Beneficial Use of CO_2 in Precast Concrete Production

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Infrastructure for CCS

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Presentation Outline

- The goals and objectives
- Benefits to the program
- Project overview
- Technical status
  - Summary on CO_2 uptake
  - Summary on cost analysis
- Accomplishment to date
- Summary

Brief Background

- Concrete is the world`s most used construction material (> 9 Btons per year)
- Concrete = aggregates + cement + water
- Consolidation & strength development with the hydration of cement (28 day standard)
- Carbonation accelerates cement hydration
  - CO_2 uptake by cement
- Concrete products in this project
  - Standard 8” concrete blocks
  - Standard 4’ x 8’ fiber-cement boards

The Goals

- Maximizing **carbon uptake** by carbonation (at least **20-25%** by cement mass)
  - Each **8”** concrete **block** shall take **0.75** lb CO_2
  - Each **4’x8’ fiberboard** shall take **10.5** lb CO_2
- Minimizing the CO_2 **utilization** cost
  -- The utilization cost shall be less than $**10/t$CO_2$**
- Minimizing the CO_2 **capture** cost
  - The capture cost shall not exceed $**50/t$CO_2$**

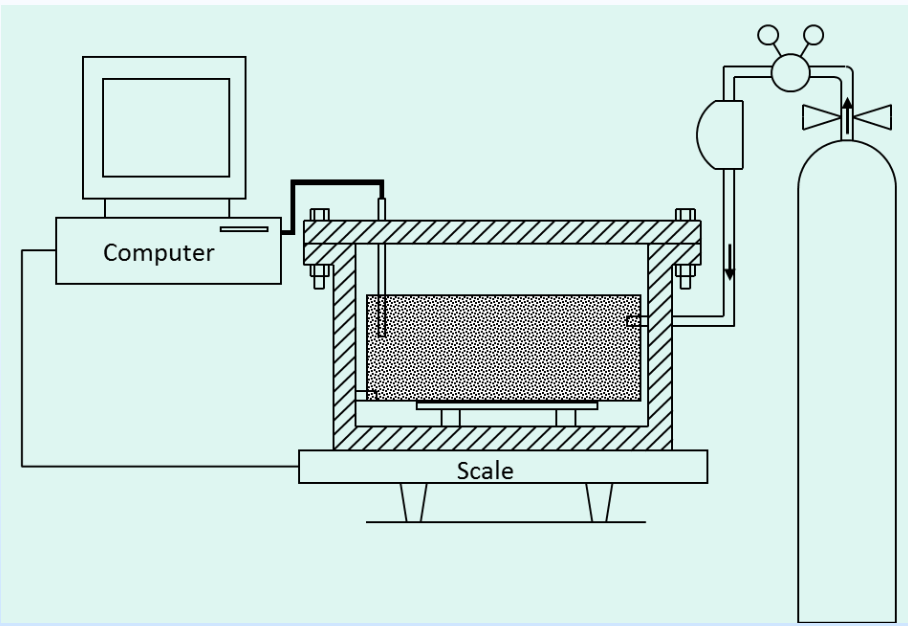
Benefit to the Program

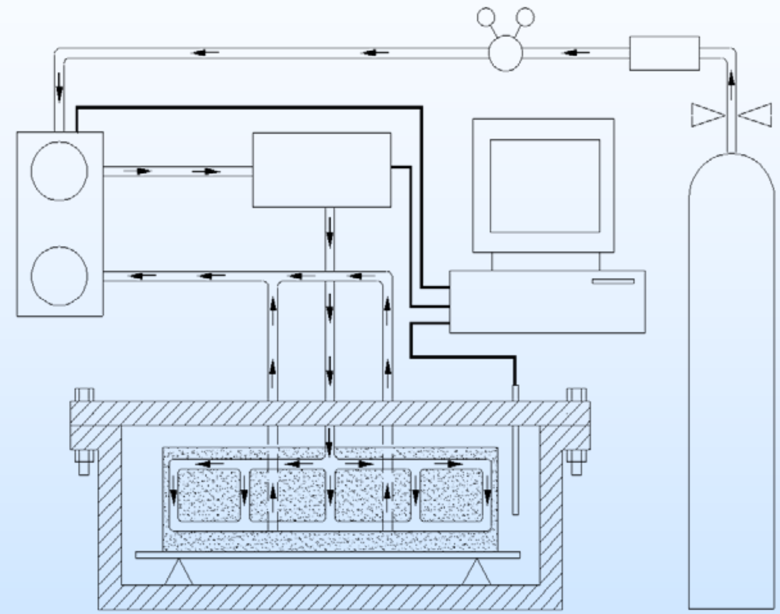
- Develop technologies that will support industries' ability to **capture** and **utilize CO_2** at the **vicinity** of the **sources**: CCS in **urban setting**.
- CO_2 storage in concrete is **permanent** and **stable** in the form of calcium **carbonates**.
- **4.3** billion blocks/year in US, CO_2 sequestering potential almost **1.5 Mt** per year.
- **9.8** billion ft^2 fiber-cement board/year in US, CO_2 utilization equivalent to **1.36 Mt** per year.
- Utilization by carbonation will continue for years to come. No time restraints!

Project Overview

- Developed carbonation process to achieve carbon uptake of 20-25% by cement mass
- Optimized the carbonation cost for practical utilization
- Optimized CO_2 capture cost (3H's self-concentrating absorption technology)
- Evaluated performance of carbonated products by comparing to conventional steam cured ones
- *The success criteria: to meet all set goals*

Summary on CO_2 Uptake





Static carbonation is energy-free, requires presetting of products and takes longer time.

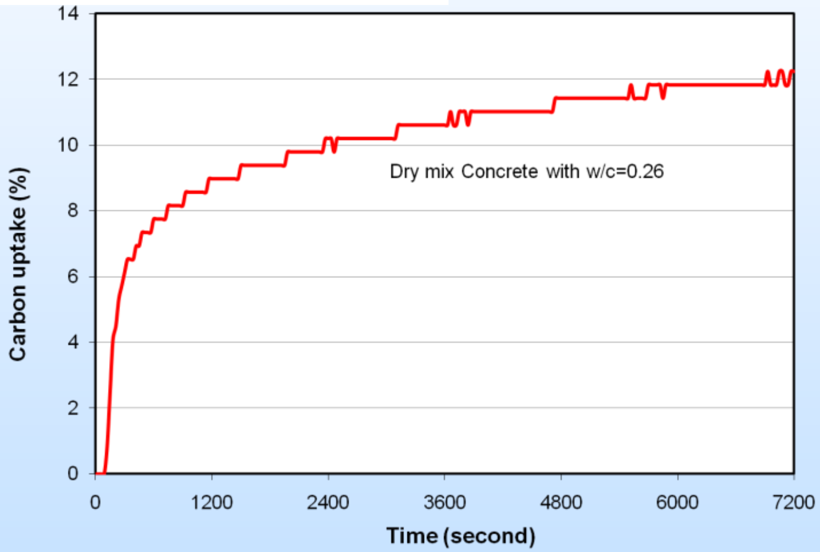
Dynamic carbonation is faster, takes less time but requires energy to circulate the CO_2 gas.

CO_2 Uptake Calculation

- Mass gain method

$$\%CO2\ uptake = \frac{(Mass)_{aft,CO2} + (Mass)_{LostWater} - (Mass)_{bef,CO2}}{M_{cement}}$$

- Mass curve method



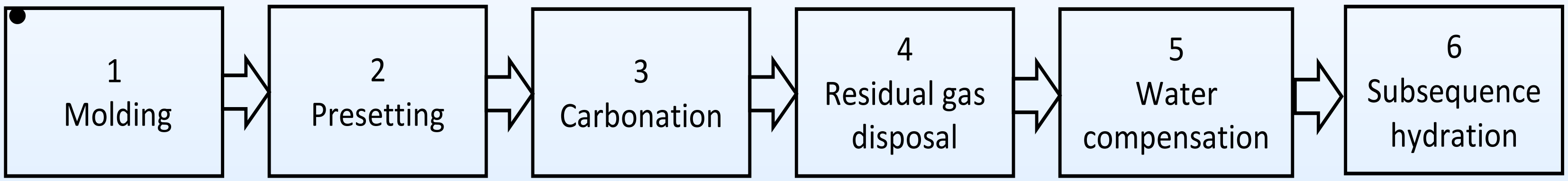
$$\%CO2\ uptake = \frac{(\Delta M_{CO2})_{masscurve}}{M_{cement}}$$

- Thermal analysis or titration analysis

$$CO_2\ Content(\%) = \frac{M_{550} - M_{1000}}{M_{Cement}} = \frac{\Delta M_{CO2}}{M_{cement}}$$

(I) Summary on CO_2 Uptake

- For static carbonation, a process is developed for optimized carbon uptake:



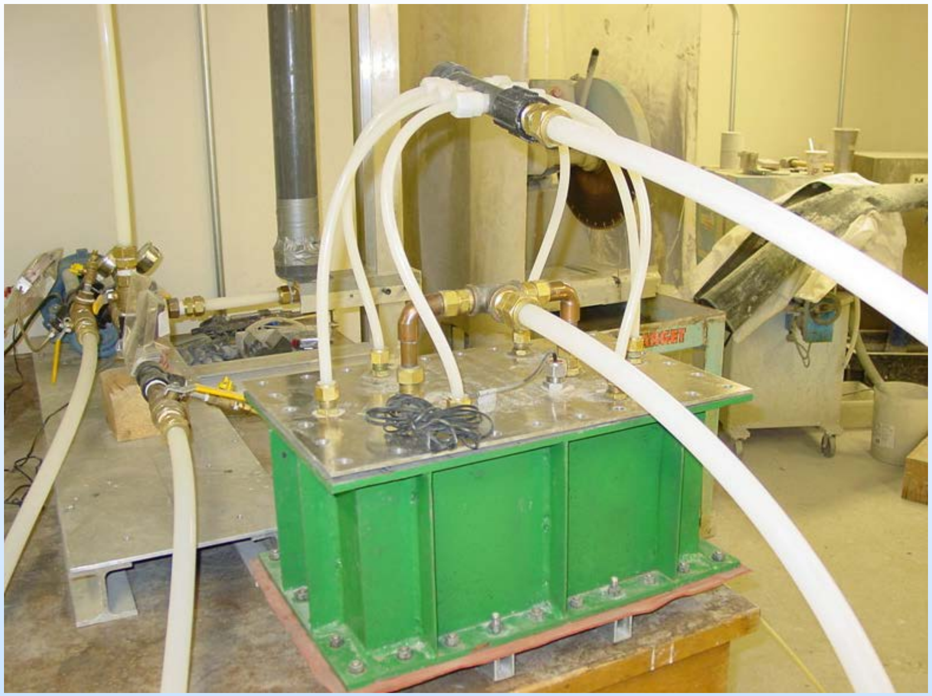
- **Presetting**: achieve **50-60%** water removal from concrete**,** making space for carbonate precipitation
- **Carbonation**: reaction between CO_2 and calcium compounds (C_2S, C_3S, $Ca(OH)_2$, C-S-H)
- "**Residual gas disposal**:" handling residual CO_2 left in chamber and not consumed by concrete.
- **Water compensation**: surface spray to saturation

Cement Based Building Products

1’x2’ fiber cement panel (0.5” thick)
Target: 0.65 lb CO_2 per 1’x2’ panel

8” concrete blocks (8”x8”x16”)
Target: 0.75 lb CO_2 per 8” block

CO_2Claves for Blocks



Single block CO_2 Clave for both static and dynamic carbonation

CO_2Clave for static carbonation of multiple 8”-blocks or 1’x2’ panels

CO_2Clave for Panels

CO_2Clave for both static and dynamic carbonation of 1’x2’ panels

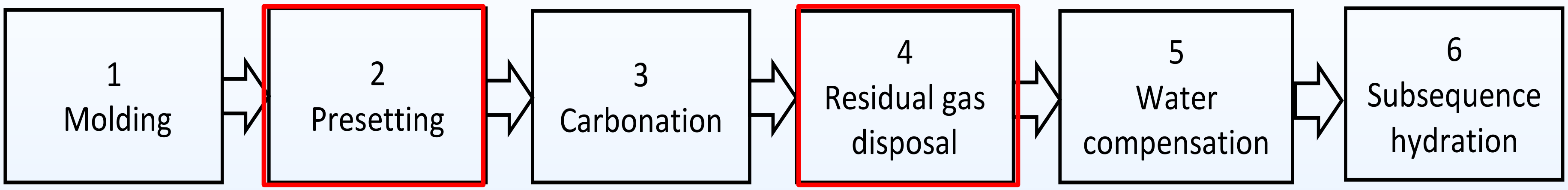
Results: Concrete Blocks

- Mix design of 8”-block of 16.5-kg (36-lb):
  - Cement = 1.6 kg (cement content 10%)
  - Water = 0.9 kg
  - Coarse aggregates = 5.6 kg
  - Fine aggregates = 8.4 kg
- **The best results: CO_2 uptake = 0.35 kg (0.77 lb)/block**
  - Presetting = 11 h (25^0C and 25%RH)
  - Wind velocity = 0.5 m/s
  - Moisture removal = 53% (based on total water)
  - **Carbonation** time = **4h** at gas pressure = 0.5 MPa
  - Carbonation **strength** at 15h = **13 MPa**,
  - **Hydration strength** (reference) after 28d = **12 MPa**

Results: Fiber Panels

- Mix design of 1’x2’x0.5” panel of 3-kg (6.6-lb):
  - Cement = 2.2 kg (cement content = 73%)
  - Water = 0.53 kg
  - Cellulose fibers = 0.27 kg
- **The best results: CO_2 uptake = 0.44 kg (0.97 lb)/1x2 panel**
  - Presetting = 18 h (25^0C and 50%RH)
  - Wind velocity = 0.5 m/s
  - Moisture removal = 60% (based on total water)
  - **Carbonation time** = **2h** at gas pressure = 0.5 MPa
  - Carbonation **flexural strength** at **20h** = **5.8-8.5 MPa**,
  - **Hydration** flexural **strength** (commercial product, 28d) = **6.9 MPa**

(II) Summary on Cost Analysis

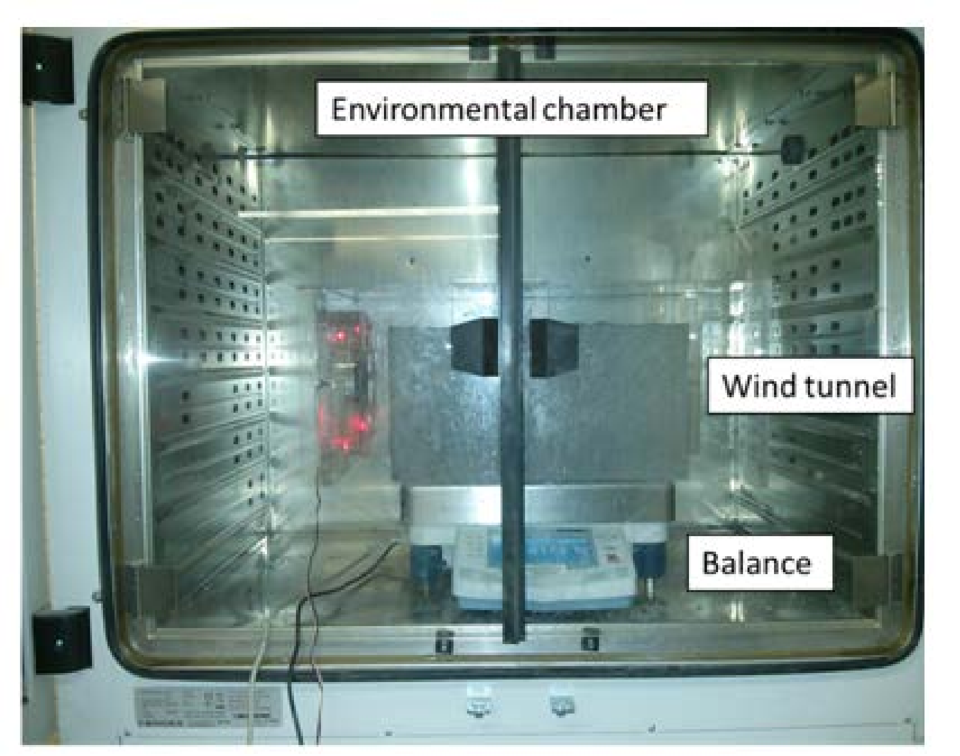


- Step 1: $0
- Step 2: $? (Energy is required to remove free water.)
- Step 3: $0 (Energy-free since gas is pressurized.)
- Step 4: $? (Energy is required to collect residual CO_2 in chamber)
- Step 5: $0
- Step 6: $0

Step 2: Cost of Presetting

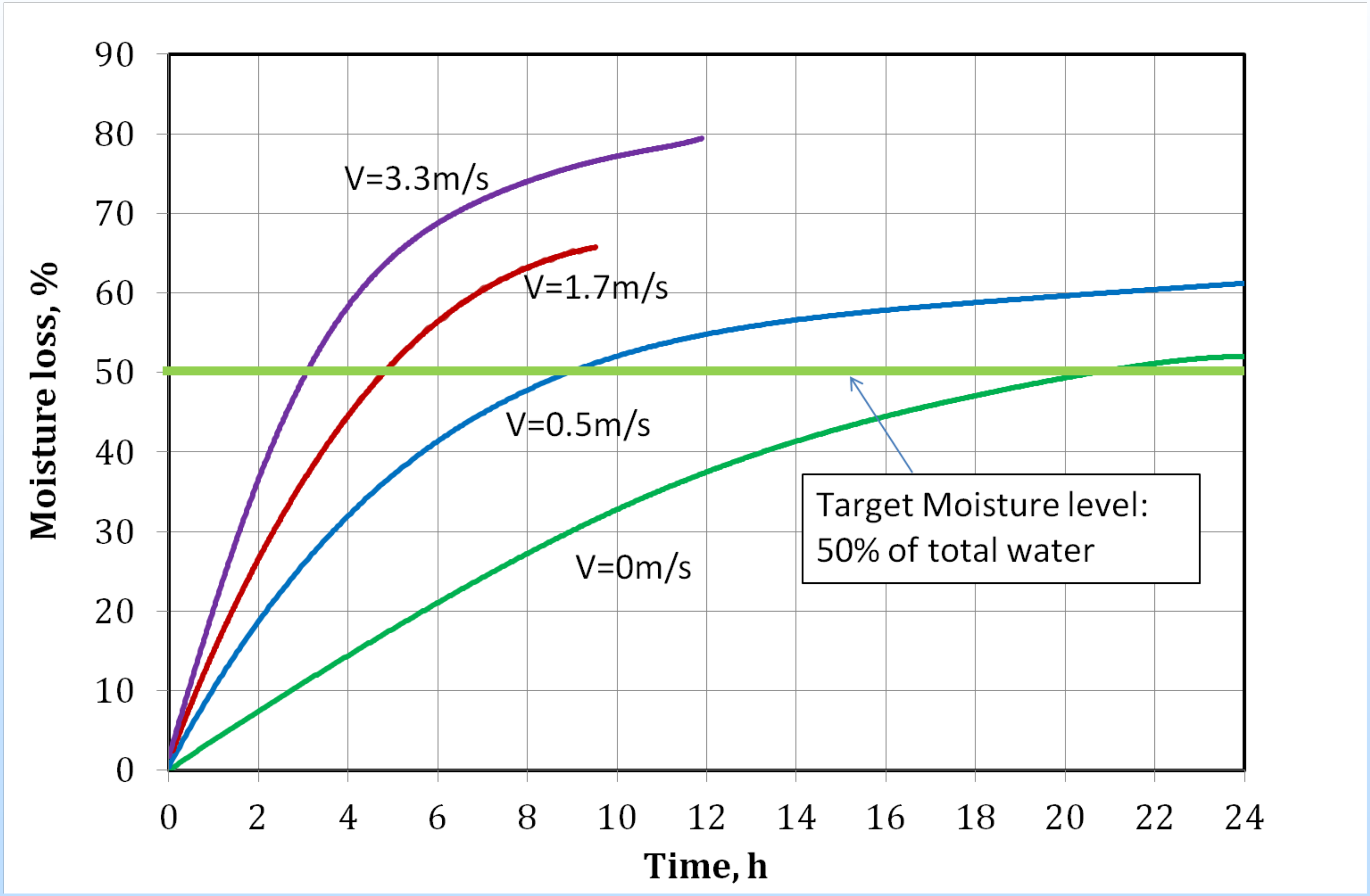
- Laboratory setup measuring wind energy due to fan drying in a controlled environment (temperature and relative humidity)

Wind tunnel is designed to dry the block and measure the power needed to generate the desired wind to reach the target moisture level.

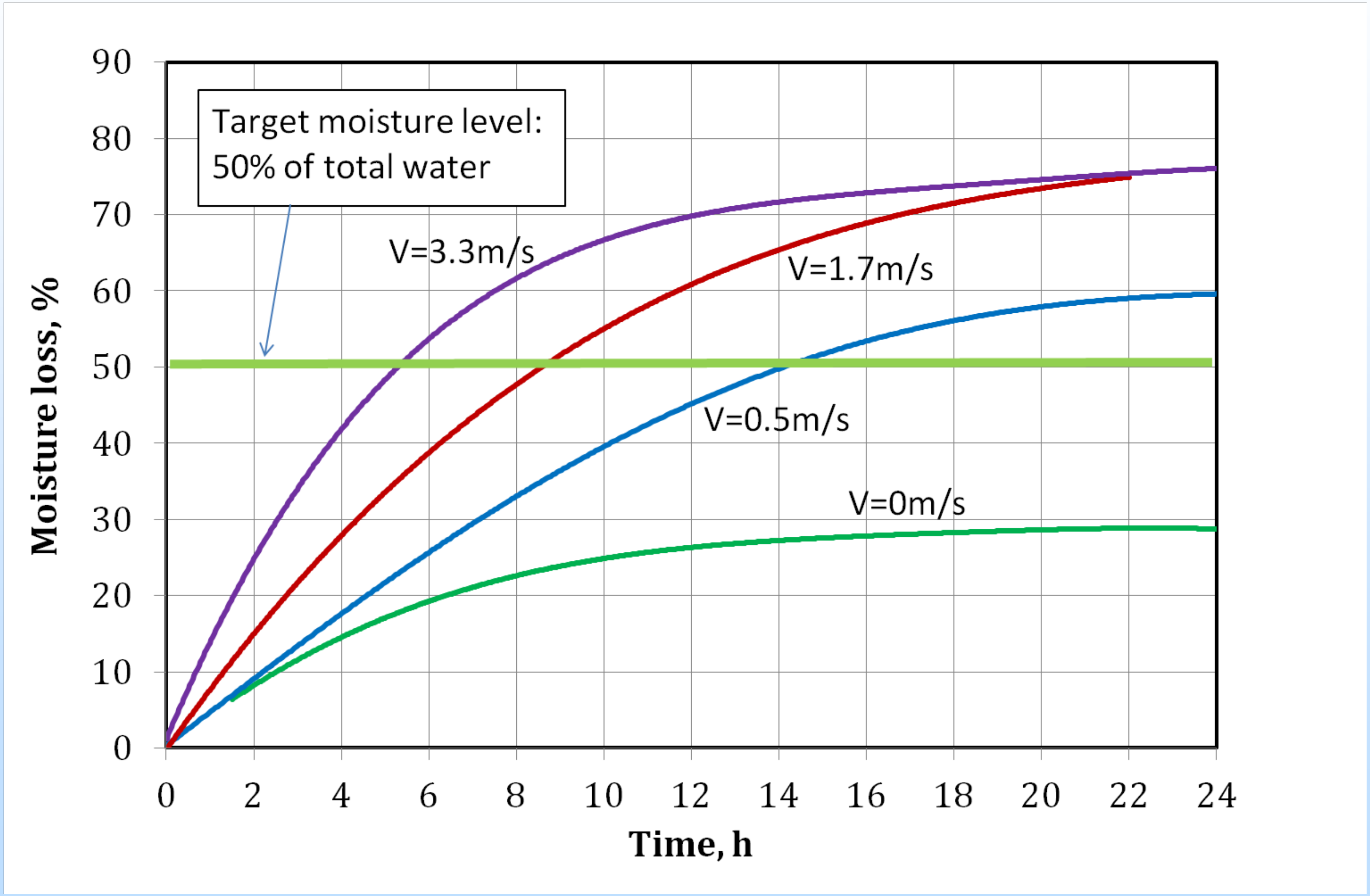


Wind tunnel is placed in an environmental chamber.

Presetting at 25^{o}C and 25%RH



Presetting at 25ºC and 50%RH



Cost of Presetting for Blocks

Table 1: Energy and cost for one ton CO2 utilization (calculated by 2941 blocks**)

Wind velocity, m/s	Electrical power* needed to generate wind Per block, (W)	20±5℃ with **25±5% RH**			20±5℃ with **50±5% RH**		
		Preset time to reach target moisture per block, (h)	Energy per tCO2, (kWh)	Cost, $/tCO2	Preset time to reach target moisture per block, (h)	Energy per tCO2, (kWh)	Cost, $/tCO2
V1=0	0	20.4	0	0	Not possible	Not possible	Not possible
V2=0.5	0.28	8.9	7.33	0.49	13.9	11.45	0.77
V3=1.7	3.04	4.8	42.92	2.89	8.8	78.68	5.30
V4=3.3	29.40	3.1	268.04	18.07	5.2	449.62	30.30

*The cost of electricity: $0.0674/kWh

**Total of 2941 blocks are required to take one ton of CO2 at carbon uptake of 0.34kg/block (=0.75lb/block)

Target moisture content: removal of 50% of free water

Cost of Presetting for Panels

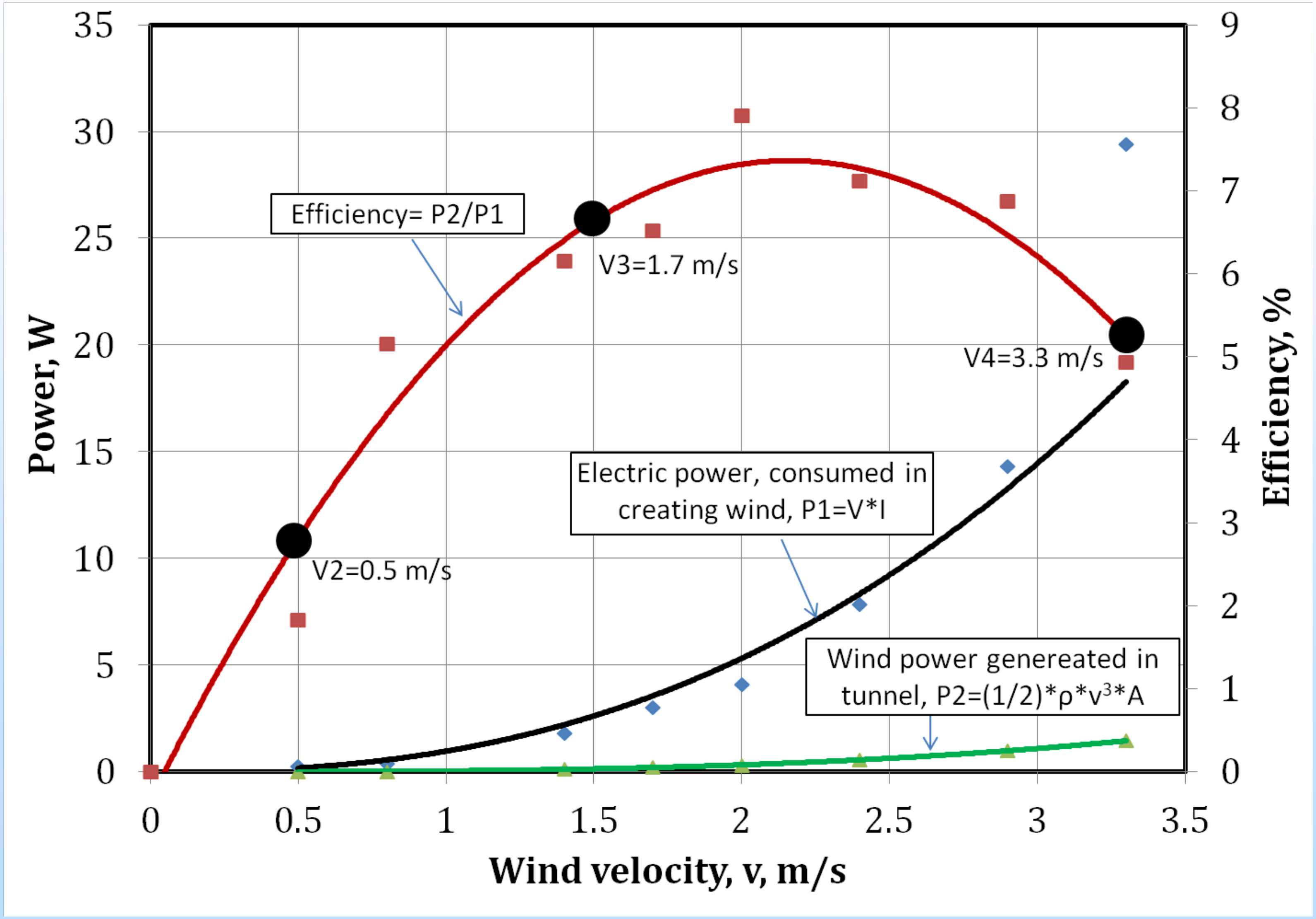
Table 2 Energy and cost for panels (20±5℃)

Environmental	Air curing time, h	Fan Dry			One panel		2273 panels (1 ton CO_2 absorption) *	
		time, h	Wind velocity, m/s	Power of fan, W	Energy consumption, kWh	Cost /panel, $**	Energy consumption, kWh	Cost /tCO_2, $*
25±5% RH	17	1	0.5	0.28	2.80E-04	1.89E-05	6.36E-01	0.043
50±5% RH	0	18	0.5	0.28	5.04E-03	3.40E-04	1.15E+01	0.772
80±5% RH	0	18	1.7	3.04	5.47E-02	3.69E-03	1.24E+02	8.383

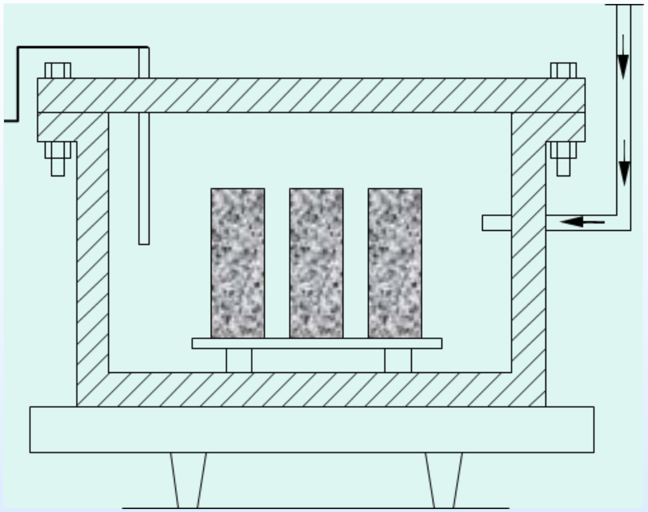
*: For one ton CO_2 absorption, the total number of panel needed is 1000/0.44=2273 panels (K-panel)

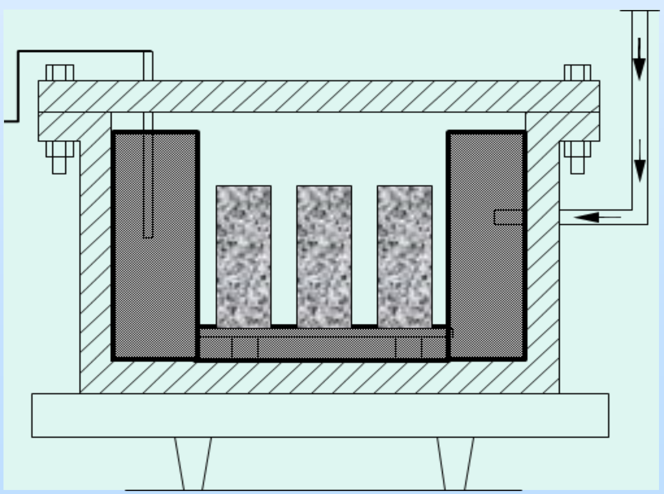
**: Rate of electricity is 0.0674/kWh

Efficiency in Presetting by Wind



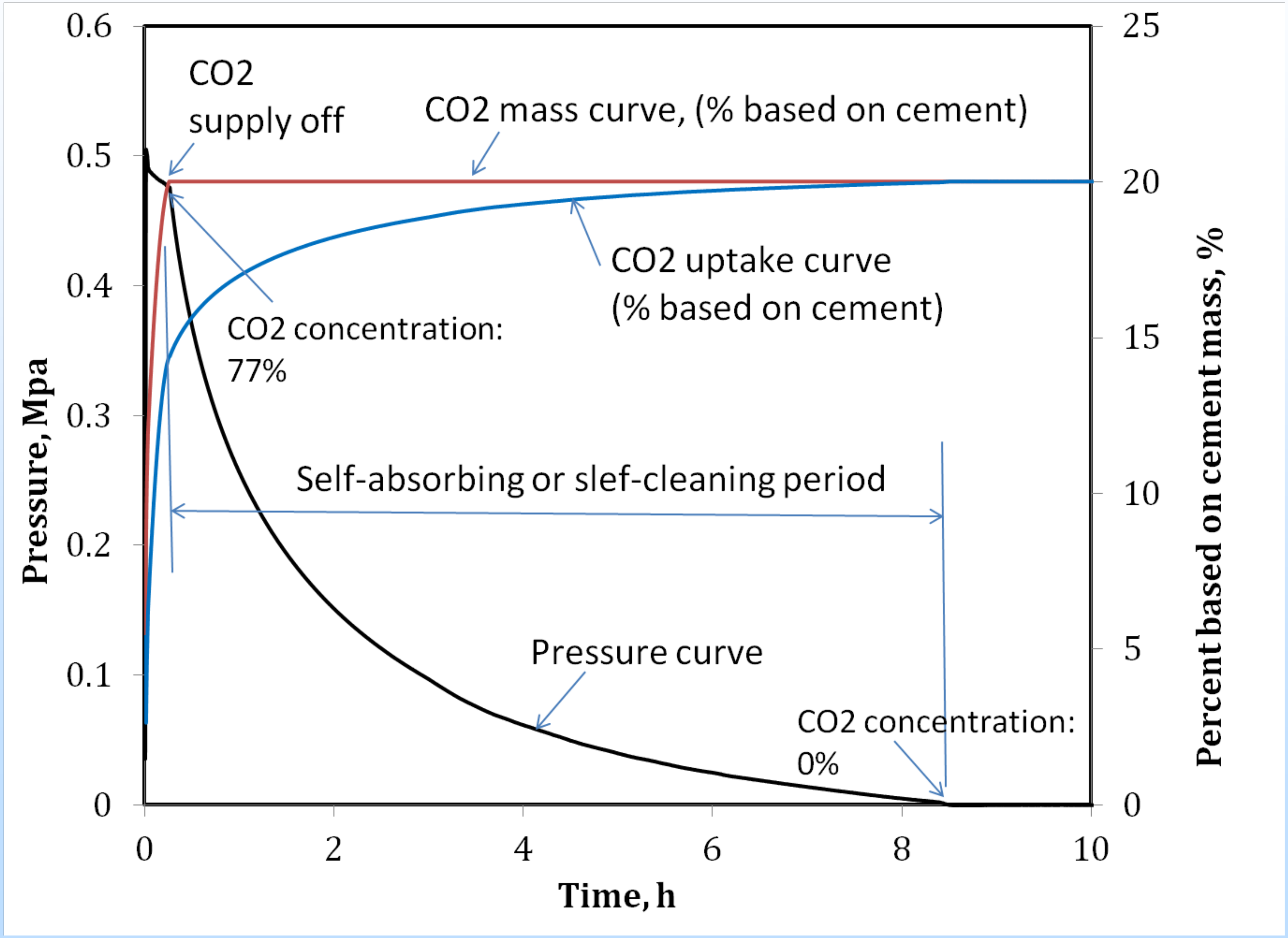
Step 4: Cost of "Residual gas disposal"





1) Using 3H self-concentrating absorption technology is fast but the cost may go beyond $10/t
2) Using "**self-cleaning**" method is energy-free and cost-free:
   - Compact chamber design to allow desired CO_2 for target uptake rate
   - Keep CO_2 at constant pressure with CO_2 valve on
   - Keep the CO_2 mass constant with CO_2 valve off. This is the period called self-absorbing or self-cleaning.
   - The zero pressure indicates zero CO_2 in chamber.

Capture of Residual CO_2 Using "Self-Cleaning" Technology



Results: CO_2 Capture Cost (**3H Company**)

- Using 3H proprietary self-concentrating absorption technology.
- Energy use evaluated by Worley Parsons. It was concluded that 3H technology could save 26% energy including compression and transport.
- The DOE baseline for CO_2 capture: the increase of cost of electricity due to CO_2 capture should be less than 35% including capital cost, transport, storage and monitoring. **Worley Parsons** confirmed that 3H technology had **met the goal**.
- It is possible to produce high purity CO_2 at **$36/t including capital cost**, **transport**, **storage** and **monitoring**.

Accomplishments to Date

- A static **carbonation** process **developed** to achieve carbon uptake of 20-25% by cement mass.
- Near-surface **dynamic** carbonation process also developed for accelerated production.
- 8” Concrete **block** to take **0.77 lb CO_2** (target: 0.75lb)
- 1’x2’ **Fiber board** can take **0.97 lb CO_2** (target: 0.65lb)
- 1 **ton** CO_2 **captured** at **$36** (capital cost, compression, transport, storage and monitoring). (target: $50/ton)
- **Utilization cost** < **$1/t$CO_2$** at concrete plant with RH of 50% or lower. (target: $10/ton)
- **Carbonated concrete** found to exhibit **improved** service life **durability** (more resistant to freeze-thaw damage, chloride permeation and sulphate attack).

Summary

- Maximum carbon uptake and minimum cost are challenging goals which are possible to achieve.
- If only process energy is included, CO_2 can be captured for $10/t, which is competitive to natural gas.
- In presetting, increase in wind efficiency from 7% to 70% will significantly reduce the utilization cost.
- A simulation model is needed to predict the carbonation degree based on the plant conditions.
- The compact chamber design for “self-cleaning” shall be tested in large scale.

Appendix

– These slides will not be discussed during the presentation, but are mandatory

Organization Chart

- McGill University (Materials development, carbonation systems, performance assessment, cost analysis.)
- 3H Company (Self-concentrating absorption system, cost analysis, carbonation systems.)

Gantt Chart

Table 1, Organizational chart (corrected in Q7 with no-cost extension)

Quarter	Date	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7
Q1	10/1-12/30, 2010	Mc+3H, 1.0						
Q2	1/1-3/30, 2011		Mc+3H, 2.1, 2.2	Mc+3H, 3.1,3.2				
Q3	4/1-6/30, 2011		Mc, 2.2	Mc, 3.1,3.2,3.3,3.4			Mc+3H, 6.1	
Q4	7/1-9/30, 2011	Mc+3H, 1.0, agreement	Mc, 2.2	Mc, 3.2,3.3,3.4	Mc, 4.1, 4.3			
Q5	10/1-12/30, 2011	Mc+3H, 1.0, agreement		Mc,3.4	Mc 4.1,4.3		1.0	
Q6	1/1-3/30, 2012		Mc, 2.2	Mc, 3.3, 3.4	Mc, 4.3		3H, 6.2	
Q7	4/1-6/30, 2012			Mc, 3.3	Mc, 4.3		3H, 6.2	Mc 7.1
Q8	7/1-9/30, 2012		Mc, 2.2		Mc, 4.3		3H, 6.2	Mc 7.1
Q9	10/1-12/30, 2012					Mc, 4.2, 5.1, 5.2	3H, 6.3, Mc, 6.1	
Q10	1/1-3/30, 2013				Mc, 4.2		3H, 6.4	
Q11	4/1-6/30, 2013						Mc+3H, 6.4, 6.5	
Q12	7/1-9/30, 2013							Mc+3H, 7.1,7.2

Q5 to Q8 are granted for no-cost extension in Budget Period 1.

Tasks to be completed: Task 5.0, performance evaluation; Task 6.5, Topical Report on Self-Concentrating Absorption Technology; Task 7.1 and 7.2, determine utilization cost .

Bibliography

– There is not yet peer reviewed publications. The following papers are in preparation:

- “Maximizing the carbon uptake in concrete blocks carbonation”. (Task 2.1, 3.2, 4.1, 4.2)
- “Performance of fiber-cement panels produced by carbonation curing”. (Task 2.2, 3.3, 4.3)
- “Freeze-thaw resistance of carbonated concrete products”. (Task 5.1)
- “Minimizing the cost in CCSU through concrete production”. (Task 6.3, 6.4, 7.1)
- “Studies on thaumasite sulphate attack on carbonated cement pastes”. (Task 5.1)
- “Cost analysis of CO_2 capture using 3H self-concentrating absorption technology”. (Task 6.2, 6.3, 6.4)