_2 savings for product (kg CO_2 /Ton Cement)*		342	450
C	Total CO_2 savings for plant (Tons CO_2/year)	a * b/1000	3420	4500

*** Estimate based on mix design and finished product weight. Will be calculated directly.**

The potential CO_2 impact considers both the CO_2 savings associated with both the production of the cement and the production of the concrete. The potential CO_2 savings are calculated assuming entire plant conversion to Solidia Cement with current technology and the future state where the technology will be more efficient.

5.3.2 CONCRETE BLOCK CUSTOMER 2
Ontario, Canada

Phase 1 Field Trial

Trial Type	Product Type
Field trial	Normal weight block
Trial duration	2/09/15 – 2/13/15

Customer Profile

Products	Normal weight blocks
Cement consumption	~ 11,000 tonnes per year
Location	Ontario, Canada
Production process	Vibropressed block, controlled environment curing

Figure 22. Picture of blocks being produced with Solidia Cement at Concrete Block Customer 2 site

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Value Proposition

Benefit Summary	Product	Process	Sustainability
Cures with CO_2 (not H_2O)	• No $Ca(OH)_2$ = improved durability • Reduced ASR • Better resistance to deicing salts • Better resistance to sulfate attack	• Reduced cement waste • Faster clean-up	• 70% reduction CO_2 / ton cement • Can use waste CO_2 • CO_2 stored as stable calcium carbonate •
28 day strength in 24hr	• Improved quality control • Broader customization	• Reduced finished concrete waste	• No added water during curing
Additional	• Same mix designs • Same raw materials • Broader choice of raw materials • Lighter cement color • Same strength / hardness	• Same mixing / forming • Minimal process modifications	• Local raw materials • Potential carbon credits

Key Objectives:

Demonstration	• Validate compatibility between Solidia Cement and customer's production process equipment. Successfully form products on customer's production line. • Demonstrate non-hydraulic properties of Solidia Cement.
Optimization	• Refine mix design and curing duration to meet performance specifications and customer expectations.
Finished Products Assessment	• Produce normal weight blocks that meet or exceed 15MPa compressive strength specification. (*CSA spec*. A154.1-04 *classification* H/15/A/M) • Produce products that meet customer's aesthetic expectations.

Preliminary Results:

Demonstration	➻ Compatibility with process equipment shown, facilities production team able to produce Solidia Cement based blocks. ➻ Non-Hydraulic nature of Solidia cement demonstrated by storing mixes overnight and observing still formable mix.
Optimization	➻ Identified Mix design with Solidia Cement that yields products which meet compressive strength specification after subjecting blocks to extended cure time. (>20hr) ■ Additional optimization of curing conditions are required to meet strength specification in under 20 hours of CO_2 curing.
Finished Products Assessment	➻ Solidia Cement based products meet 15 MPa strength specification when cured for >20hr. More detailed testing to be included in final report. ➻ Lighter shade of block is appealing.

Customer Assessment

- Owner would like to pursue Solidia technology adoption.
- Owner requires a product to compete with other green products due to frequent requests from architects.
- Owner would like to see further improvement of product performance, which will take place at Solidia's Piscataway NJ location using customer supplied raw materials.
- Owner was open to changes in mix design for future work as long as the current source of aggregate is used and aesthetic quality maintained.
- Pending results, an additional trial is desired at an alternate location.
- Owner's other facility will be further assessed as an option for conversion.
- Owner expressed interest in post processing of blocks to achieve architectural finishes.

Next Steps

Activity	Date	Status
Finished product assessment	4/20/2015	➢
Detailed trial summary	4/9/2015	➢
Trial report	5/7/2015	➢
Curing condition optimization	6/08/2015	➢
Ship samples to customer	6/26/2015	➢
Post-trial review	6/26/2015	➢
Implement P3 system	12/1/2016	■

➢= Completed ■ = Not yet complete

Potential CO_2 Impact

	Plant Information:	**Formula**	**Masonry: CMU (current)**	**Masonry: CMU (future)**
A	Plant Cement Consumption (tons/year)		11000	11000
B	CO_2 savings for product (kg CO_2/Ton Cement)*		342	450
C	Total CO_2 savings for plant (Tons CO_2/year)	a * b/1000	3762	4950

*** Estimate based on mix design and finished product weight. Will be calculated directly.**

The potential CO_2 impact considers both the CO_2 savings associated with both the production of the cement and the production of the concrete. The potential CO_2 savings are calculated assuming entire plant conversion to Solidia Cement with current technology and the future state where the technology will be more efficient.

5.3.3 CONCRETE BLOCK CUSTOMER 3
Ontario, Canada

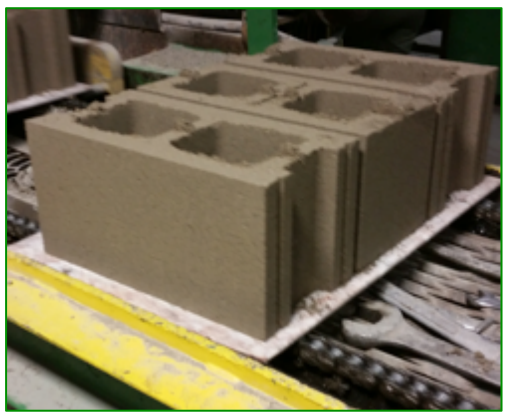
Phase 1 Combination

Trial Type	Product Type
Field trial	Normal weight Block
R&D trial	Lightweight block primarily comprised of expanded slag
Trial duration	2/17/15 – 2/20/15 (8 batches over 3 days)

Customer Profile

Products	Normal and lightweight autoclaved blocks
Cement consumption	~10,000 tonnes per year
Location	Ontario, Canada
Production process	Vibropressed block; autoclave curing

Figure 23. Solidia Cement based blocks after forming



Value Proposition

Benefit Summary	Product	Process	Sustainability
Cures with CO_2 (not H_2O)	• No $Ca(OH)_2$ = improved durability • Reduced ASR • Better resistance to deicing salts • Better resistance to sulfate attack	• Reduced cement waste • Faster clean-up • ***Reduced energy cost of curing***	• 70% reduction CO_2 / ton cement • Can use waste CO_2 • CO_2 stored as stable calcium carbonate
28 day strength in 24hr	• Improved quality control • Broader customization	• Reduced finished concrete waste	• No added water during curing
Additional	• Same mix designs • Same raw materials • Broader choice of raw materials • Lighter cement color • Same strength / hardness	• Same mixing / forming • Minimal process modifications • Fewer admixtures required	• Local raw materials • Potential carbon credits

<u>Field Trial:</u> Normal weight block

Key Objectives:

Demonstration	• Validate compatibility between Solidia Cement and customer's production process equipment. Successfully form products on customer's production line.
Optimization	• Refine mix design and curing duration to meet performance specifications and customer expectations.
Finished Products Assessment	• Produce normal weight blocks that meet or exceed 15 MPa compressive strength specification. (*CSA spec*. A154.1-04 *classification* H/15/A/M) *Customer would prefer 25Mpa.* • Produce products that meet customer's aesthetic expectations.

Preliminary Results:

Demonstration	➢ Compatibility with process equipment shown, facilities production team able to produce Solidia Cement based blocks.
Optimization	➢ Mix design and 18hr CO_2 curing duration are acceptable for block production.
Finished Products Assessment	➢ Solidia Cement based products test at 20MPa on average with a high of high of 25MPa. More detailed testing to be included in final report ➢ Customer feels the product aesthetics are ***"marketable".***

<u>Research Trial:</u> Lightweight block

Key Objectives:

Evaluation	• Evaluate the incorporation of Solidia Cement and Solidia CO_2 curing with expanded slag based lightweight blocks and the associated production process.
Optimization	• Refine mix design and curing duration with attention to performance specifications and customer expectations.

Preliminary Results:

Evaluation	■ Two batches of lightweight block were produced. In both cases, either water content or mixing sequence was flawed; this led to poor forming. Due to trial time constraints, additional trials with lightweight block were scheduled to take place at Solidia. Raw materials shipped, in-house trials underway.
Optimization	■ Optimization work to take place with customer's raw materials at Solidia's Piscataway NJ location.

Customer Assessment

- Owner would like to pursue Solidia technology adoption.
- Owner indicated that products made during trial were “highly marketable”.
- Owner believes that Solidia Cement based products will be readily accepted in the market.
- Owner indicated that due to time constraints, additional optimization around lightweight blocks would have to occur at Solidia’s Piscataway NJ facility.
- Owner requires a strategy for converting an autoclave to be compatible with Solidia’s curing process.
- Following this, owner would like to convert 1 of 5 autoclaves to produce 4200 Solidia Cement based blocks per cycle.
- Owner believes that a CO_2 curing process would significantly reduce curing cost compared to current autoclave curing process.
- Pending success with single autoclave conversion, owner would be willing pursue a full technology adoption.

Next Steps

Activity	Date	Status
Finished product assessment	4/23/15	➽
Detailed trial summary	4/28/15	➽
Trial report	5/8/15	➽
Post-trial review	6/12/15	➽
Lightweight block curing optimization	6/20/15	➽
Implement P3 system	12/1/2016	■

➽= Completed ■ = Not yet complete

Potential CO_2 Impact

	Plant Information:	**Formula**	**Masonry: Block (current)**	**Masonry: Block (future)**
A	Plant Cement Consumption (tons/year)		10000	10000
B	CO_2 savings for product (kg CO_2/Ton Cement)*		342[1]	450[1]
C	Total CO_2 savings for plant (Tons CO_2/year)	a * b/1000	3420[1]	4500[1]

[1] These values do not yet include energy savings associated with avoiding the high temperatures and pressures of the incumbent, autoclave process.

*** Estimate based on mix design and finished product weight. Will be calculated directly.**

The potential CO_2 impact considers both the CO_2 savings associated with both the production of the cement and the production of the concrete. The potential CO_2 savings are calculated assuming entire plant conversion to Solidia Cement with current technology and the future state where the technology will be more efficient.

5.3.4 CONCRETE BLOCK CUSTOMER 4 / PAVER CUSTOMER 1

Ontario, Canada

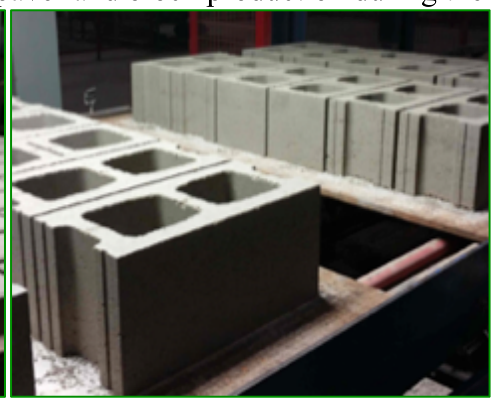
Phase 1 Field Trial

Trial Type	Product Type
Field trial	60mm pavers & normal weight block
Trial date	2/23/15 – 2/27/15 (Pavers: 2 days 4 batches, Blocks: 1 day 2 batches)

Customer Profile

Products	Pavers, blocks, & decorative stone veneer
Cement consumption	~ 12,000 tonnes per year
Location	Ontario
Production process	Vibropressed, tall chamber, controlled environment curing

Figure 24. Solidia Cement based paver and block production during the trial



Value Proposition

Benefit Summary	Product	Process	Sustainability
Cures with CO_2 (not H_2O)	• No $Ca(OH)_2$ = improved durability • Reduced ASR • Better resistance to deicing salts • Better resistance to sulfate attack	• Reduced cement waste • Faster clean-up • Reduced cost of curing • Rapid cure	• 70% reduction CO_2 / ton cement • Can use waste CO_2 • CO_2 stored as stable calcium carbonate
28 day strength in 24hr	• Improved quality control • Broader customization	• Reduced finished concrete waste	• No added water during curing
Additional	• Same mix designs • Broader choice of raw materials • Lighter cement color • Same strength / hardness	• Same mixing / forming • Minimal process modifications • Fewer admixtures required	• Local raw materials • Potential carbon credits

<u>Field Trial:</u> Normal weight block

Key Objectives:

Demonstration	• Validate compatibility between Solidia Cement and customers production process equipment. Successfully form products on customer's production line.
Finished Products Assessment	• Produce normal weight blocks that meet or exceed 15MPa compressive strength specification. (*CSA spec*. A154.1-04 *classification* H/15/A/M)

Preliminary Results:

Demonstration	➻ Compatibility seen with process equipment, facilities production team able to produce Solidia Cement based blocks.
Finished Products Assessment	➻ Solidia Cement based products meet 15 MPa strength specification when CO_2 cured for ~20hr. More detailed testing to be included in final report.

<u>Field Trial:</u> 60mm pavers

Key Objectives:

Demonstration	• Validate compatibility between Solidia Cement and customers production process equipment. Successfully form products on customer's production line. • Demonstrate non-hydraulic properties of Solidia Cement.
Optimization	• Refine mix design and curing duration to meet performance specifications and customer expectations.
Finished Products Assessment	• Produce 60mm pavers that meet 50MPa strength specification.

Preliminary Results:

Demonstration	➻ Compatibility seen with process equipment, facilities production team able to produce Solidia Cement based pavers. ➻ Non-Hydraulic nature of Solidia cement demonstrated by storing mixes overnight and observing still-formable mix.
Optimization	➻ Mix design and 18hr CO_2 curing duration yield 60mm products that meet compressive strength criteria.
Finished Products Assessment	➻ Solidia Cement based products tested at 58MPa on average. More detailed testing to be included in final report

Customer Assessment

- Vice President of Technical Services is interested in pursuing pavers as the primary product for Solidia technology adoption.
- Vice President of Manufacturing Concrete Products interested in incorporating CO_2 curing capabilities at another facility that primarily produces blocks
- VP of Technical Services sees advantages associated with the non-hydraulic nature of Solidia Cement in the form of increased product color capabilities. Before combining at the press, multiple color types are stored in hoppers; this is limited due to the setting of the mix.
- VP of Technical Services will conduct tests on products made during trial; pending results, a review will be scheduled to discuss plans moving forward with technology adoption
- Customer has experience with CO_2 in block production process. CO_2 infrastructure remains on site. Customer has stopped using this process.

Next Steps

Activity	Date	Status
Finished product assessment	5/06/2015	➽
Detailed trial summary	4/28/2015	➽
Trial report	5/14/2015	➽
Post-trial review	6/11/2015	➽
Implement P3 system	12/1/2016	■

➽= Completed ■ = Not yet complete

Potential CO_2 Impact

	Plant Information:	Formula	Masonry: Block (current)	Masonry: Block (future)	Masonry: Paver (current)	Masonry: Paver (future)
a	Plant Cement Consumption (tons/year)		1000	1000	10000	10000
b	CO2 savings for product (kg CO2/Ton Cement)*		342	450	342	457
c	Total CO2 savings for plant (Tons CO2/year)	a * b/1000	342	450	3420	4570

*** Estimate based on mix design and finished product weight. Will be calculated directly.**

The potential CO_2 impact considers both the CO_2 savings associated with both the production of the cement and the production of the concrete. The potential CO_2 savings are calculated assuming entire product line conversion to Solidia Cement with current technology and the future state where the technology will be more efficient.

For this manufacturer approximately 10,000 tonnes of cement is used per year to produce pavers, approximately 1,000 tonnes of cement is used to produce blocks and the remainder is for decorative stone veneer. The potential CO_2 impact was calculated based off the current production of the manufacturer.

5.3.5 PAVER CUSTOMER 2

Quebec, Canada

Phase 1 Combination

Trial Type	Product Type
Field trial	Pavers, 200 x 100 x 60mm (7 batches)
R&D trial	Pressed slab, 400 x 600 x 65mm (1 batch)
Trial duration	7/20/15 – 7/27/15 (8 batches over 4 days)

Customer Profile

Products	Masonry hardscape products (pavers & SRW)
Cement consumption	~8,000 tonnes per year
Location	Quebec, Canada
Production process	Vibropressed forming, high-rise chambers, uncontrolled

Figure 25. Solidia Cement based large paver produced during the trial

Value Proposition

Benefit Summary	Product	Process	Sustainability
Cures with CO_2 (not H_2O)	• No $Ca(OH)_2$ = improved durability • Reduced ASR • Better resistance to deicing salts • Better resistance to sulfate attack	• Reduced cement waste • Faster clean-up • Reduced cost of curing • Rapid cure	• 70% reduction CO_2 / ton cement • Can use waste CO_2 • CO_2 stored as stable calcium carbonate
28 day strength in 24hr	• Improved quality control • Broader customization	• Reduced finished concrete waste	• No added water during curing
Additional	• Same mix designs • Broader choice of raw materials • Lighter cement color • Same strength / hardness	• Same mixing / forming • Minimal process modifications • Fewer admixtures required	• Local raw materials • Potential carbon credits

Field Trial: Pavers, 200 x 100 x 60mm

Key Objectives:

Demonstration	• Validate compatibility between Solidia Cement and customer's production process equipment. Successfully form products on customer's production line.
Optimization	• Refine mix design and curing duration to meet performance specifications and customer expectations.
Finished Products Assessment	• Produce pavers that meet or exceed CSA A231 50MPa compressive strength specification. • Produce products that meet customer's aesthetic expectations.

Preliminary Results:

Demonstration	➻ Compatibility with process equipment shown, facilities production team able to produce Solidia Cement based blocks.
Optimization	➻ Mix design and 20hr CO_2 curing duration are acceptable for paver production.
Finished Products Assessment	➻ Solidia Cement based products surpassed 50MPa requirement. Detailed testing to be included in final report. ➻ Customer feels the product aesthetics are acceptable.

Development Trial: Slab paver, 400 x 600 x 65mm

Key Objectives:

Evaluation	• Evaluate the use of Solidia Cement in slab products.
Finished Products Assessment	• Subject slabs to post-processing "shot blasting" and evaluate surface finish.

Preliminary Results:

Evaluation	➻ Slabs successfully formed with Solidia Cement. Mix water content slightly off, target densities not achieved.
Finished Products Assessment	➻ Products subject to shot-blasting after 20 hours of curing. Surface finish texture rougher than intended, machine settings can be adjusted. Defects from forming without proper water content noted.

Customer Assessment

- Plant manager does not see any necessary change in operation when making Solidia Cement based products.
- Vice President says, "***This cement is lighter, which is better.***"
- Products that require post-processing are in high demand. This post-processing is restrictive due to long curing times and requires substantial non-value added activity. Products are picked up with a forklift 7 times before being shipped. Solidia curing could streamline this process.
- Plant manager believes that the advantages will more than make up for the cost of investment
- Customer will evaluate performance of products made during the trial through strength and durability testing.

Next Steps

Activity	Date	Status
Trial Summary	8/11/15	➻
Finished product assessment	9/25/15	➻
Trial report	9/25/15	➻
Post-trial review	10/9/15	➻
Implement P3 system	12/1/2016	■

➻ = Completed n = Not yet complete

Potential CO_2 Impact

	Plant Information:	Formula	Masonry: Paver (current)	Masonry: Paver (future)
a	Plant Cement Consumption (tons/year)		8000	8000
b	CO2 savings for product (kg CO2/Ton Cement)*		342	457
c	Total CO2 savings for plant (Tons CO2/year)	a * b/1000	2736	3656

*** Estimate based on mix design and finished product weight. Will be calculated directly.**

The potential CO_2 impact considers both the CO_2 savings associated with both the production of the cement and the production of the concrete. The potential CO_2 savings are calculated assuming entire product line conversion to Solidia Cement with current technology and the future state where the technology will be more efficient.

For this manufacturer approximately 8,000 tonnes of cement is used per year to produce pavers. The potential CO_2 impact was calculated based off the current production of the manufacturer.

5.3.6 PAVER CUSTOMER 3
Quebec, Canada

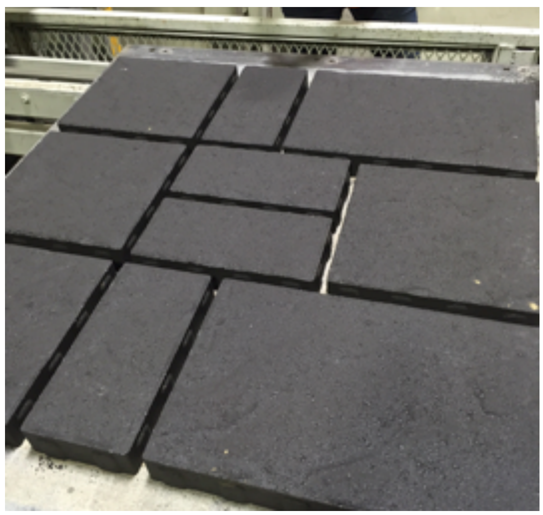
Phase 1 Field Trial

Trial Type	Product Type
Field trial	60mm Large Size Pavers
Trial duration	11/16/2015 – 11/20/2015 (5 Batches over 4 days)

Customer Profile

Products	Large Slab Pavers
Location	Québec
Production process	Vibropressed, Uncontrolled environment curing

Figure 26. Solidia Cement based pavers produced during the trial



Field Trial: Large Slab 60mm Pavers

Key Objectives:

Demonstration	• Validate compatibility between Solidia Cement and customer's production process equipment. Successfully form products on customer's production line.
Optimization	• Refine mix design and curing duration to meet performance specifications and customer expectations with attention to cost savings and product performance.
Finished Products Assessment	• Produce large slab pavers that meet or exceed customers 4.5 MPA flexural strength expectations. • Produce products that meet customer's aesthetic expectations. • No evidence of efflorescence in Solidia based products.

Preliminary Results:

Demonstration	➻ Compatibility with process equipment shown, facilities production team able to produce Solidia Cement based pavers.
Optimization	➻ Four batches produced used a 1:1 replacement of Portland Cement with Solidia Cement. One batch was produced using a 10% cement reduction. All other raw material proportions were kept the same. Efflorescence reducing admix was eliminated. All batches formed well and had desired appearance in plastic state. Curing conditions used during the trial were adjusted during the week with strength improvements seen.
Finished Products Assessment	➻ Solidia Cement based products made during the trial test as high as 4.9 MPA flex compared to 4.5 MPA flex customer target. ➻ Lighter shade of cement was appealing to customer

Customer Assessment

- Customer is interested in three areas regarding Solidia Cement; efflorescence mitigation, inventory reduction in terms of carrying costs and potential carbon credits.
- Products made during the trial meet color and texture expectations.

Next Steps

Activity	Tentative Date	Status
Trial report: 1st version	12/11/2015	➻
Finished product assessment for trial samples, freeze thaw data	2/12/2016	➻
Value Model Presentation to Customer	7/15/2016	■
Implement P3 system	12/1/2016	■

➻ = Completed ■ = Not yet complete

Potential CO_2 Impact

	Plant Information:	Formula	Masonry: Paver (current)	Masonry: Paver (future)
A	Plant Cement Consumption (tons/year)		15000	15000
B	CO2 savings for product (kg CO2/Ton Cement)*		342	457
C	Total CO2 savings for plant (Tons CO2/year)	a * b/1000	5130	6855

*** Estimate based on mix design and finished product weight. Will be calculated directly.**

The potential CO_2 impact considers both the CO_2 savings associated with both the production of the cement and the production of the concrete. The potential CO_2 savings are calculated assuming entire product line conversion to Solidia Cement with current technology and the future state where the technology will be more efficient.

For this manufacturer approximately 15,000 tonnes of cement is used per year to produce pavers. The potential CO_2 impact was calculated based off the current production of the manufacturer.

5.3.7 HOLLOW CORE SLAB CUSTOMER: RESEARCH TRIAL
Alberta, Canada

The purpose of the research trial was to test the compatibility of Solidia Cement with the customer's mixing and forming process to produce a concrete object for curing and to determine if the CO_2-curing chamber and equipment are functional with the customer's current equipment set up. Product curing was conducted in the partner's manufacturing facility in a portable curing chamber supplied and operated by Solidia Technologies.

Solidia conducted a research trial at Hollow Core Slab Customer site that tested the feasibility of the current hollow core curing equipment on an industrial scale and to collect real world data to compare with the predictive CFD model. The data collected during this trial will be used to determine if the CFD model can be used to estimate the length of hollow core slab can be cured using the current equipment.

This trial was used to determine the ease of installing and using the hollow core CO_2-curing equipment into the facilities existing hollow core equipment set up. The next step is to use this model to begin determining how to scale up this CO_2-curing equipment for a Phase 1 trial and production runs.

Hollow Core Slab Research Trial

Phase - Product Development

Trial Type	Product Type
R&D trial	20 cm, 25 cm and 30 cm Hollow Core (16 meters long) without strands
Trial date	4/20/2015 – 4/25/2015

Customer Profile

Products	20 cm, 25 cm and 30 cm Hollow Core Slab
Location	Alberta
Production process	Standard Hollow Core Extrusion Process

Figure 27. Cured hollow core slab made with Solidia Cement during customer trial

Customer Assessment

- Hollow Core Slab Customer would like to pursue Solidia technology adoption.
- Hollow Core Slab Customer communicated that the current sealing system was feasible and easy to install.
- Hollow Core Slab Customer will work with Solidia to develop a scalable production process.
- Hollow Core Slab Customer indicated that all sizes of hollow core were successfully produced.
- Hollow Core Slab Customer would like to perform a second hollow core trial at the same site.

- Hollow Core Slab Customer indicated that products made during trial had a satisfactory aesthetic appearance that met their standards.
- Hollow Core Slab Customer expressed advantage of Solidia Cement in the cleaning process.

Next Steps

Activity	Date	Status
Finished product assessment	05/31/15	➽
Detailed trial summary	05/15/15	➽
Trial report	05/15/15	➽
Post-trial review	Weekly Meetings with Hollow Core Slab Customer	➽
Development of production process	5/1/2016	➽
Research trial	5/19/2016	➽

➽= Completed   ■ = Not yet complete

Key Objectives:

Curing Profile	• Develop curing profiles for 16 meter long Solidia Cement based hollow core of different sizes (20 cm) observing the variation of the curing profile as a function of the length and geometry over the hollow core slab.
Validation	• Validate calculations made by Solidia regarding curing behavior of 16 meter long hollow core slab.
Mix Design	• Water content and raw material proportions are modified with attention to formability, and performance.
Evaluation	• Finished product assessment to be performed by observation of surface finish and by compression testing.
Process/ Equipment Changes	• Identify any changes in production process and workflow, modify the current set up to meet the needs of the facility and to move on to the next stage of the hollow core production.

Preliminary Results:

Curing Profile	• The curing profile for the 20 cm hollow core was confirmed. • The data collected from the 25 cm hollow core indicates that increasing the thickness of the hollow core translates into an increase in the drying period of the hollow core, and that each size of hollow core has a critical drying period.
Validation	• The predictions made by Solidia were confirmed with the results and the data obtained in this trial. The existing curing system is able to successfully cure 15 meter long hollow core sections.
Mix Design	• The water content was adjusted to attain workability needed to extrude the hollow cores, studies must be performed to avoid agglomeration of coarse aggregates when extruding.
Evaluation	• The finished product was satisfactory after visual inspection; compressive strength testing and carbonation testing are underway to confirm these observations.
Process/ Equipment Changes	• Modifications to the gas conditioning unit and manifold design are necessary for scale up, in order to cure more than 16 meters of product. Increasing the heating capabilities of the bed as well as the size of the chiller will allow longer hollow core slab lengths to be successfully cured.

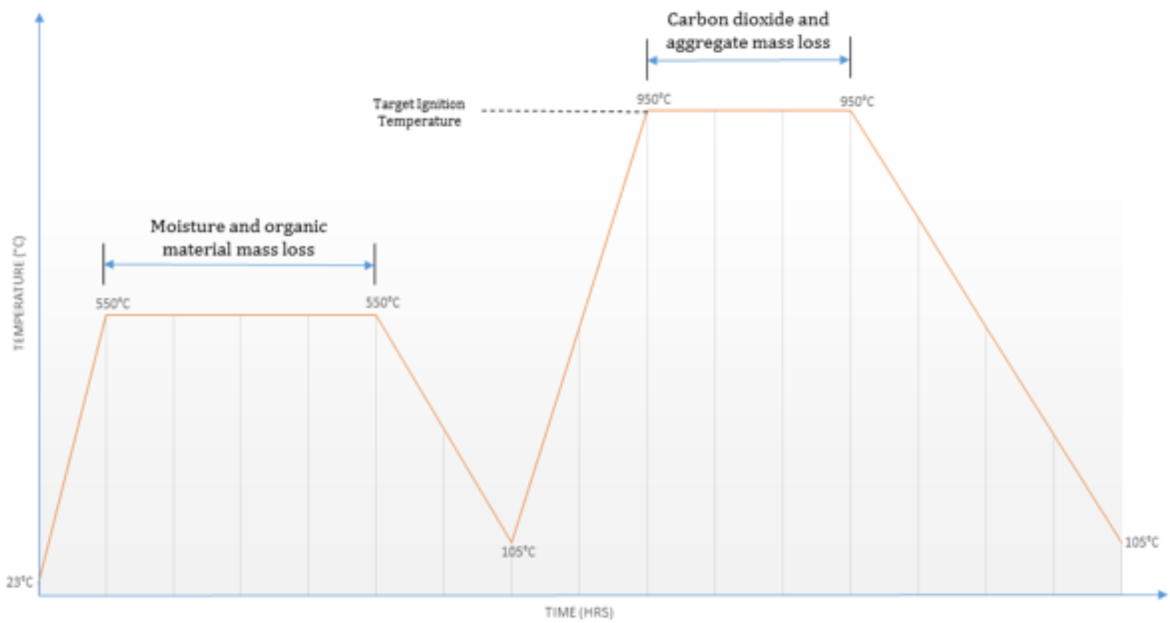
5.3.8 Measurement of CO2 Storage in Hollow Core Slab

In order to calculate the amount of CO_2 sequestered within a hollow core slab, core samples were drilled at intervals along the length of a cured hollow core slab that was prepared using the above set-up. These samples were oven dried at 105°C for 72 hours to remove any residual moisture, and placed in a furnace at 550°C for 4 hours to remove any remaining bound water or organic material. Once fully dried, the samples are heated to 950°C at a ramp up rate of 10°C/min. After 3 hours at 950°C, the samples are returned to 105°C and mass loss was recorded. This mass loss was then corrected to account for mass loss from the aggregates.

The remaining mass difference represents the amount of CO_2 sequestered during the curing process and is attributed to the thermal decomposition of $CaCO_3$ which is the primary reaction product of Solidia Cement carbonation.

A schematic of the process described above is shown in **Figure 28**.

Figure 28. Schematic of the loss on ignition process used to measure CO_2 sequestration in the hollow core slab sample



The hollow core CO_2 sequestration measured by Loss on Ignition (LOI) are shown in **Table 8**. The average CO_2 uptake as a % CO_2 by mass of concrete is seen to be 3.18%. ***This translates to 424lbs (192kg) of CO_2 being sequestered for every ton of Solidia Cement used in a hollow core slab (21.19% CO_2 by mass of cement).***

Table 8. Hollow Core CO_2 Sequestration Measured by Loss on Ignition (LOI)

Loss on Ignition			CO_2 Uptake		
Sample #	Sample Mass Loss 550-950°C (g)	Aggregate Mass Loss 550-950°C (g)	Corrected CO_2 Uptake (g)	% CO_2 by mass of concrete	% CO_2 by mass of cement
1	5.70	0.045	5.655	3.50%	23.31%
2	4.80	0.044	4.756	3.00%	19.98%
3	4.50	0.044	4.456	2.83%	18.84%
4	5.40	0.045	5.355	3.33%	22.19%
5	5.00	0.040	4.960	3.44%	22.93%
6	3.90	0.038	3.862	2.86%	19.04%
7	4.60	0.040	4.560	3.19%	21.24%
8	3.80	0.034	3.766	3.11%	20.75%
9	4.70	0.039	4.661	3.31%	22.04%
10	4.90	0.042	4.858	3.26%	21.71%
11	9.10	0.081	9.019	3.14%	20.91%
12	6.90	0.055	6.845	3.46%	23.09%
13	7.30	0.070	7.230	2.88%	19.21%
14	8.10	0.068	8.032	3.29%	21.96%
15	5.70	0.055	5.645	2.90%	19.31%
16	7.20	0.060	7.140	3.35%	22.33%
17	7.40	0.066	7.334	3.13%	20.87%
18	8.20	0.070	8.130	3.27%	21.80%
			Average	**3.18%**	**21.19%**
			Std Dev.	0.002	0.014

Table 9 provides the calculated CO_2 footprint reduction associated with the conversion of hollow core manufacturing from Portland cement to Solidia Cement at the Hollow Core Slab customer in Alberta. The table breaks down the CO_2 footprint reduction into the reduction in CO_2 emissions during cement manufacturing and the CO_2 captured during the curing of concrete products.

For the purposes of this analysis, it will be assumed that Solidia Cement will replace Portlant cement on a 1:1 basis by weight. Thus, the hollow core manufacturing operation at the Hollow Core Slab Customer plant in Alberta will consume 15,000 tonnes of either Portland cement or Solidia Cement (**Table 9**, line a).

The production of one tonne of traditional Portland cement clinker involves the release of about 0.82 tonnes of CO_2. Approximately two-thirds of the CO_2 emissions can be traced to the chemical decomposition of limestone, while the remainder is emitted from the combustion of fossil fuel used to heat the kiln to 1450°C. The low lime content and reduced kiln temperatures associated with Solidia Cement production enables both the CO_2 released through the decomposition of limestone and the CO_2 emitted from the combustion of fuel to be reduced by 30%. In this manner, CO_2 emissions at a cement plant can be reduced from 0.82 tonnes of CO_2 per tonne of Portland cement clinker to 0.57 tonnes of CO_2 per tonne of Solidia Cement clinker (line b). Thus, CO_2 emissions at the cement plant are reduced by 0.25 tonnes per tonne of cement clinker produced (line c)

By converting the hollow core manufacturing operation at the Hollow Core Slab Customer in Alberta to Solidia Cement, CO_2 emissions at the cement plant are reduced by 6,125 tonnes (line j = line a x line c).

As described above in **Table 8**, Solidia Concrete will capture and store approximately 0.219 tonnes of CO_2 per tonne of Solidia Cement used in the concrete formulation (**Table 9,** line d). The CO_2-curing process will also vent approximately 0.03 tonnes of CO_2 into the atmosphere per tonne of Solidia Cement used in the concrete (**Table 9,** line e). In total, 0.249 tonnes of CO_2 are required to cure Solidia Concrete containing one tonne of Solidia Cement (**Table 9,** line f).

The CO_2 used in the Solidia Concrete curing process is industrial-grade CO_2 sourced from industrial waste flue gas streams. This CO_2 must be collected at the flue gas site, purified, liquefied, and transported to the concrete manufacturer. Linde, a supplier of industrial grade CO_2, calculates the total average CO_2 emission associated with these operations to be about 0.9 lbs CO_2 per Nm^3 product, or ~0.2 lbs./lbs. CO_2 product delivered. Thus, the "current CO_2 cost" associated with Solidia Concrete curing is calculated to be 0.0498 tonnes of CO_2 per tonne of Solidia Cement (**Table 9,** line g = 0.2 x line f).

Thus, the net CO_2 captured and stored during the curing of Solidia Concrete is 0.1692 tonnes per tonne of cement today (**Table 9,** line h = line d - line g).

By converting the hollow core manufacturing operation at the Hollow Core Slab Customer in Alberta to Solidia Cement, the net CO_2 captured at the concrete plant is 2,538 tonnes (Table 9, line k = line a x line h).

In total, the reduction in CO_2 footprint associated with converting the hollow core manufacturing operation at the Hollow Core Slab Customer in Alberta from Portland cement to Solidia Cement is 6,288 tonnes (Table 9, line m = line j + line k).

Table 9. Carbon footprint reduction for hollow core manufactured at the Hollow Core Slab Customer site in Alberta (for Solidia Cement and Solidia Concrete compared to Portland cement and concrete)

		Formula	Unit	Paver and Block Manufacturer #2 Plant	
				SC Concrete (LafargeHolcim Plant)	OPC Concrete (LafargeHolcim Plant)
	General Product Specifications				
a	Cement consumed at LafargeHolcim, Edmonton, Alberta Plant		tonne	15000	15000
	Cement Production CO_2 Footprint				
b	CO_2 emitted during production of one tonne Clinker [a]		tonne	0.57	0.82
c	CO_2 saved/tonne SC Clinker [b]		tonne	0.25	0
	Concrete Curing CO_2 Footprint (per ton of cement used in concrete)				
d	CO_2 Sequestered		tonne	0.219	0
e	CO_2 waste		tonne	0.03	0
f	Total CO_2 Used	d + e	tonne	0.249	0
g	CO_2 "Cost" (current state)	f * 0.20 [c]	tonne	0.0498	0
h	Net CO_2 Sequestered during Curing (current state)	d - g	tonne	0.1692	0
	CO_2 Saved using Solidia Technology				
j	CO_2 saved during cement production	a * c	tonne	3750	0
k	CO_2 captured during curing	a * h	tonne	2538	0
m	total CO_2 saved	j + k	tonne	6288	0
	CO_2 Footprint Reduction				
n	CO_2 Footprint reduction (current state)		tonne	51.12%	N/A

Footnotes:
a. From Lafarge
b. Trials conducted at Lafarge Whitehall indicate that Solidia Cement (SC) clinker can be produced in a cement kiln while emitting 31% less CO_2 when compared to the production of OPC clinker. It is assumed that all other energy costs associated with the production of the final cement product are equivalent for SC and OPC.
c. Linde has performed detailed CO_2 footprint analysis for its plants in the US. The analysis includes raw gas purification, compression, liquefaction and transport via trucks or rail cars to customer sites. The total average CO_2 emission associated with the various operations is about 0.9 lbs CO_2 per Nm^3 product, or ~0.2 lbs/lbs CO_2 product delivered.

5.3.9 Identify Additional Customers

Building on the successes of the Phase 1 trials, the scope of Solidia's customer base was extended beyond the four Category 1 customers at the midpoint of this grant. The project has added two additional paver customers in Quebec and the hollow core customer in Alberta. It also outlines a plan to finalize the fundamental research and move forward with the commercialization of architectural precast wall panels, also in Alberta. The work with architectural precast and hollow core slabs opens new opportunities for Solidia's technology in the building infrastructure market. The Solidia and LafargeHolcim marketing teams will continue to seek out opportunities to develop the technology with new partners to further extend the market reach in the precast field.

The additional customers will continue to be identified and added to the Phase 1 trial pipeline. A detailed market analysis, and marketing campaign will be outlined in the subsequent Section 5.4.4, and will lay-out the plan for taking the precast products to market.

5.4 Milestone 4: Market Launch Plan Ready for at Least 1 Precast Application

Market Launch Plans have been created for three precast applications; pavers, blocks and hollow core slabs.

Section 5.4.1 will address Milestone 4: Task 1, in which mix-design and CO_2-curing optimization on the hollow core slab application was completed in anticipation of a commercial trial at the Hollow Core Slan Customer in Alberta.

Section 5.4.2 will address Milestone 4: Task 2, and describe Solidia's selection of primary CO_2 partners. Local CO_2 suppliers have been identified for each Phase 1 customer and for potential Phase 3 implementations.

Section 5.4.3 will address Milestone 4: Task 3, and describe the initial retrofits of curing stations at two locations; a U.S.-based paver and block customer, and the Hollow Core Slab Customer facility in Alberta. Commercial grade product was produced at each of these two locations.

Section 5.4.4 will address Milestone 4: Task 4, and describe commencement of a marketing campaign in collaboration with LafargeHolcim in Alberta.

5.4.1. Milestone 4 Task 1 Optimize Products based on Test Results

Based on the scale-up work described in section 5.2.3, a series of commercial trials were undertaken at the Hollow Core Slab Customer site in Alberta during the period May 9 through May 19, 2016 to test the scalability and reproducibility of the process developed in-house at Solidia Technologies to cure a 16 meter long section of hollow core slab of 20 cm thickness.

Since uniform curing had already been established for a 20 cm thick 16 meter long hollow core section through the in-house work at Solidia Technologies, the first trial included the incorporation of reinforcement strands in this configuration of hollow core slab.

Figure 29 shows the end plates designed for supporting the gas tight sealed tarp chamber while providing a sealable slot in the bottom section to allow for the reinforcement strands to pass through. These strands, located at the bottom of the hollow core slab, are pre-tensioned prior to the extrusion of the concrete and remain in tension until the concrete has cured. The tension on the strands is released prior to cutting the hollow core slab. The slippage on the strand after the release of tension is measured to access the degree of cure. For the degree of cure to be acceptable a slippage of no more than 5-6 mm is desired. **Figure 29** also shows the ports for gas inlet (top) and outlet (bottom) on the end plate.

A 20 cm thick extruded hollow core slab at the Hollow Core Slab Customer site in Alberta from this trial with a set-up of the plenum and the fan mounted on top can be seen in **Figure 30**.

Subsequently, attempts were made to produce a 25 cm and a 30 cm thick hollow core slab in 16 meter length. Although uniform curing was not obtained in these trials where thicker sections (25 cm and 30 cm thick hollow core sections), the sections that cured sufficiently were able to satisfy the strand slippage criteria. Additionally, the trial included scale-up of the process to a 32 meter hollow core slab section with a thickness of 20. A laconic summary of this trial is covered in section 5.4.3.C.

Figure 29. End plate designed for supporting the gas tight sealed tarp chamber while providing a sealable slot in the bottom section to allow for the reinforcement strands to pass through

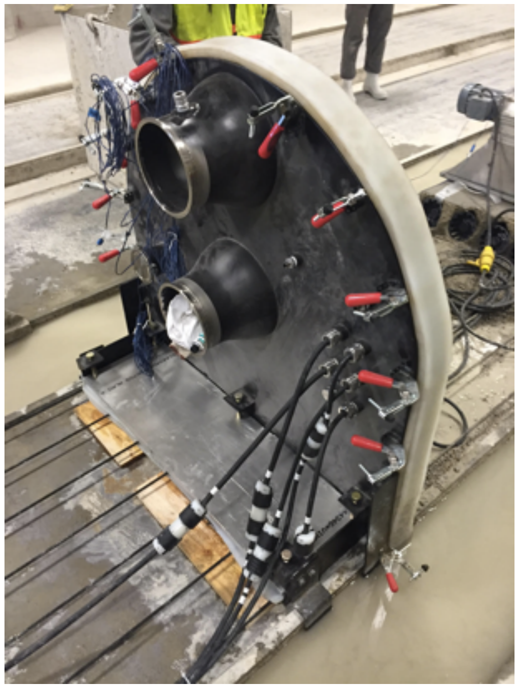


Figure 30. A 20 cm thick 16 meter long extruded hollow core bed at the Hollow Core Slab Customer site in Alberta with a set-up of the plenum and the fan mounted on top

5.4.2 Milestone 4 Task 2 Secure CO_2 supply arrangements

Solidia has teamed with Air Liquide to secure a supply of industrial grade CO_2 in Alberta and worldwide.

A world leader in industrial gases and related technologies, Air Liquide is present in 80 countries (including Canada) with more than 50,000 employees. Oxygen, nitrogen and hydrogen have been at the core of the company's activities since its creation in 1902. They are a major supplier of industrial and food grade CO_2 as well. Air Liquide's ambition is to be the leader in its industry, delivering long-term performance and acting responsibly.

The company relies on competitiveness in its operations, targeted investments in growing markets and innovation to deliver profitable growth over the long-term. Air Liquide's revenues amounted to €15.4 billion in 2014. Air Liquide is listed on the Paris Euronext stock exchange (compartment A) and is a member of the CAC 40 and Dow Jones Euro Stoxx 50 indexes.

In November of 2015, Air Liquide announced the acquisition of Airgas, itself a leading supplier of packaged gases and related products in the United States and Canada. Once it is completed, this acquisition will increase Air Liquide's share and coverage of the industrial and food grade CO_2 marketplace.

5.4.3 Milestone 4 Task 3 Retrofit curing equipment at target precast plant

A. Background: General Description of Phase 3 Technology Implementation

Solidia Technologies has developed novel CO_2-curing processes and is in the beginning stages of implementing these processes at commercial precast concrete facilities. Phase 1 technology implementation trials, discussed in Section 5.3, served to verify the ability to incorporate Solidia Cement and CO_2-curing processes with the products, processes, and equipment at a prospective customer's precast concrete facility. In addition to this verification, the compatibility of the CO_2-curing process with the customer's site is evaluated. Areas where this process can add value to a concrete manufacturer's products are explored and documented during Phase 1 trials.

Phase 3 implementations are designed to follow Phase 1 trials at specific precast concrete manufacturers. These implementations involve converting a single curing station to allow for production of a Solidia Cement-based product (*typical precast facilitates will have between 10 and 20 curing stations*). Phase 1 results, as well as the concrete manufacturer's willingness to adopt the technology, are considered when choosing a site for Phase 3 technology implementation.

The adoption of CO_2-curing at a precast concrete manufacturing facility will require a certain level of capital investment. The Solidia approach to this challenge attempts to minimize this investment. The bulk of the concrete manufacturer's processing equipment, including raw materials storage and conveyance, concrete mixing, concrete forming, and concrete product handling, will remain unchanged after conversion to CO_2-curing. The capital investment necessary to enable CO_2-curing is concentrated at the concrete curing station. Here, the capital investment can be divided into two distinct sections;

- The gas conditioning system, which manages the temperature, humidity and CO_2 concentration within the curing chamber, and;
- Mechanical modifications to the existing curing station.

The specific components of the gas conditioning system and modifications to the curing chamber are described in detail in this Section. It is projected that the conversion of an entire standard concrete paver and/or block manufacturing facility in this manner will require a capital investment of approximately $1,500,000 (U.S.)

Phase 3 implementations at two locations, one in the U.S. and one in Alberta, Canada, will be described below. These two sites were chosen for the following considerations:

- The geographical locations are aligned with Solidia's strategic goals.
- High level of technical competence at the facilities gives Solidia confidence that the production process will be effectively adopted.
- Product types have been pre-qualified by Solidia as per Section 5.3.
- Each manufacturer expressed a strong desire to adopt Solidia Cement and CO_2-curing technology.

B. Equipment Installation at U.S.-based Paver and Block Manufacturer

Note: *Equipment installation at U.S.-based Paver and Block Manufacturer, and the subsequent proof of concept for its operation, was funded by through U.S. Department of Energy research contract DE-FE0004222. As such, this work was not charged to the CCEMC project, and is included in this report for information purposes only.*

Site selection for Solidia's first commercial curing equipment retrofit was an important decision based on several criteria including geographic location, product line offering, addressed market, ownership support, and finally, a culture supportive of innovation.

U.S.-based Paver and Block Manufacturer's proximity to the Solidia Technologies plant in New Jersey, as well as positioning in an important downstream commercial market, were important factors in geographic site selection. Close proximity to the Solidia Technologies plant enabled convenient access for plant engineers and technicians to visit the customer site with the frequency and flexibility necessary to undertake a pilot conversation. Additionally, the U.S.-based Paver and Block Manufacturer is situated within 200 miles of one of the largest residential and commercial construction markets in the United States, offering attractive access to distribution channels and quality end-use prospects. Finally, U.S.-based Paver and Block Manufacturer's executive leadership demonstrated active involvement in all phases of the commercialization project, supported fully by an innovative culture both willing and able to execute production and subsequent market entry strategies.

U.S.-based Paver and Block Manufacturer operates production plants in five locations in New Jersey and Pennsylvania. The largest of the plants is located in New Jersey and consumes approximately 25,000 tonnes of cement per year. The combined cement consumption of all of the production plants under the umbrella of U.S.-based Paver and Block Manufacturer is approximately 57,000 tonnes.

The New Jersey plant is split into two production areas: one for the production of concrete blocks and the other for the production of pavers. Each of these production lines includes concrete mixing capability, a dedicated vibro-casting machine, and a bank of curing chambers. Solidia and U.S.-based Paver and Block Manufacturer have focused on the production of pavers during the Phase 3 implementation.

Description of the Concrete Curing System

U.S.-based-Paver and Block Manufacturer cures pavers in tall, narrow chambers, shown in **Figure 31**. Racks of uncured pavers are robotically loaded into the chambers. After the racks have been loaded, roll-down doors are closed before beginning the curing cycle.

The chamber selected for the Phase 3 conversion is the end chamber on the paver product line. This bay was selected on the basis of its location. As an end chamber, Solidia Technologies was able to convert the enclosure to a CO_2-curing system with minimum impact on the remainder of U.S.-based Paver and Block Manufacturer's production. It will also allow access to the location through a large overhead door located in the back of the building.

The chamber is approximately 5 ft wide (double bay is 10ft wide), 17 ft tall, and 75 ft long. The chamber consists of 14 rows (levels) and 20 columns for a total of 280 boards per bay. The bays are paired, with one roll-up door covering two bays. The conversion to CO_2-curing covered one bay. The other half of the paired bay contains the ductwork for CO_2 distribution and is closed off with a blank wall.

Figure 31. U.S.-based Paver and Block Manufacturer's curing chambers with roll-down doors

Chamber Preparation and Sealing

The first step in retrofitting the curing chamber was preparing the face of the chamber for accepting a new chamber door. This involved the installation of a custom doorframe to mate with a newly designed door.

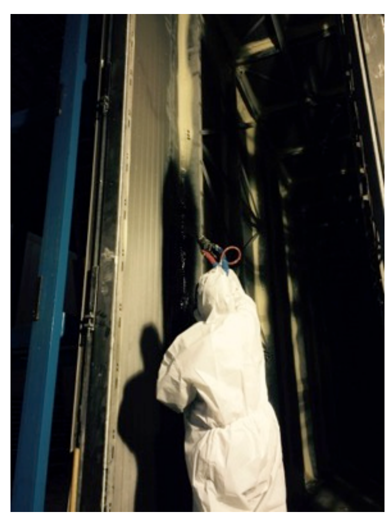
Once the new doorframe was mounted on the chamber face, the existing polystyrene insulation inside the chamber was replaced with magnesium oxide board to create a stronger interior surface (**Figure 32**). The chamber interior was then media blasted to clean and roughen the surface (**Figure 33**). Finally, the interior surface was coated with Rhinoliner™ to prevent gas leaks and maintain a secure CO_2 environment within the chamber (**Figure 34**).

The process of sealing the chamber proved to be one of the most challenging and time consuming aspects of the project. Many leak tests and inspections had to be carried out with corrective actions being implemented after each test.

Figure 32. Magnesium oxide board installation

Figure 33. Sandblasting

Figure 34. Spray coating



Door Fabrication and Installation

Solidia collaborated with CDS to design, fabricate and install a chamber door to be used at U.S.-based Paver and Block Manufacturer's facility. The finished chamber door is shown in **Figure 35**. Angled guides and rollers were attached to the sides of the door, allowing the weight of the door to provide the necessary force to create the gas-tight seal. A silicone gasket was used around the frame of the door, which contacts the doorframe mounted on the front face of the curing chamber.

A door manipulation device was installed on rails above the curing chamber. This device, shown in **Figure 36**, lowers the door to close and seal the chamber, and raises the door to open the chamber. When the chamber is opened, the rail system is able to move the door to a docking station on the side of the chamber. The operation of the door manipulation device is illustrated in **Figure 37**.

Figure 35.
Completed door

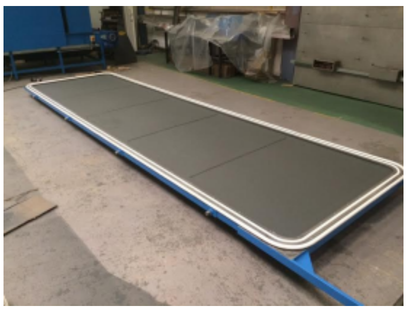
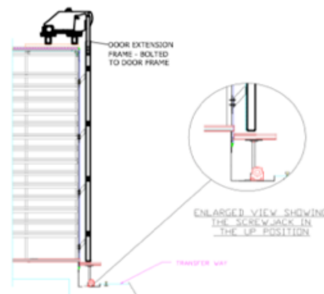


Figure 36.
Door carriage installed

Figure 37.
Door manipulation design

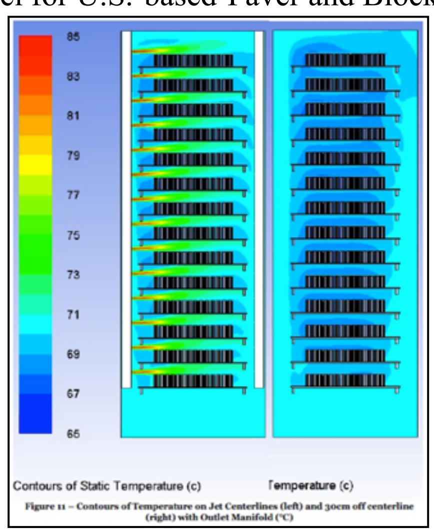


Gas Flow and Distribution Within the Curing Chamber

To assure successful CO_2-curing on an industrial scale, temperature and relative humidity must be recreated within and throughout a commercial curing chamber. To accomplish this, Solidia teamed with Alden Labs to design gas flow and distribution systems for CO_2-curing chambers. Alden's expertise lies in designing complex gas flow systems using Computational Fluid Dynamic (CFD) modeling.

Figure 38 shows two-dimensional "slices" of the CFD model prepared for the chamber conversion at U.S.-based Paver and Block Manufacturer's facility. Note that the gas flow in this chamber runs across the chamber width.

Figure 38. CFD model for U.S.-based-Paver and Block Manufacturer



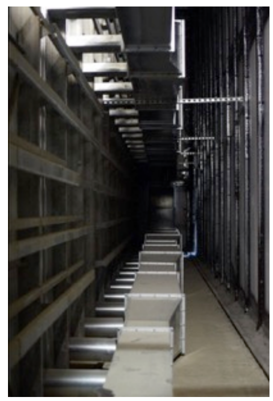
Ductwork Design and Installation

As per the CFD modeling, interior ductwork for U.S.-based Paver and Block Manufacturer's curing chamber was designed and installed. Large cross-section ducts, for inlet and outlet gas flow, were installed along the length of the chamber. Vertical sections were added to the inlet ducting to direct gas flow over each row of product. These vertical sections are required for each column throughout the length of the chamber. For the outlet ducting, verticals are not required. Rather, larger diameter openings are distributed throughout the outlet ducting length, along the bottom of the chamber.

Figures 39 and **40** below show the ductwork installed on-site in U.S.-based-Paver and Block Manufacturer's curing chamber. The vertical sections of the inlet ductwork shown in **Figure 39** were installed within the open center rack that separates the two sides of the double bay. The inlet and outlet distribution ducts shown in **Figure 40** were installed in the empty half of the double bay.

Figure 39. Vertical inlet ductwork installed

Figure 40. Inlet and outlet headers installed



Gas Conditioning System Design and Installation

Solidia and Linde, an industrial gas company and supplier of industrial grade CO_2, collaborated to design and build energy-efficient gas conditioning systems for CO_2-curing. The gas conditioning system is composed of a heat exchanger/condenser, a heating system and a blower. The system feeds warm, dry CO_2 into the inlet duct of the curing chamber and receives moist CO_2 from the outlet duct. During the initial curing stages, pure CO_2 is introduced into the curing chamber at relatively high flow rates to displace all the air inside the chamber. Once the chamber is purged, the inlet flow rate is reduced to a level that maintains a high concentration of CO_2 in the chamber. The equipment was specifically sized for use at U.S.-based Paver and Block Manufacturer.

Figures 41 through **43** show different stages of the Gas Conditioning System installation. **Figure 41** shows the heater installed in its final location. **Figure 42** shows the completed Gas Conditioning System from the heater's location. In this photograph, the heater is in the center-foreground, and the heat exchanger is located to the left, behind the heater. **Figure 43** shows the opposite end of the Gas Conditioning System. The main blower is located at the lower left, while the heat exchanger is again located at the rear on the right.

Figure 41. Gas conditioning system - heater

Figure 42. Gas conditioning system - view from heater

Figure 43. Gas conditioning system - view from side opposite heater

Figure 44. Temporary CO_2 tank

Other Site Preparation

A temporary, 26-ton CO_2 tank, acquired from Air Liquide (**Figure 44**), and a silo dedicated to Solidia Cement (**Figure 45**) were installed at U.S.-based Paver and Block Manufacturer's facility. The auger leaving the cement silo was tied into an existing screw, allowing for minimally invasive operation.

Figure 45. Solidia Cement silo installed (left)

Paver Curing Equipment Commissioning

The first stage of the Equipment Commissioning phase was to test the gas conditioning equipment's individual system components and their operating range. All components were verified as functional within their target operating ranges.

The second stage involved the development of component operational methods that effect control over the key CO_2-curing process parameters (temperature, humidity, CO_2 concentration, mass flow rates). This included developing a process to purge the chamber by replacing air with CO_2 inside the chamber with attention to efficiency and time. A "plug-flow" method was utilized to displace air with heavier CO_2. Operating conditions that avoid gas mixing during the purging stage were identified to maximize gas stratification. This stage also included programing adjustments to the system that ensure proper component sequencing during recipe-based operation.

The third stage required the chamber to be fully loaded with products for the purpose of validating the uniformity of gas composition inside the chamber during normal production. The chamber was fully loaded during this stage with 280 boards holding 8,400 pavers weighing a total of 43,400 kg, approximately 6,580 kg of this weight being water (**Figures 46 and 47**). In addition to characterizing uniformity in the system, filling the chamber to capacity was required to simulate a full load on the system's components, ensuring that control set points could be achieved.

Figure 46. Commissioning Run #1 production line

Figure 47. Chamber loading

In order to measure uniformity inside the chamber, iButton® sensors were used to record the local temperature and relative humidity at strategically placed locations throughout the chamber, over time. Data from iButton® sensors was then compiled and graphed to visually display the uniformity in the system at a given set-point and time (**Figures 48 and 49**). Pavers from these locations were also measured for residual water, color value, and compressive strength.

Chamber profiles verified that the modeling and ductwork design provided for a CO_2 curing environment within the targeted range of uniformity. At normal operating conditions, maximum temperature and humidity gradients of 10°C and 10%RH respectively were measured inside the chamber.

Figure 48. Chamber temperature profile

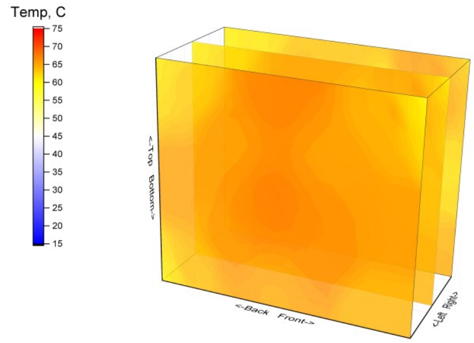
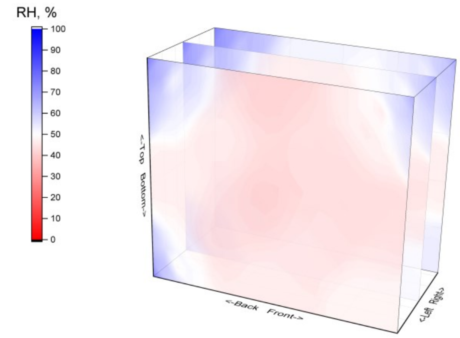


Figure 49: Chamber RH profile



Paver Product Commissioning

While U.S.-based Paver and Block Manufacturer produces a wide range of paver types, two main product types were chosen for commissioning and initial market launch. The goal of the Product Commissioning stage was to refine product formulations and CO_2 curing recipes to be used for regular production with attention to cost, aesthetics, performance, and processing efficiencies.

Existing product formulations were used as a starting point when developing formulations for Solidia Cement-based products to be used at U.S.-based Paver and Block Manufacturer. A one-to-one replacement of cementitious material (Cement + Fly ash) to Solidia Cement was used for the Product Commissioning Runs.

During the first few concrete batches feeding Commissioning Run #1, paver moisture content and machine settings were dialed-in to achieve a formable and aesthetically acceptable product. These conditions were recorded to set future production parameters. After Commissioning Run #1's curing cycle was complete (20hr), product was unloaded from the chamber. Samples from predetermined boards were removed during this unloading stage; all additional products were palletized and placed in product inventory.

Compressive testing results for products made during Commissioning Run #1 can be seen in **Table 10**. This compressive testing was performed in compliance with ASTM C-936, which states that average compressive strength must be greater than or equal to 8,000 psi with no samples less than 7200 psi.

Table 10: Compressive Strength Results for Pavers Produced During Commissioning Run #1

Commissioning Run #1	Average	Minimum	Maximum	Standard Deviation
Compressive Strength (psi)	9,651	8,399	11,854	831

** Values represent a sample size of 20 pavers*

Testing during this Commissioning Run verified that Solidia Cement-based products at U.S.-based Paver and Block Manufacturer are able to meet compressive strength specifications. The stored carbon content for the pavers made during this commissioning stage was measured at 23.6% of the cement mass in the concrete product.

Solidia Cement-based products from U.S.-based Paver and Block Manufacturer will reach the marketplace and see actual service beginning in June, 2016.

C Equipment Installation at Hollow Core Slab Customer site in Alberta

The process using the gas tight sealed tarp chamber described in section 5.2.3 used to produce 16 meter hollow core slabs at Solidia (without strands) and at Hollow Core Slab Customer's Alberta plant (with strands) was scaled-up to produce 32 meter hollow core slabs of 20 cm thickness with strands. This demonstrated that the curing equipment concept can be scaled-up to produce longer lengths of the hollow core slab. In doing so, the CO_2 gas conditioning system was also scaled-up to support the scaled-up process requirements. Two gas conditioning systems were used simultaneously for curing the 32 meter long, 20 cm thick, hollow core slab.

A schematic for the set-up configuration is shown in **Figure 50**. In this configuration, three plenums with fans mounted on top are placed on top of the hollow core slab. Two of these assemblies were placed at ends of the slab and one in the center. The fans at the ends were configured to blow gas into the hollow core slab whereas the fan in the center was configured to suck gas out of the hollow core. Holes were placed to access the cores of the hollow core slab using the plenum base, as described earlier in Section 5.2.3. (Refer to **Figure 11**), half way between each of these plenum and fan assemblies to facilitate circulation of gas within the cores of the hollow core slab.

Figure 50. Schematic showing arrangement of plenums with fans mounted on top with two inlets and two outlets on each of the end plates needed to cure longer hollow core sections

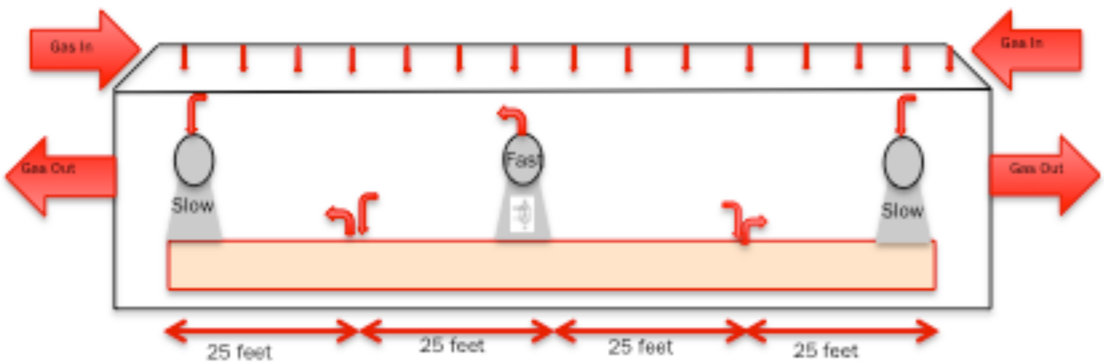


Figure 51 shows the gas tight sealed tarp chamber set-up at the Hollow Core Slab Customer plant to cure a 32 meter extruded section of hollow core. In this instance a 20 cm thick hollow core slab is inside the gas tight sealed tarp chamber. A similar set-up can be also used for a 25 cm and 30 cm thick hollow core slab.

Also seen in **Figure 51** are the inlet hose (yellow) and outlet hose (black) that transport the CO_2 gas back and forth to the gas tight sealed tarp chamber from the gas conditioning system.

Using the above set-up a 32 meter long, 20 cm thick, hollow core slab was successfully cured at the Hollow Core Slab Customer plant. **Figure 52** shows the three sections of hollow core slabs - bottom two 9 meter long and top one 6 meter long - that resulted from the 32 meter long cured hollow core slab.

Figure 51. The gas tight sealed tarp chamber set-up for curing a 32 meter long hollow core slab at the Hollow Core Slab Customer plant in Alberta

Figure 52. Three sections of hollow core slabs - bottom two 9 meter long and top one 6 meter long - that resulted from the 32 meter long cured hollow core slab

A successful cure was achieved and was characterized by all the 7 strands, located at the bottom of the hollow core slab, passing the strand slippage criteria upon release of the tension after the curing was stopped. **Figure 53** shows a cross section from the cured hollow core concrete slab where a strand passes through the slab. No slippage of the strand in the cured concrete is observed.

Figure 53. A cross-section from the 32 meter long, 8” thick, cured hollow core slab showing the area where a strand passes through the slab

Using a similar strategy of scale-up, 25 cm and 30 cm thick, 32 meter long hollow core slabs will be prepared in subsequent trials, which are to be scheduled at a later date. Upon successful scale-up to the 32 meter length, a second round of scale-up is planned. In this second round, the process will be further expanded to 73 meter long hollow core slabs – the maximum length possible at the Hollow Core Slab Customer plant - for all the three thicknesses produced there, i.e., 20 cm, 25 cm and 30 cm. A schedule for these activities is also yet to be ascertained.

5.4.4 Milestone 4 Task 4 Begin Marketing Campaign in Collaboration with LafargeHolcim

Solidia and LafargeHolcim have taken a targeted marking approach to the applications that are being commercialized in Alberta , and throughout the rest of Canada. For Category 1 applications, Solidia is working closely with LafargeHolcim to target precast customers that meet the criteria outlined in Milestone 1. In order to launch products in this category, Solidia will work with the precast producer's sales force to implement two different approaches. The first is the blind switch approach. This is integrating the new Solidia product into the existing product line without any advertising or announcement. This approach is possible in both the residential and commercial markets, as the Canadian (CSA) standards for concrete allow new technologies to stand on performance characteristics.

The second approach is to leverage the enhanced performance characteristics and green aspects of Solidia's technology in a new product line. Solidia would recommend that this is done in combination with the "blind switch" approach, as the technology has benefits that reduce the precast producers overall cost in production. Solidia and LafargeHolcim are instructing the precast producers that choose to take this approach to market the products in Category 1 on more than just the green aspects, so they are not considered niche products, and thus limited to a smaller market share.

Solidia will rely on the existing marketing and distribution chains in use by the Category 1 manufacturers. Solidia will assist the manufacturers in creating a brand for the product through directed advertising, and marketing campaigns to the four key distribution channels for the products. These channels are listed below:

1. Direct Sales to Large Contractors:
    a. These contractors are located in major distribution centers, and handle the majority of the commercial contracts as well as larger residential remodeling and new construction.
    b. Accounts for 45% of Category 1 sales in this marketplace.
2. Specialized Distributors:
    a. These customers offer products from a range of manufacturers.
    b. They coordinate with smaller contractors and DIY homeowners who are looking for higher end products.
    c. Accounts for 30% of Category 1 sales
3. Big Box Retailers:
    a. These customers are focused primarily on cost.
    b. They are large volume purchasers of lower end products.
    c. Accounts for 10% of Category 1 sales
4. Direct Sales from Producer Location
    a. Showrooms
    b. Co-ordination with installers
    c. Accounts for 15% of Category 1 sales

The concrete paver market data for Western Canada is projected to reach a total of $95MM in 2016. The breakdown of the market is listed in **Table 11** below:

Table 11: Geographical Breakdown of the Paver Market in Western Canada

	Population (millions)	Sales Per capita (sft)	Price / sft	Revenue (millions)
BC	4.7	2.4	$3.50	$39.5
Alberta	4.2	2.4	$3.50	$35.3
Sask	1.1	2.4	$3.50	$9.2
Manitoba	1.3	2.4	$3.50	$10.9
Total	**11.3**			**$94.9**

In comparison, the entire Canadian market for pavers is approximately $300 million. Of this total market, Alberta makes up about 12%. The majority of producers are focused in the major urban population areas.

In 2016 there will be approximately 10 million square feet of pavers produced in Alberta, 27 million square feet in Western Canada, and 90 million square feet in all of Canada. It is expected that the concrete block market in Alberta is similar, if not larger than the concrete paver market in total concrete consumption. Since there is no definitive data available, it is assumed that the concrete block market mirrors the paver market for the purposes of this report.

The approach for Category 2 applications requires a very different pathway. For structural and semi-structural applications such as hollow core slabs, Solidia will be relying on LafargeHolcim's connections with the architectural and engineering community to create a pull for the product and specify it in future work. In Alberta, three criteria must be met for a product that is not made with hydraulic cement (i.e. Solidia Cement is a non-hydraulic cement) to be accepted in a building project:

1. Sign-off and Professional Engineer stamp from the engineer responsible for the project.
2. Approval of the building owner
3. Sign-off from building code or city official.

One of the main objectives of the trial being conducted at the Hollow Core Slab Customer plant in Alberta is to build confidence with the specifying community that the Solidia product is a viable replacement for Portland Cement based hollow core slabs, and can be installed in the same applications. The trial will serve to increase Solidia's visibility in the architectural and engineering community, and to produce samples for validation.

The specifying engineers and architects will be the main focus of the directed marketing campaign for Category 2 products. Hollow Core Slab Customer in Alberta and Solidia will work to educate this community through a series of directed advertisements in trade magazines and online journals and "lunch and learns" at the offices of the building professionals. The goal of these targeted marketing campaigns is to make the specifying community aware of the performance benefits and green nature of the concrete products to make them more likely to specify the Category 2 products and create a pull in the marketplace.

In Alberta, there are 1.5 million square feet of hollow core slab forecast to be produced in 2016. Of this total production, the Lafarge Precast Edmonton plant accounts for approximately 65% of the total market share. In total, the market in Western Canada is approximately 6 million square feet, and the total Canadian market for hollow core slab is estimated to be 13.5 million square feet.

The totalized CO_2 reduction potential for the products shown below is outlined in Table 10. This includes the reduction from cement manufacturing and CO_2 stored in the concrete during the curing process.

The formulae for calculation of the total reduction of CO_2 footprint are as follows:

Category 1 Products:
Concrete Mass x (15%) = Cement Mass
Cement Mass x (17%) = CO_2 Stored During Concrete Curing (as per Table 9)
Cement Mass x (25%) = CO_2 Avoided During Cement Manufacturing (as per Table 9)
CO_2 Stored + CO_2 Avoided = Total Reduction in CO_2 Footprint

Category 2 Products:
Concrete Mass x (21%) = Cement Mass
Cement Mass x (17%) = CO_2 Stored During Concrete Curing (as per Table 9)
Cement Mass x (25%) = CO_2 Avoided During Cement Manufacturing (as per Table 9)
CO_2 Stored + CO_2 Avoided = Total Reduction in CO_2 Footprint

Table 12: Total Annual CO_2 Footprint Reduction in Total Markets (Tonnes)

		Concrete Mass	Cement Mass	CO_2 Stored	CO_2 Avoided	Reduction in CO_2 Footprint
Alberta	Masonry & Pavers	2,800,000	420,000	71,400	100,800	172,200
	Hollow Core	65,000	13,000	2,210	3,120	5,330
West Can	Masonry & Pavers	7,560,000	1,134,000	192,780	272,160	464,940
	Hollow Core	260,000	52,000	8,840	13,000	21,840
Canada	Masonry & Pavers	25,200,000	3,780,000	642,600	907,200	1,549,800
	Hollow Core**	585,000	117,000	19,890	29,250	49,140

**Estimated

6. Greenhouse Gas and non-GHG Impacts

GHG Benefits Associated with Solidia Cement and Solidia Concrete

Concrete is the world's second most utilized substance, exceeded only by the consumption of water. Over 30 billion tonnes of concrete, containing approximately three billion tonnes of Portland cement, are manufactured and used every year. According to a 2005 study by the World Resources Institute on greenhouse gas emissions by major industries, the cement industry is responsible for 3.8% of the total global greenhouse gas emissions, which is equivalent to 5-7% of industrial CO_2 emissions (reference 1). Other studies show that the cement industry accounts for about 5% of global anthropogenic carbon dioxide emissions (reference 2). According to the International Energy Agency IEA), the cement industry must reduce CO_2 emissions by 66% in order to help limit global temperature rise to 2-3°C by 2050 (reference 3).

Though current industry strategies, which include the use of energy-efficient process technologies, alternative fuels, and supplementary cementitious materials, may help reduce emissions moderately, there is a clear need for a transformative innovation.

Solidia Technologies' patented cement chemistry and concrete curing processes offer the building materials and construction industries the ability to manufacture cement and concrete products within existing plants and use traditional design specifications to meet the IEA's CO_2 emissions reduction goal, with minimal requirements for new supply chains and capital investment.

Solidia Cement is composed of a family of "green," low-lime calcium silicate phases, similar, but not identical to the chemistry of Portland cement. As a result, it can be produced in existing cement kilns using the same raw materials that are used to make Portland cement, albeit in different proportions. Solidia Cement is produced using less limestone and at lower temperatures than are necessary for Portland cement. These factors translate into a reduction in the CO_2 emissions during cement manufacturing, from 820 kg per tonne of Portland cement clinker to 570 kg per tonne of Solidia Cement clinker (~30% reduction).

To create Solidia Concrete products, water, aggregates and Solidia Cement are mixed, formed into the desired shape and then reacted with gaseous CO_2 to produce a durable binding matrix. The curing process sequesters up to 300 kg of CO_2 per tonne of cement used.

Quantification of Expected Annual GHG Benefits

The province of Alberta has two cement-manufacturing plants; one in Exshaw and one in Edmonton. The annual cement consumption in Alberta is estimated to be around 2.5 million tonnes (reference 4) excluding oil well cement, thus resulting in at least 2 million tonnes of CO_2 emissions annually. It will be assumed that precast concrete manufacturing consumes approximately 20% of this cement while cast-in-place concrete manufacturing consumes the balance.

For the purpose of this analysis, it will be assumed that the CO_2 emissions associated with the production of one tonne of cement will be reduced from 820 kg for Portland cement to 570 kg for Solidia Cement (see **Table 9**). This equates to a reduction of CO_2 emissions of 0.25 tonne per tonne of Solidia Cement produced.

Similarly, it will be assumed that a net of 0.17 tonne of CO_2 is stored in Solidia Concrete for each tonne of Solidia Cement used in the concrete production (also see **Table 9**).

Tables 13, 14 and **15** show the CO_2 impacts as Solidia Cement / Solidia Concrete technologies are adopted by the precast market segment in Alberta, the cast-in-place market segment in Alberta and the total concrete market in Alberta, respectively. Each table shows the projected market penetration, the projected CO_2 emissions reductions at cement plants, the CO_2 storage in concrete and the total CO_2 footprint reduction (emission reductions plus storage).

Table 13: GHG Impact on Precast Market Segment in Alberta

	% Penetration	CO_2 Reduced (Tonnes)	CO_2 Stored (Tonnes)	Total CO_2 Reduction (Tonnes)
2016	0.25%	300	200	500
2017	1.0%	1,200	800	2,000
2018	4.5%	5,500	3,700	9,200
2019	11.4%	13,800	9,400	23,200
2020	24%	28,700	19,600	48,300
2025	50%	60,000	40,800	100,800
Total Market	100%	120,000	81,600	201,600

Table 14: GHG Impact on Cast-in-Place Market Segment in Alberta

	% Penetration	CO_2 Reduced (Tonnes)	CO_2 Stored (Tonnes)	Total CO_2 Reduction (Tonnes)
2016	0	0	0	0
2017	0	0	0	0
2018	0.17%	790	530	1,320
2019	0.33%	1,580	1,060	2,640
2020	1.0%	4,800	3,240	8,040
2025	20%	96,000	66,000	162,000
Total Market	100%	480,000	326,400	806,400

Table 15: GHG Impact on Total Concrete Market Segment in Alberta

	% Penetration	CO_2 Reduced (Tonnes)	CO_2 Stored (Tonnes)	Total CO_2 Reduction (Tonnes)
2016	0%	300	200	500
2017	.2%	1,200	800	2,000
2018	1%	6,290	4,230	10,520
2019	3%	15,380	10,460	21,500
2020	6%	33,500	22,840	56,340
2025	26%	156,000	106,800	262,800
Total Market	100%	600,000	408,000	1,008,000

Note that the penetration into the cast-in-place concrete market lags that into the precast concreter market. This is because the CO_2-curing of concrete is more easily managed for precast products, which are typically manufactured in factory environments. The development of process technology to allow entry into the cast-in-place concrete market will be the subject of Solidia Technologies' CCEMC Grand Challenge Round 2 proposal.

Other Environmental Benefits

Other pollutants associated with cement production, such as mercury, NOx, and SOx, are also reduced by conversion from Portland cement to Solidia Cement. Mercury emissions are tied to both limestone consumption and coal consumption. As the requirement for these raw materials are reduced by 30% in Solidia Cement manufacturing, the mercury emissions are reduced by approximately 30%.

Based on the annual cement usage stated above (three billion tons), it is estimated that1.5 billion tons of water is chemically consumed annually during concrete production. Another 1 billion tons of water is lost to evaporation during the concrete curing process, which may last up to 28 days. Water is used, but is not consumed, during the Solidia Concrete curing process. It can be collected and reused, with recycle rates in excess of 60%, and potentially as high as 100%.

References:

1. WRI (2005) Navigating the numbers. Greenhouse Gas Data and International Climate Policy, World Resources Institute. ISBN 1-56973-599-9.
2. About Cement, World Business Council for Sustainable Development Cement Sustainability Initiative.
3. www.wbcsdcement.org/pdf/technology/WBCSDIEA_Cement%20Roadmap_centre_spread_actual_size.pdf.
4. http://www.cement.ca/en/Contact-Us.html

7. Overall Conclusions

In the course of this CCEMC Grand Challenge Round 1 program, Solidia Concrete CO_2-curing technology has been successfully translated from laboratory scale to pilot manufacturing scale to full manufacturing scale. This has been demonstrated for a wide variety of precast concrete products. This translation has allowed verification of the following attributes of Solidia Concrete products and of Solidia Concrete manufacturing:

- Solidia Concrete products permanently and safely store significant quantities of CO_2, equal to over 20% of the cement mass used in the concrete.
- Solidia Concrete products meet basic CSA standards and appeared poised for acceptance by the concrete marketplace.
- Solidia Concrete products offer a number of attractive manufacturing economies when compared to their Portland cement based counterparts. These include reduced raw materials waste, reduced dependence on admixtures to control efflorescence, shorter curing time to full concrete strength, faster equipment clean-up, reduced equipment maintenance, and improved inventory management. These economies more than offset the need to purchase CO_2, and retrofit curing systems to handle CO_2.

The result has been considerable interest among precast concrete manufacturers across Canada. Potential adopters include concrete block, paver, hollow core slab, architectural panel and pipe manufacturers in Quebec, Ontario and Alberta. ***It is important to note that no environmental incentives have been required to attract this commercial interest.***

Solidia Technologies is now poised to transfer CO_2-curing technology to concrete manufacturers to enable the realization of the benefits described above. To accomplish this task, two strategic partners will provide critical support:

- LafargeHolcim is one of the world's largest producers of cement, and is also a manufacturer of precast concrete products. As a result, they are positioned to be both the initial supplier of Solidia Cement and a launch customer of Solidia Cement, in Canada and worldwide. ***Of importance to the CCEMC Grand Challenge program, LafargeHolcim operates a cement manufacturing plant in Exshaw, Alberta.*** With an existing marketing and sales team that spans the globe, LafargeHolcim will also serve as the Solidia Cement point of contact with the concrete industry.
- Air Liquide is a world leader in industrial gases and related technologies. As a primary producer of industrial grade CO_2 in Canada and worldwide, Air Liquide will provide CO_2 gas and gas handling expertise to Solidia Cement customers. In addition, they will design and construct the equipment needed to retrofit a concrete manufacturer's curing system to allow CO_2-curing.
  .

The primary, unanswered question at this point in time involves the use of Solidia Cement and CO_2-curing in cast-in-place concrete applications. Penetration of the cast-in-place market is necessary to reach the full environmental benefit of the Solidia Cement / Solidia Concrete technologies. This will be one of the topics addressed in Solidia Technologies' CCEMC Grand Challenge Round 2 application.

Together, Solidia Technologies, LafargeHolcim and Air Liquide are capable of enabling the adoption of CO_2-curing technology throughout Alberta, allowing the cement and concrete industries the opportunity to reduce their collective CO_2 footprint by 1 million tonnes per year.

8. Scientific Achievements

The primary technical achievement associated with this CCEMC Grand Challenge Round 1 program has been the translation of Solidia Concrete CO_2-curing technology from the laboratory scale to pilot manufacturing scale to full manufacturing scale. Prior to the onset of the program in Alberta (and a concurrent program funded by U.S. Department of Energy research contract DE-FE0004222 in the U.S.), Solidia Technologies had limited experience in curing large quantities of concrete in non-laboratory environments.

Translating from laboratory scale to full manufacturing scale involved a tenfold increase in curing system volume (from 20 m^3 to 200 m^3). Both the concrete mass treated within the curing system and the water removed from the curing atmosphere increased by a factor of eighty (from 0.5 tonne to 40 tonnes of concrete; from 0.2 tonne to 16 tonnes of water).

These jumps required the use of computational fluid dynamic modeling techniques to design gas conditioning and distribution systems capable of maintaining the target CO_2-curing environment (temperature, relative humidity and CO_2 concentration) uniformly throughout the system volume.

They also required significant process engineering and equipment engineering efforts to assure that the key system components (heat exchanger, condenser, heater, blower, gas plenums) operated in concert to achieve the desired outcomes.

9. Next Steps

The next steps in the development of Solidia Cement and Solidia Concrete technologies are divided into three basic categories; Technical, Marketing, and Program.

From a *technical* perspective, Solidia Technologies will focus on the precast curing process and the development of capability to extend this process to cast-in-place concretes.

- Retrofit curing systems (or install alternate start-up capability) at addition precast manufacturing sites to enable Solidia Concrete manufacturing.
- Refine start-up CO_2-curing systems to achieve equipment standardization and allow quick and easy installation
- Optimize CO_2-casting equipment and processes to assure efficient use of CO_2
- Develop technology to allow economical transformation of an entire concrete plant to CO_2-curing.
- Quantification of all material and process benefits which enable adoption of the CO_2-curing technology without environmental incentives.
- Demonstration and evaluation of three different cast-in-place curing techniques.

From a *marketing* perspective, Solidia Technologies and LafargeHolcim will partner to set the foundation for the widespread use of CO_2-curing technology in Alberta.

- Identify complete list of Alberta-based precast concrete manufacturers.
- Define and implement plan for introduction of industrial scale CO_2-curing technology at selected launch customers in paver and masonry marketplaces.
- Expand marketing base to include other non-structural precast applications (e.g. roof tiles, retaining walls)
- Expand marketing base to include precast semi-structural and structural applications (architectural panels, hollow core lab, pipe, and transportation infrastructure).
- Verify value to each launch customer.
- Establish Solidia Cement and CO_2 supply chains for each launch customer.
- License launch customers.

From a *program* perspective, the logical "Next Step" is application to the CCEMC Grand Challenge Round 2. From the very beginning of the Grand Challenge program, it has been Solidia Technologies intent to participate in all three rounds. The plans for Rounds 2 and 3 are as follows:

- *Round 2* (2016-2018) will continue to address the precast concrete market, extending the reach of Solidia Concrete into structural applications. In addition, Solidia Technologies and LafargeHolcim will partner to begin the development of cast-in-place CO_2-curing technologies.

- *Round 3* (2018-2020) will complete the penetration of Solidia Concrete into precast markets, complete the development of cast-in-place curing technologies, and begin the market penetration of Solidia Concrete in cast-in-place applications.

10. Communications Plan

Solidia will utilize a combination of communication tools and platforms to inform interested constituents on project progress. All communications will have a strong bias towards driving technology awareness, technology trials, technology pilots, and ultimately, successful technology adoption and full commercialization. Targeted third party constituents include Alberta government entities and officials, relevant cement and concrete trade groups (e.g. the Interlocking Concrete Paving Institute and the National Concrete Masonry Association), relevant codes/standards organizations (CSA and NRC), the architect/specifier community, and finally, prospective cement and concrete manufacturers.

The principle hub platform for all communications will be Solidia's website (www.solidiatech.com). A comprehensive inventory of press resources are available, including press photos, Solidia's You Tube channel, challenge briefs, science briefs, Solidia's Twitter feed, and a news feed. Solidia's website also hosts a "news" tab that includes a news archive, press releases, and technology white papers. Solidia will drive website traffic through participation in relevant trade association events, speaking engagements, and in person visits.

The communication plan also includes in field constituent contact leveraging Solidia's cement and concrete start up partner Lafarge Holcim. Lafarge Holcim has an extensive network of commercial sales and marketing professionals who regularly interact with the targeted third party constituents. In addition to the tools previously outlined on Solidia's website, these professionals are also armed with product literature, trial videos, power point presentations, and case studies from concrete producers from around the world who are currently engaged in Solidia's technologies. The same can be said for leveraging the sales and marketing expertise offered by Solidia's industrial gas equipment and supply partner, Air Liquide.