Developing process and procedures for the refinement of surf clam and ocean quahog shells into calcium carbonate ($CaCO_3$): Phases II

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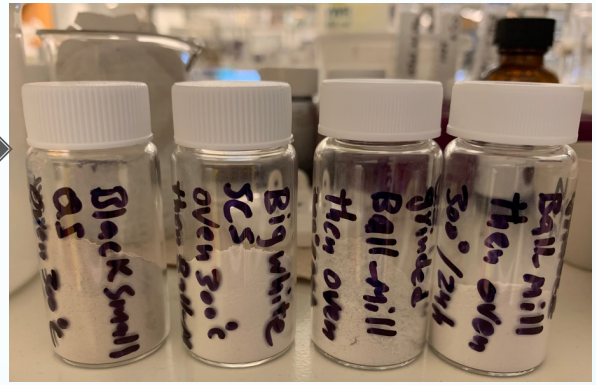
Recap

- In **phase I** of the project, we developed a process for cleaning, washing, and grinding the two shell species, including surf clam shells (SCS) and quahog shells (QS) and we also established a platform to perform a full analysis of the products.

Surf clam shells (SCF)

Ocean Quahog shells (QS)

Processing



Characterization:

- Morphology
- Element (EDX)
- Structure (ATR-FTIR)
- Thermal property (TGA)
- Digestibility

Phase II: Proposed plan

- Increase the scale of our process to produce enough samples for feed/paper industries;
- Reach out to the feed and paper industries for understanding their requirement for the $CaCO_3$ and modify the product to meet those requirements;
- Find parties for washing, grinding, and oven heating of the shells for kilogram scale production;
- Perform a full analysis of the product required for the selected industry;
- Conduct a detailed and more realistic economic study for the large-scale production of the powdered $CaCO_3$.

Scaled-up production of $CaCO_3$

HARROP
Fire our imagination

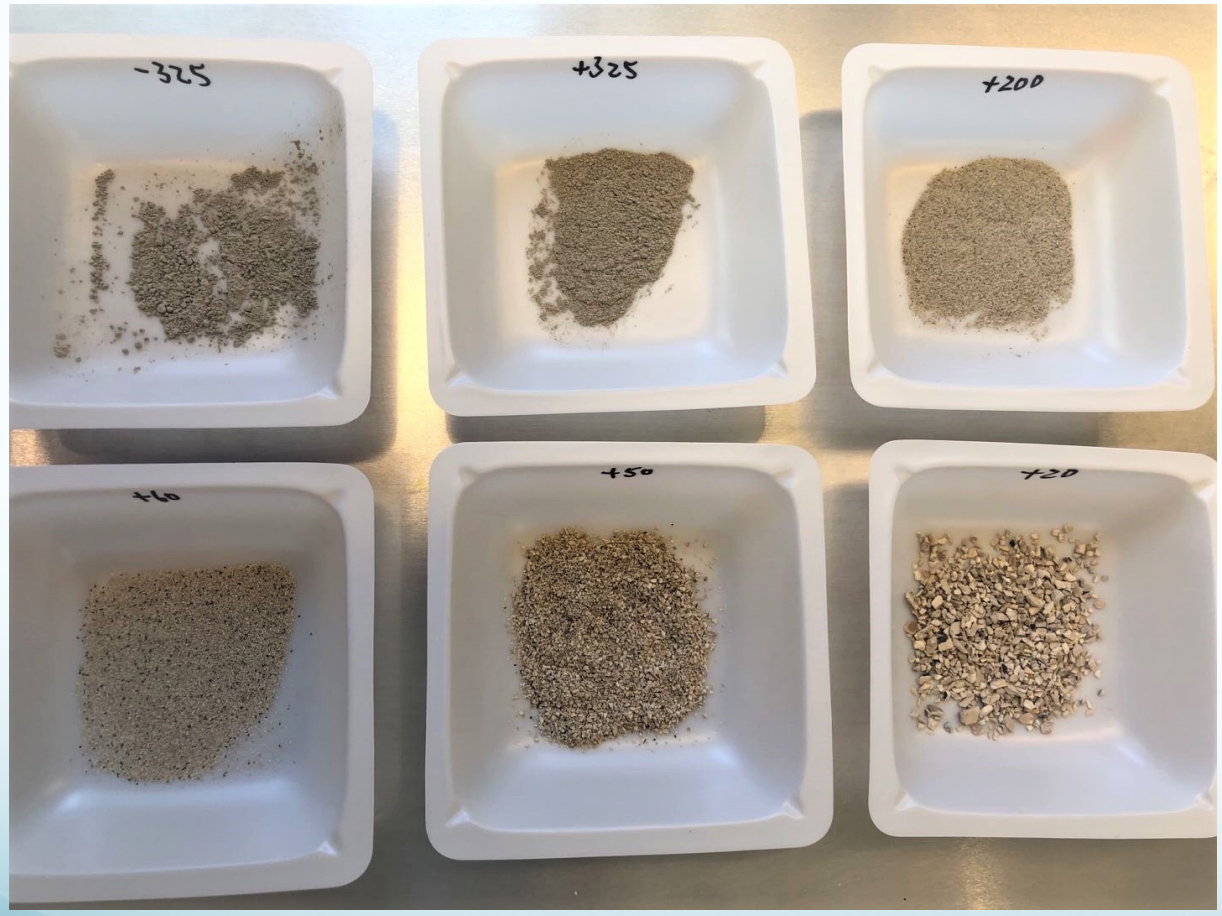
Harrop Industries, Inc.
3470 E. Fifth Avenue
Columbus, Ohio 43219-3816

- The party we worked with is **Harrop Industries, Inc**.

- Raw shell samples (6 x 5 kg) sent to Harrop.

Salvatore Lamonica	Atlantic Cape Fisheries
	
	
Sea Watch	Lamonica Fine Food

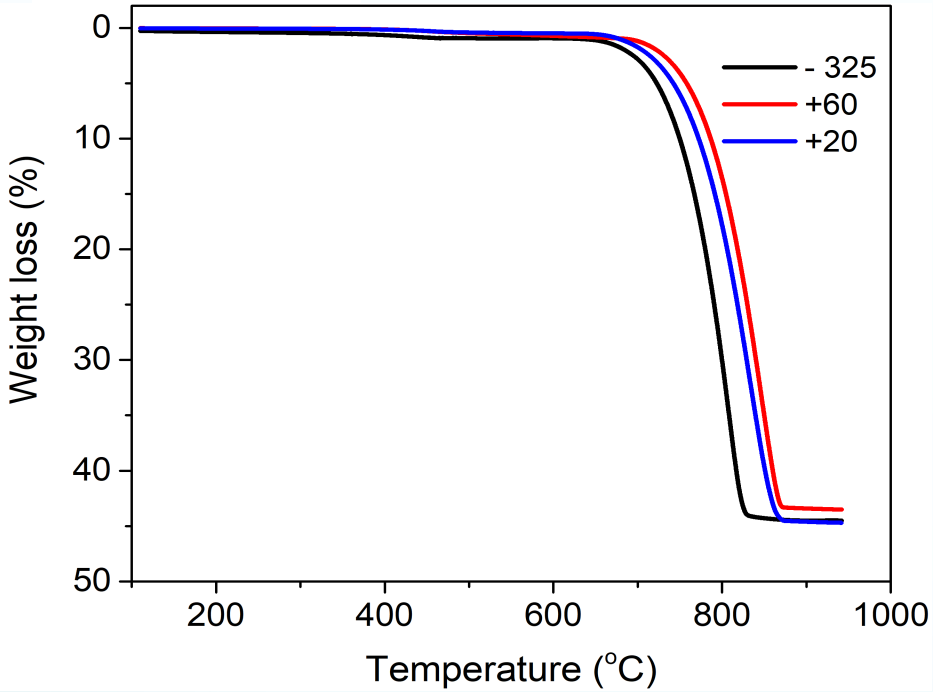
Processed $CaCO_3$ samples received from Harrop



Physicochemical Characterization:

- Color
- $CaCO_3$ content (TGA)
- Structural characterization (FTIR)
- In vitro solubility
- Loose bulk density
- pH

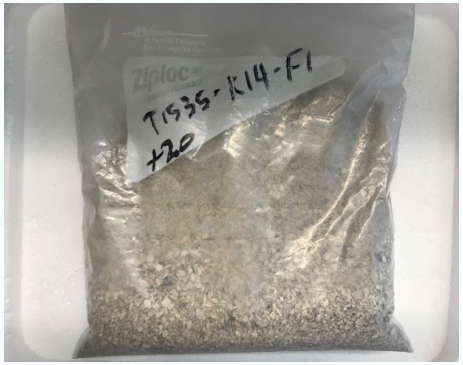
Thermal characterization of the $CaCO_3$ samples (TGA)

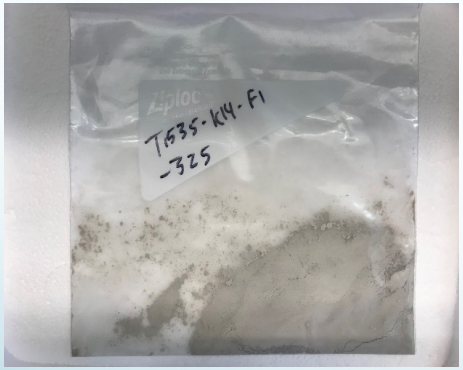


- The $CaCO_3$ contents of samples are higher than 97%, which is comparable to the commercial calcium carbonate (96.5%, HUBERCARB® Q series)
- Particle size of samples did not affect the content of $CaCO_3$.

Sample	Weight loss				$CaCO_3$ (%)
	Moisture (%) 20-125 °C	Organic matter (%) 125-600 °C	CO_2 (%) 600-900 °C	Total weight loss (%) 20-900 °C	
-325	0.28	0.77	43.26	44.32	98.39
+60	0.02	0.73	42.70	43.44	97.11
+20	0.04	0.46	43.23	43.74	98.31

Elemental analysis using ICP-MS of Harrop $CaCO_3$ samples





	Sample name		
Elements	+20	-325	Animal feed[1] (NRC)
DM%			
Ca	37.38	36.86	35.8-38.5
P	0.01	0.03	0.01-0.02
Na	0.49	0.48	0.06-0.08
Cl	n/a	n/a	0.02
K	0.00	0.01	0.08-0.11
Mg	0.02	0.03	1.61-2.06
S	0.12	0.14	0.04-0.08
Fe	0.01	0.11	0.06-0.35
Cu	0.00	0.01	
Mn	0.00	0.01	0.02
µg/g			
Pb	0.22	n/a	< 0.5
As	0.23	1.44	< 3
Hg	nd	nd	< 0.5
Zn	nd	n/a	
Se	nd	nd	
Cd	nd	nd	

- Calcium contents of coarse and fine $CaCO_3$ samples meet the requirement (35-38.5%).
- ICP-MS analysis was conducted at Virginia Tech (VA).

Virginia-Maryland College of Veterinary Medicine

1. https://www.pig333.com/articles/calcium-carbonate-as-a-pig-feed-ingredient_17514/

Proposed 3 scenarios for the $CaCO_3$ production from shells

Input: two seashells

SCS QS

Processing

3 scenarios

Output: 3 $CaCO_3$ products

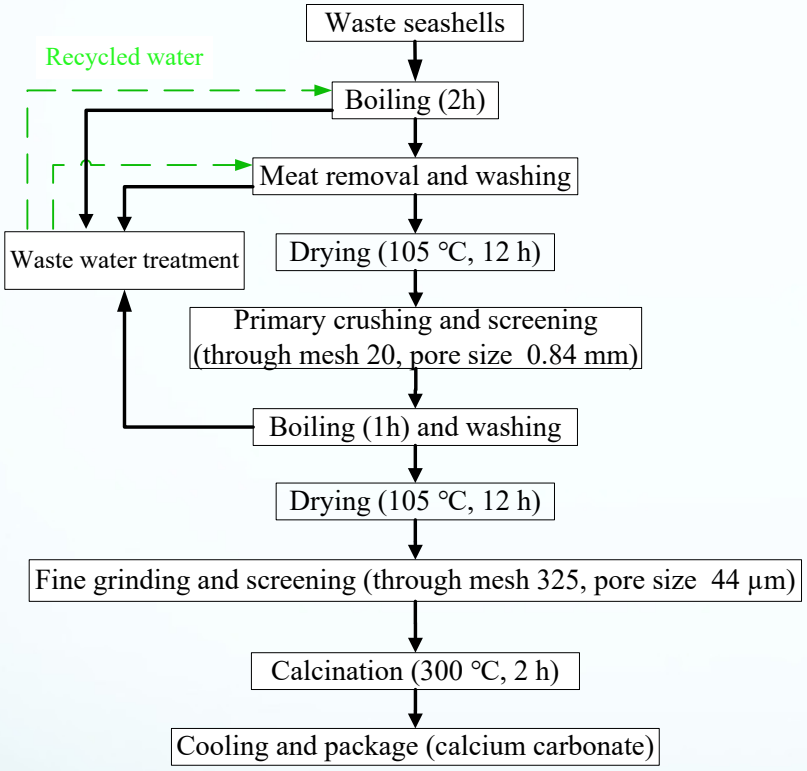
SQ1

SQ2

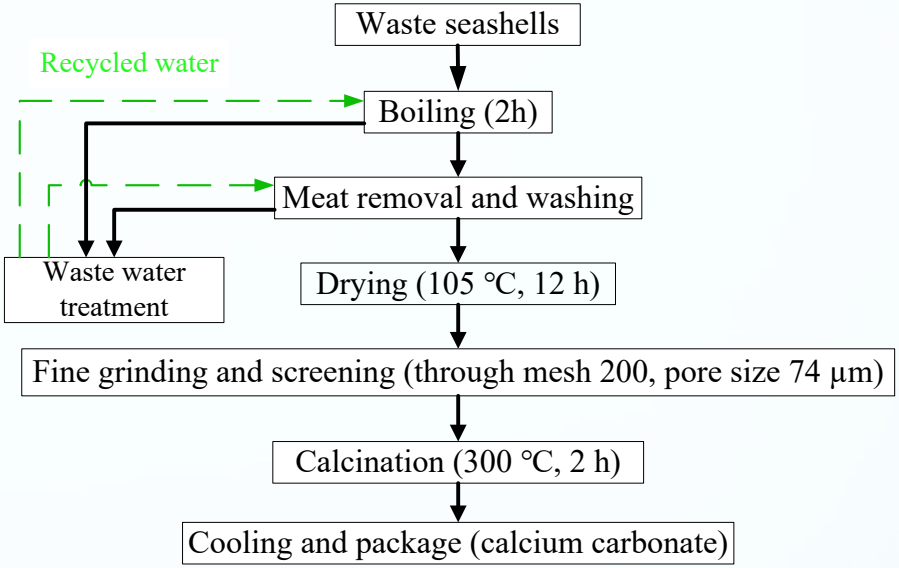
SQ3

Product	CaCO3 (%, w/w)	Particle size	Color	Target customer
SQ1	≥ 98%	Pass through mesh 325	White	Pharmaceutical and food sectors
SQ2	≥ 98%	Pass through mesh 200	Off-white	Paper
SQ3	≥ 96%	Pass through mesh 325	Off-white	Agriculture and construction

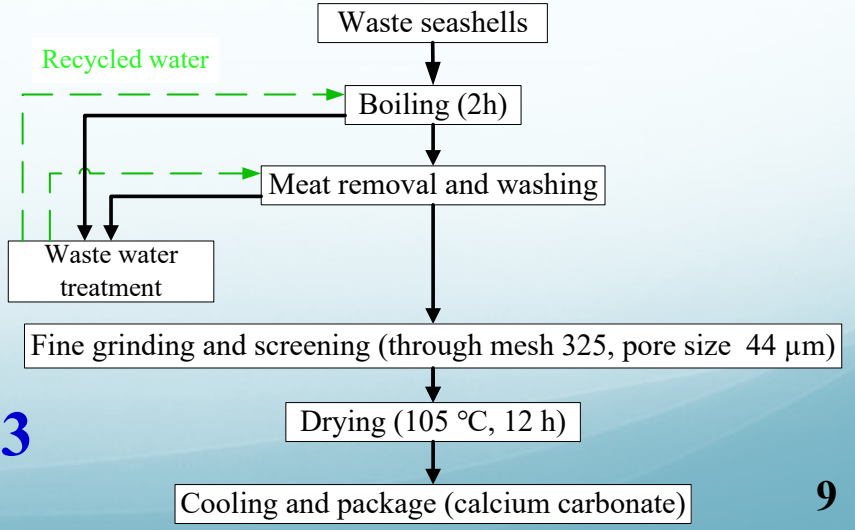
Process diagram of SQ1



Process diagram of SQ2



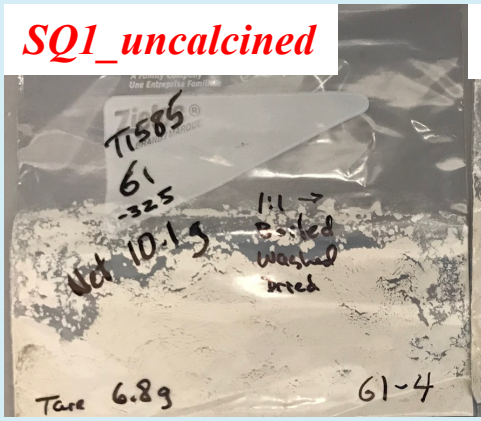
Process diagram of SQ3



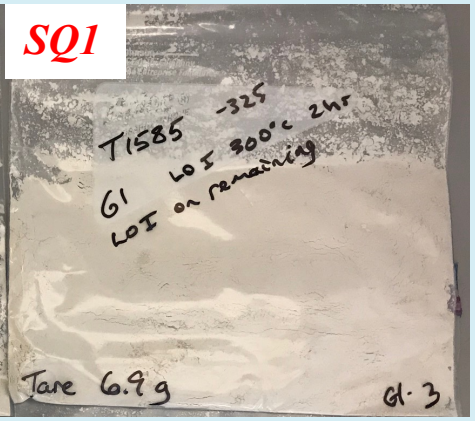
SQ1, SQ2, and SQ3 samples received from Harrop

- **SQ1** ○ Highest quality; Particle size ≤ 44 µm

SQ1_uncalcined

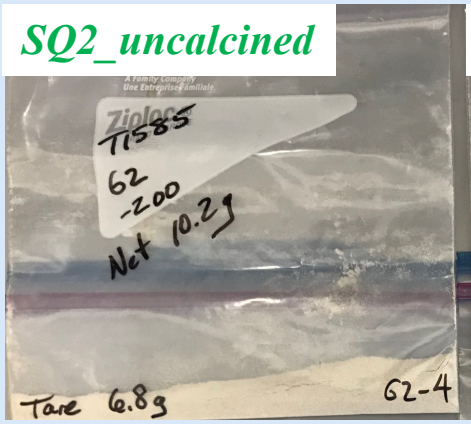


SQ1

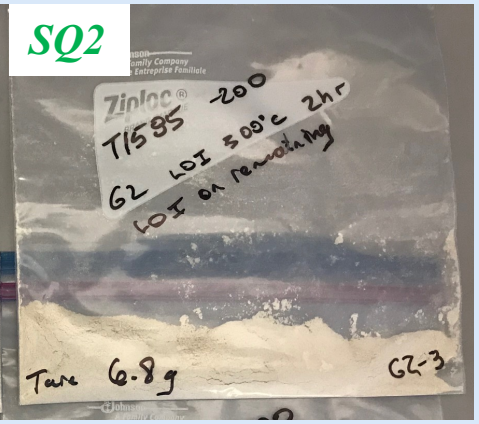


- **SQ2** ○ Particle size ≤ 74 µm

SQ2_uncalcined



SQ2



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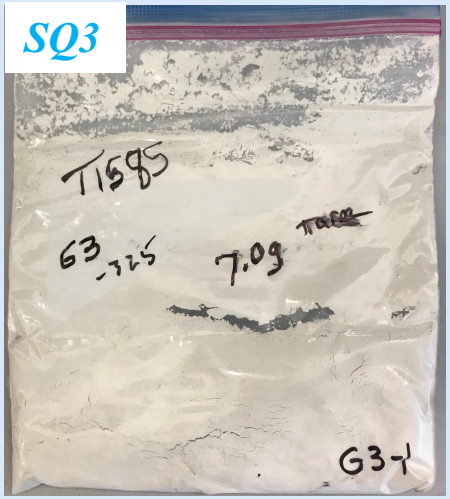
- **SQ3**
  - ○ Lowest quality; Particle size ≤ 44 µm
  - ○ Uncalcined

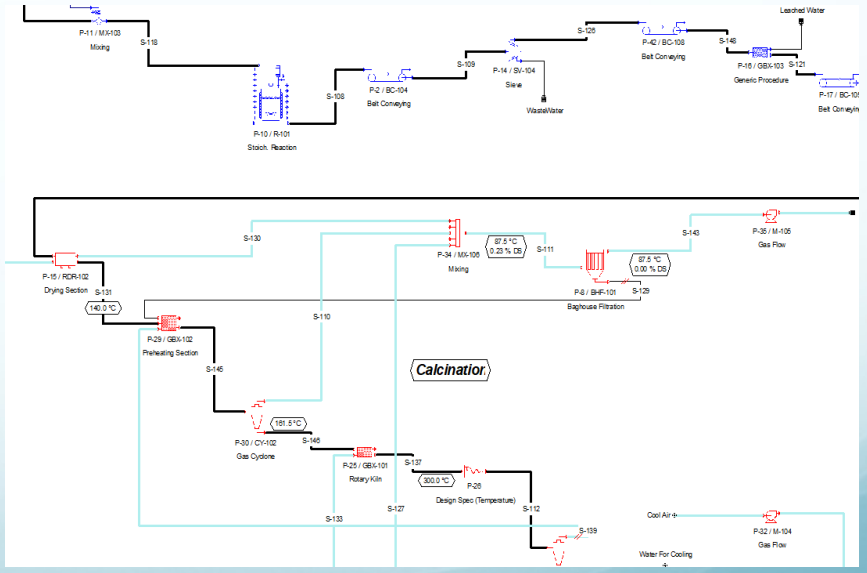
SQ3



Techno-economic analysis (TEA) for $CaCO_3$ production from SCF and QS

- Why TEA? It is a method that can be used to evaluate the economic performance of a proposed process to produce new products.

  - Answer the key question: Is the $CaCO_3$ production from SCF and QS economically feasible?



- Process simulation and economic analysis using professional software.

Designed survey for collecting information of plant location and capacity

Ocean Quahog shell and Surf clam shell production survey

This survey is initiated by Cornell University, and it aims to collect information for studying the management of waste Ocean Quahog and Surf clam shells in the U.S. Any risks from completing this survey are not anticipated. Questions or additional information, please contact Dr. Alireza Abbaspourrad: alireza@cornell.edu. We appreciate it if you can respond to the survey by **February 28, 2022**.

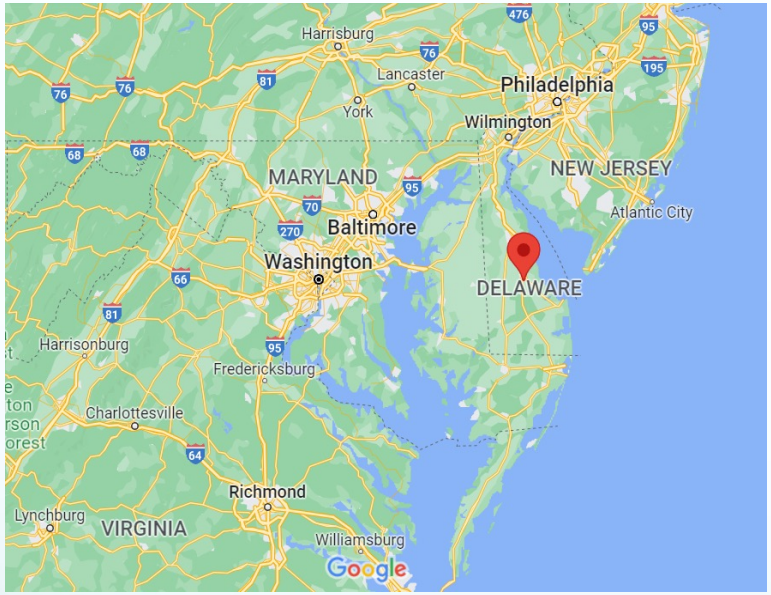
Note: Data should be from the 2021 production year.

1. Where is your clam processing plant located (state and city)?
2. Which percentage of each species do you process? Please specify the % of Surf clam and % of Ocean Quahog.
3. What is the annual production of waste shells in your plant?
4. When is the peak period for the production of waste shells (please indicate by month, e.g. May through November)?
5. What is the estimated percentage of waste shell generation that occurs during your peak period?
6. What is the monthly production of waste shells during the peak period?
7. How do you manage the waste shells currently?
8. Your contact information (name, email, and phone number)?

The survey can be accessed here: https://forms.gle/cLFshev6AUsLsfLz6

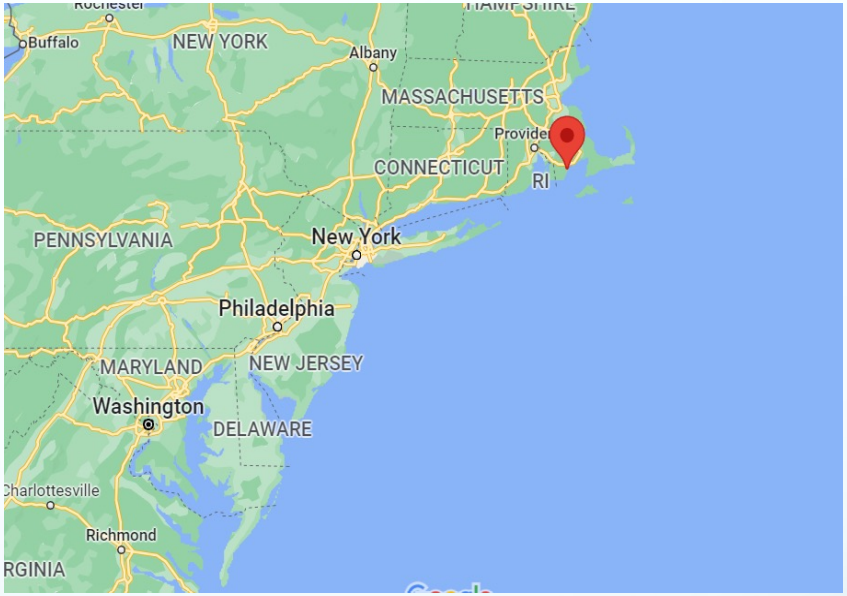
Plant location & capacity (2 survey responses)

1) Delaware



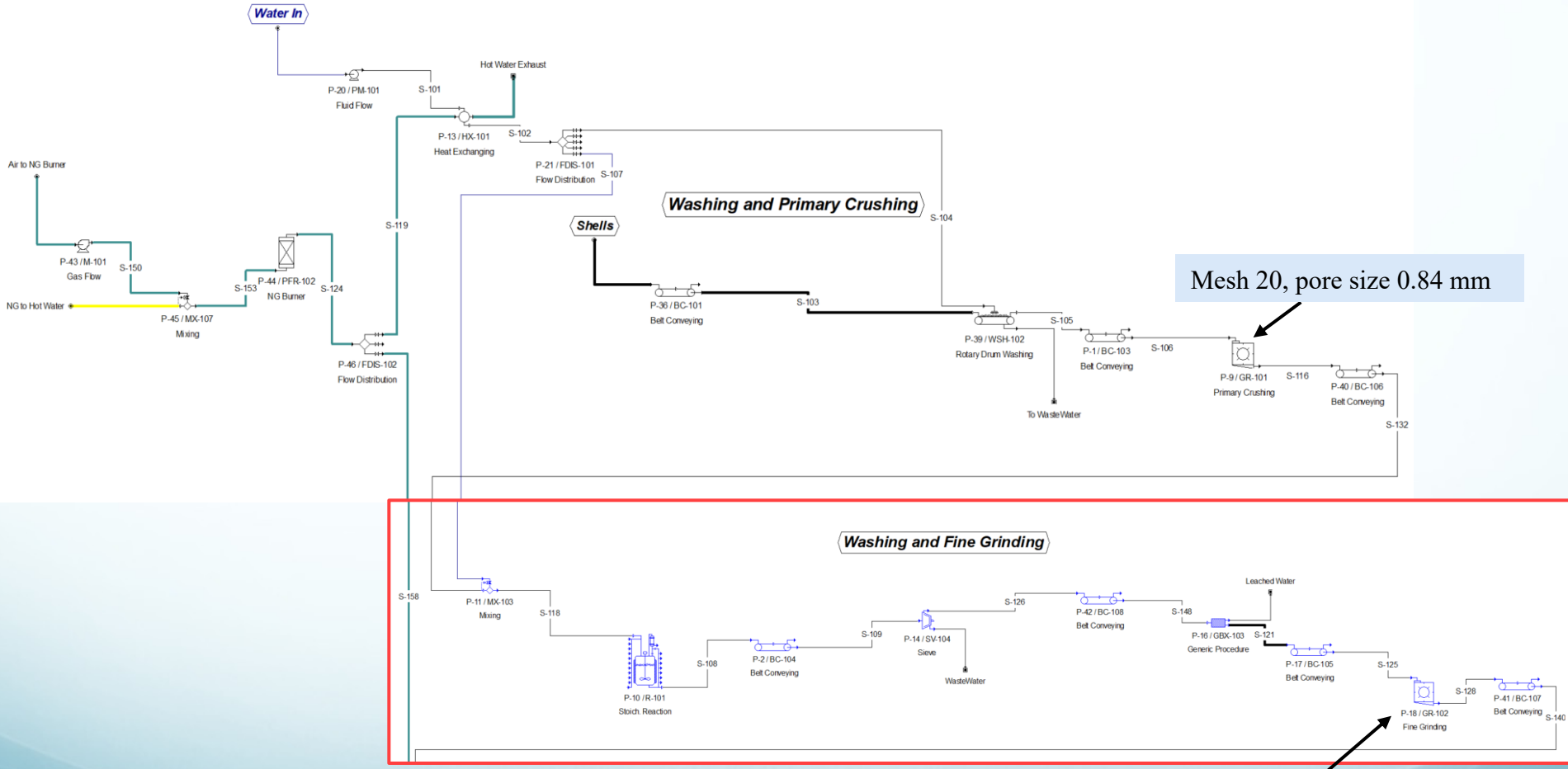
- Capacity
  - 4.5 million pounds/ month Apr to Sep (6 months)
  - 60% OQ, 40% SC

2) MA (Massachusetts)

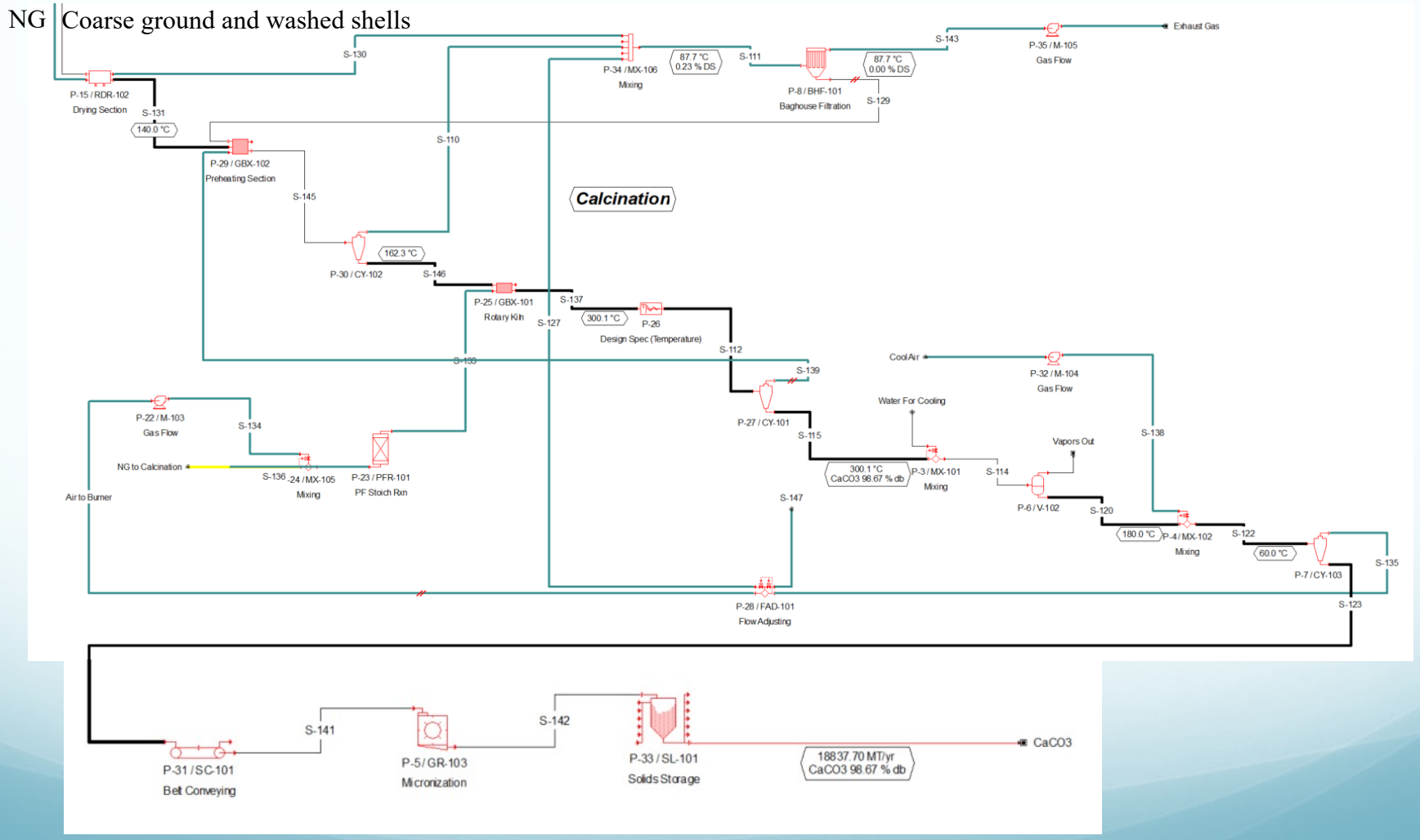


- Capacity
  - 4-9 million pounds/ month
  - 12 months
  - 82% OQ, 18% SC

Process simulation in SuperPro Designer with a daily capacity of 68 MT shells and 56.5 MT SQ1

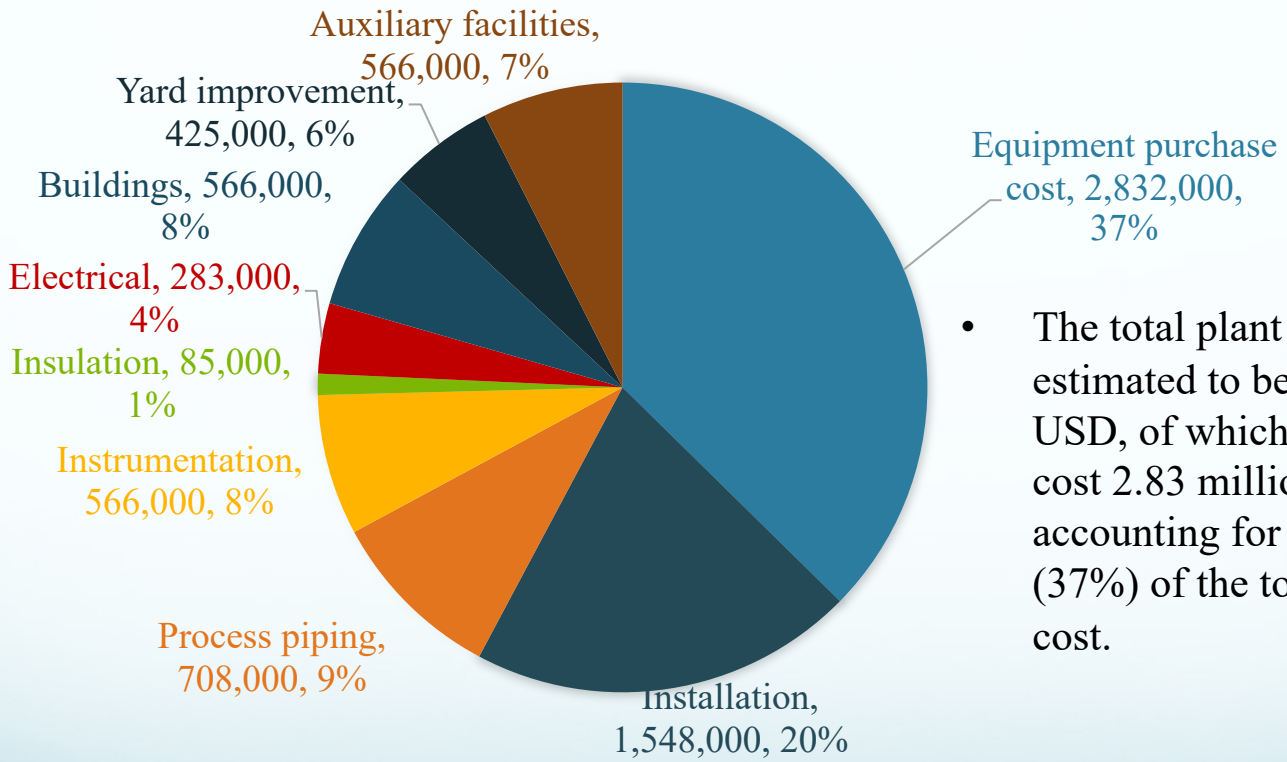


Process simulation in SuperPro Designer with a daily capacity of 68 MT shells and 56.5 MT SQ1



Fixed capital cost (2022 prices in USD) for SQ1 production

- Total plant direct cost (TPDC, $7,580,000)

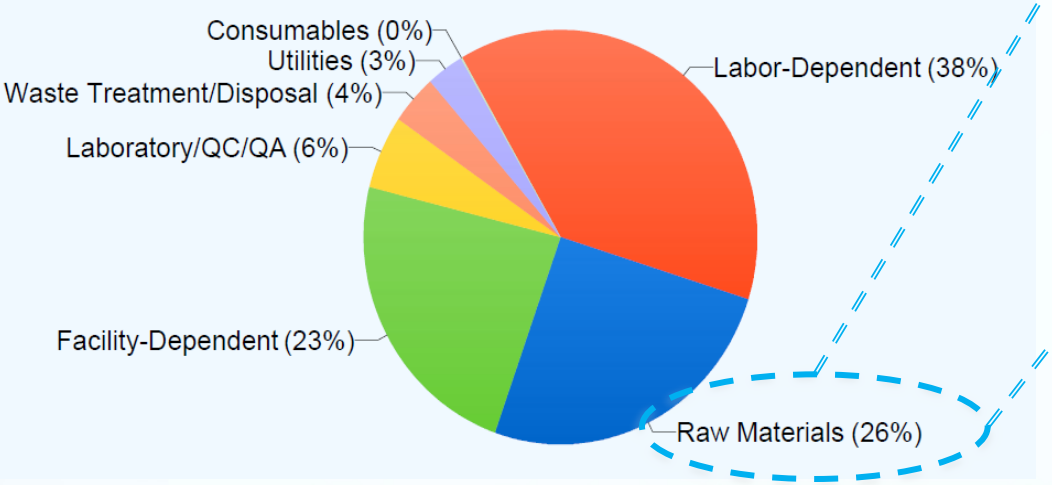


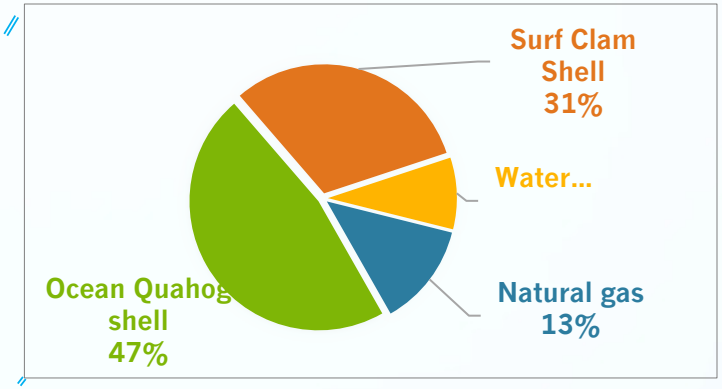
- The total plant direct cost is estimated to be 7.58 million USD, of which, the equipment cost 2.83 million USD, accounting for the largest portion (37%) of the total plant direct cost.

- Total plant indirect cost (TPIC, $4,548,000)
- Contractor's fee & contingency (CFC, $1,819,000)
- Fixed capital cost (FCT)= TPDC + TPIC+CFC= $13,974,000

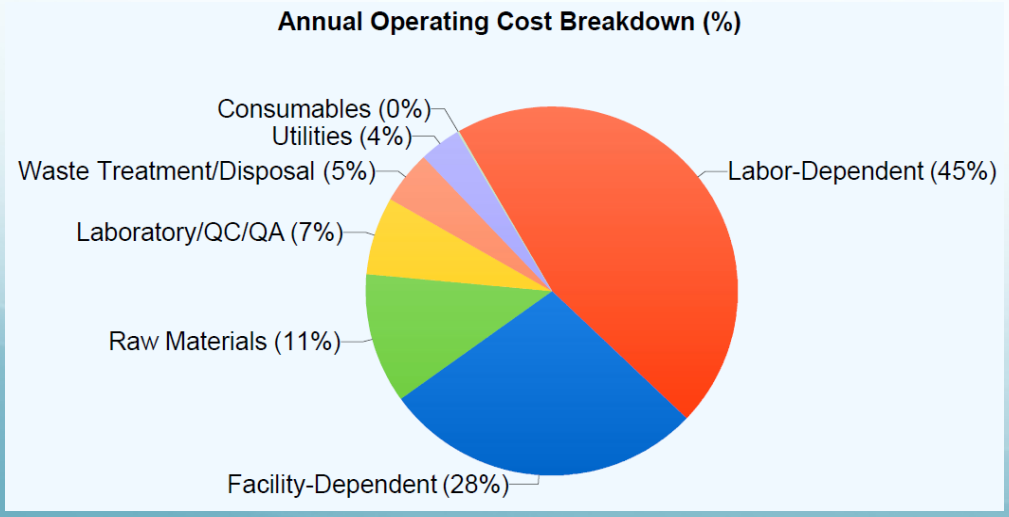
Annual operating cost breakdown for SQ1 production

❑ **$100/MT raw seashell**





❑ **$20/MT raw seashell**



The total annual operating cost is estimated to be $11,356,000, of which labor cost accounts the main part, accounting for 38%, followed by raw materials (26%).The cost of raw shell (Quahog and Surf clam, $100/t) accounts 78% of the total raw materials cost.

- When the cost of seashells decreases from $100/MT to $20/MT, the total annual operating cost could be $9,542,000 (16% decrease).

Economic evaluation summary of SQ1 production

*MP: main product; IRR: internal rate of return; NPV: net present value.

	$100/MT seashell	$20/MT seashell
Total Capital Investment	15,367,000$	15,203,000$
Capital investment charged to this project	15,367,000$	15,203,000$
Operating cost	11,356,000$/yr	9,542,000$/yr
Revenues	18,838,000$/yr	18,838,000$/yr
Cost basis annual rate	18,837,697 kg MP/yr	18,837,697 kg MP/yr
Unit production cost	0.6 $/kg MP	0.51 $/kg MP
Net unit production cost	0.6 $/kg MP	0.51 $/kg MP
Unit production revenue	1.00 $/kg MP	1.00 $/kg MP
Gross margin	39.71%	49.35%
Return on investment	45.14%	54.57%
Payback time	**2.22 years**	**1.83 years**
IRR (after taxes)	29.54%	35.28%
NPV (at 7.0% Interest)	31,719,000 $	41,503,000 $

- By setting a SQ1 selling price of $1/kg, the project seems very profitable with a payback time of just 2.33 years. The payback time could be further shorted when the cost of raw seashells decreases.

Economic evaluation comparison of SQ production

Note: the economic evaluation is assumed that the cost of raw shell is **$20/MT** and daily capacity is 68 MT raw seashell.

	SQ1	SQ2	SQ3
Total Capital Investment	15,203,000$	11,824,000$	5,853,000$
Operating cost	9,542,000$/yr	7,209,000$/yr	5,049,000$/yr
Revenues	18,838,000$/yr	9,735,000$/yr	6,940,000$/yr
Unit production cost	0.51 $/kg MP	0.37 $/kg MP	0.25 $/kg MP
Unit production revenue	1.00 $/kg MP	0.50 $/kg MP	0.35 $/kg MP
Gross margin	49.35%	25.94%	27.24%
Return on investment	54.57%	24.75%	32.76%
Payback time	**1.83 years**	**4.04 years**	**3.05 years**
IRR (after taxes)	35.28%	15.50%	20.39%
NPV (at 7.0% Interest)	41,503,000 $	7,684,000 $	6,747,000 $

*MP: main product; IRR: internal rate of return; NPV: net present value.

Summary

- Lab-scale process for high quality $CaCO_3$ was successfully developed, and the process is scalable.
- Environmentally friendly processes for producing three grades $CaCO_3$ products (SQ1, SQ2, SQ3) for different applications were designed. The quality of SQ series produced in scaled-up process was evaluated.
- It is profitable to produce SQ series products from ocean quahog and surf clam shells based on the techno-economic analysis, especially when the cost of raw shells is low.
- Three market reports were obtained and are conforming the growing demand for sustainable $CaCO_3$.
- 100 gr of each sample is ready to be shipped.

Thank You!

Abbaspourrad Lab
Email: alireza@cornell.edu

March 2022