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A better whey:

The production of multiple high-value products from Greek yogurt acid whey *via* filtration and acid-catalyzed lactose hydrolysis

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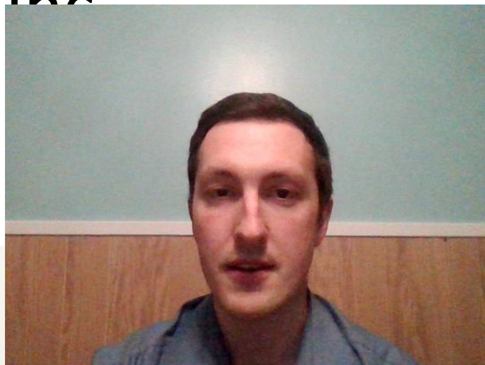
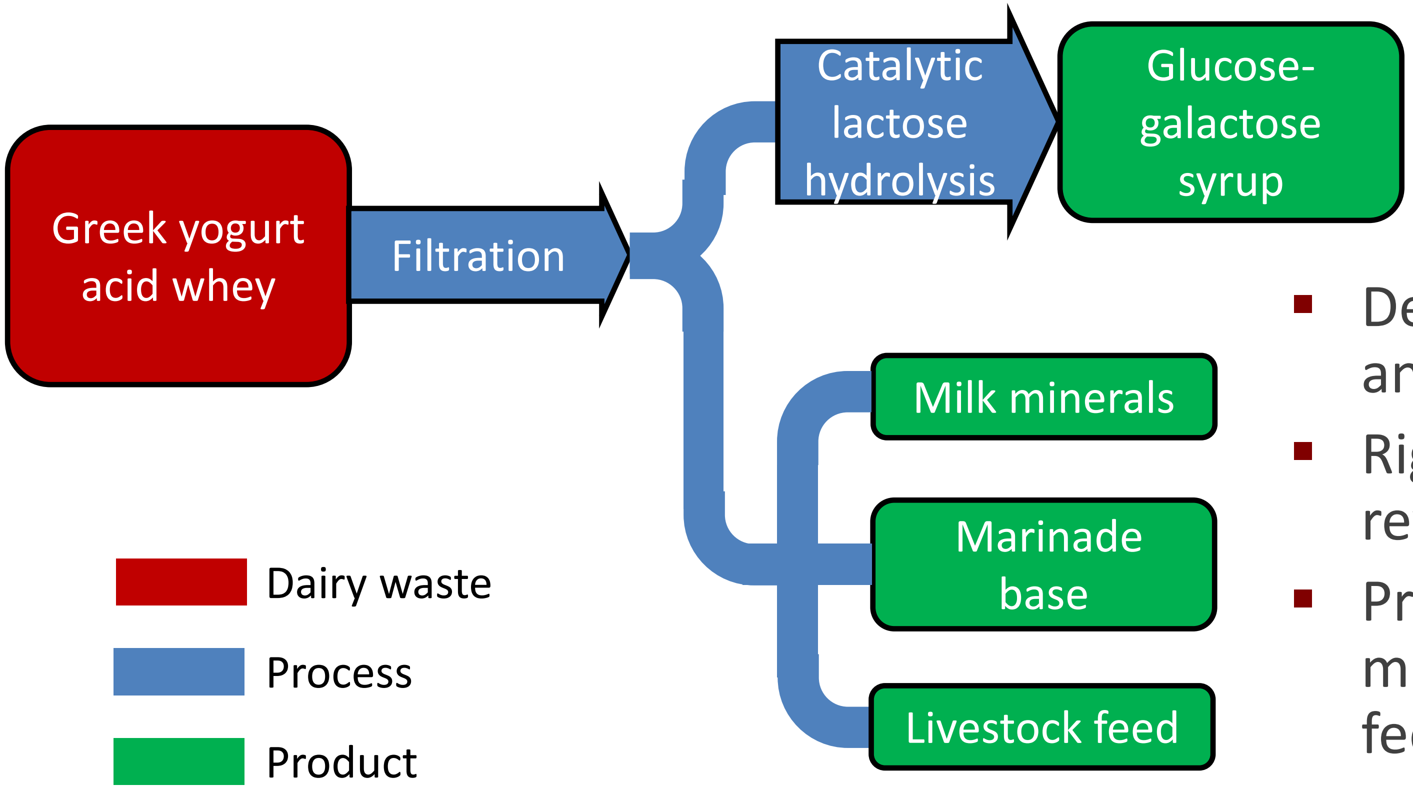
PhD of Chemical Engineering from UW-Madison

(Dr. George Huber and Dr. Scott Rankin, advisors)

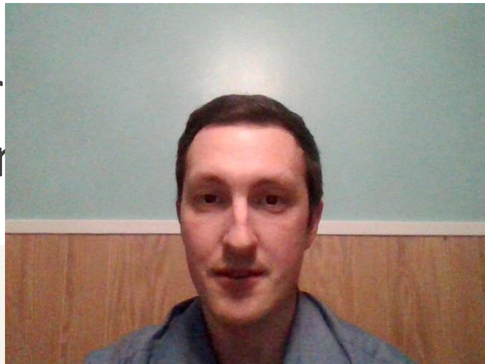
October 26, 2021



UW GAW Process: waste to multiple products



- Demonstrated technology in pilot plant and laboratory continuous flow reactor
- Rigorous economic model shows potential revenues of $19 million/year
- Products are glucose-galactose syrup, milk minerals, a marinade base, and a livestock feed
- **Validated glucose-galactose syrup for use in soft-serve ice cream**
- Looking for partners inter commercializing the techr



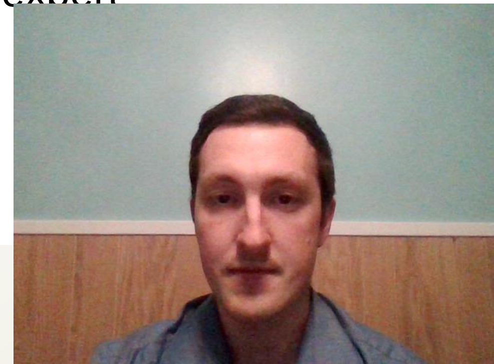
Our Team

George Huber
- Professor of Chemical and Biological Engineering
- Catalysis expert

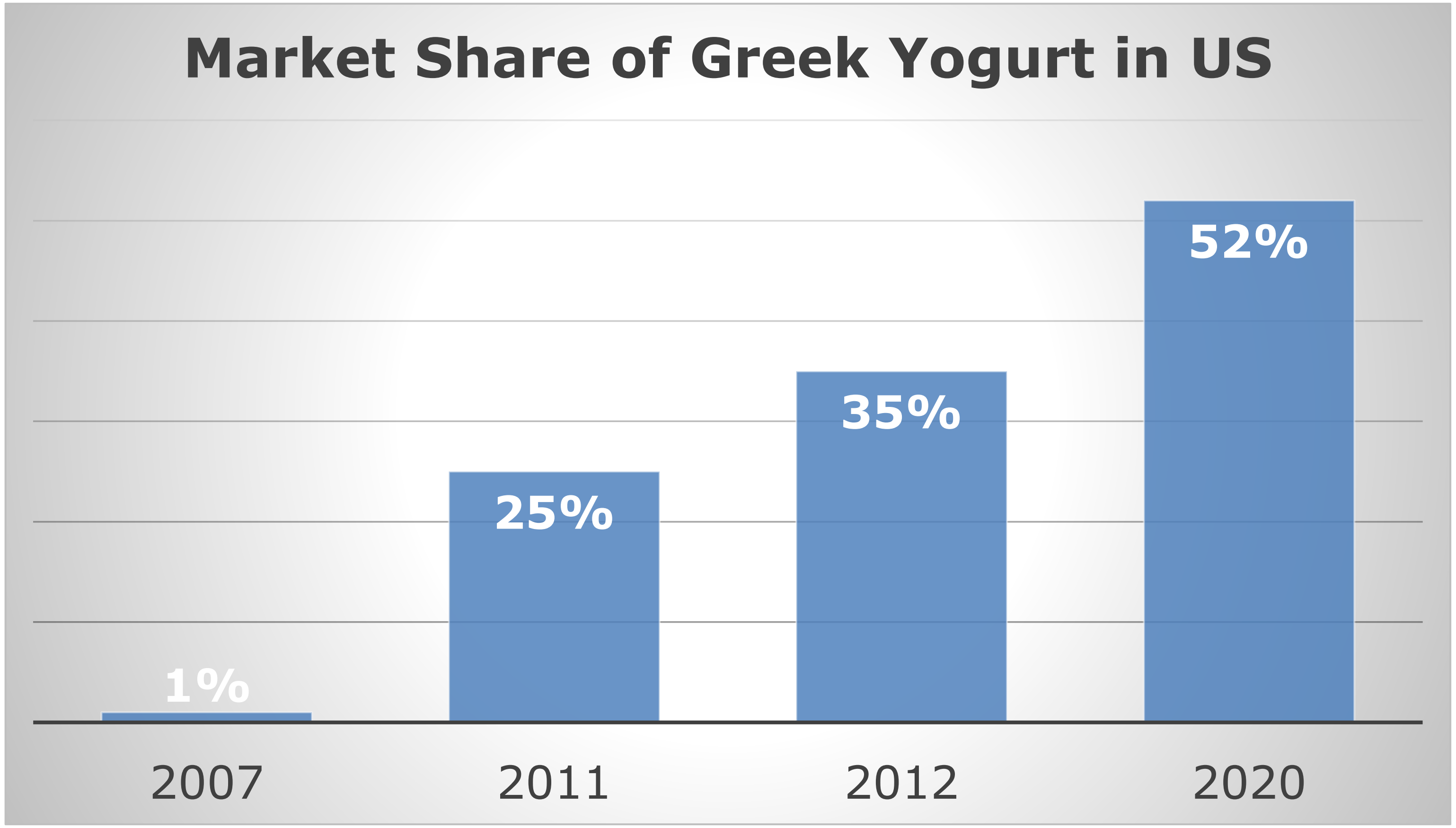
Scott Rankin
- Professor of Food Science
- Department chair of Food Science Department
- Expert in Dairy Science

Jarryd Featherman
- Recent UW-Madison Chemical Engineering graduate
- Heads process scale-up and industrial outreach

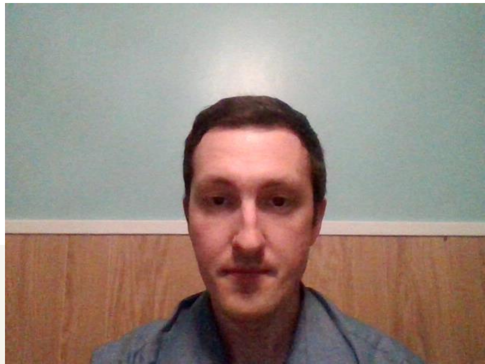
Mike Molitor
- Pilot Plant Manager for the Center for Dairy Research
- Filtration expert



Rise of Greek yogurt

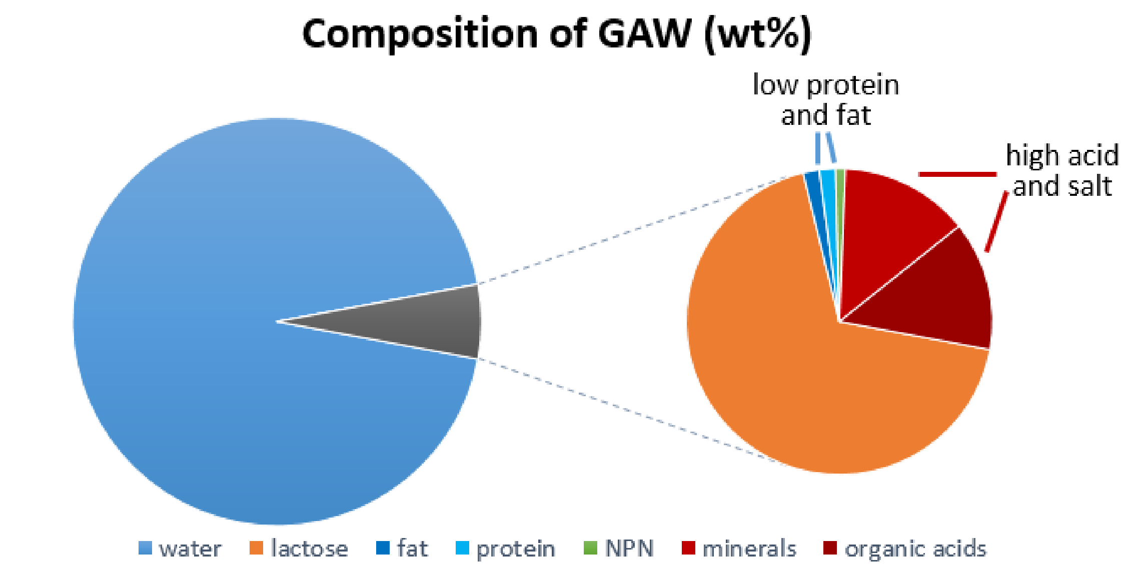


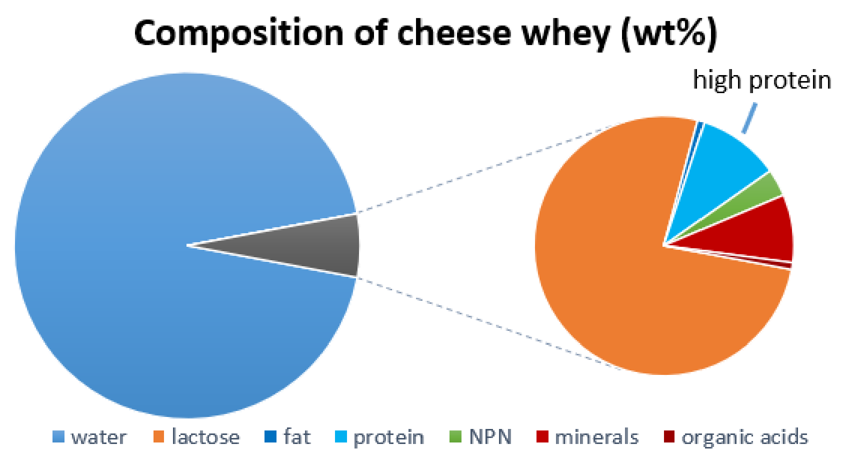
- 2-3 lbs Greek yogurt acid whey (GAW) per pound Greek yogurt
- 2 million tons GAW/year



https://www.packagedfacts.com/Yogurt-Innovation-Greek-7206794/
https://www.foodnavigator-usa.com/Article/2013/04/09/The-rise-of-Greek-yogurt.-But-is-the-growth-sustainable
https://www.statista.com/topics/2351/greek-yogurt/

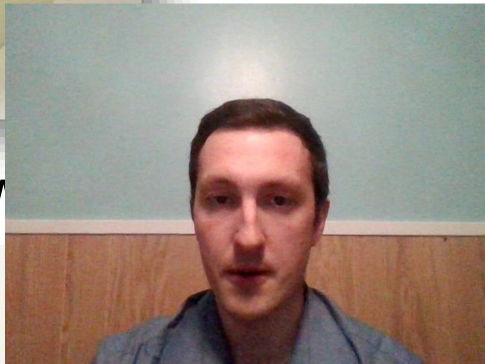
GAW has low protein





https://dairyprocessinghandbook.tetrapak.com/

Greek yogurt acid w

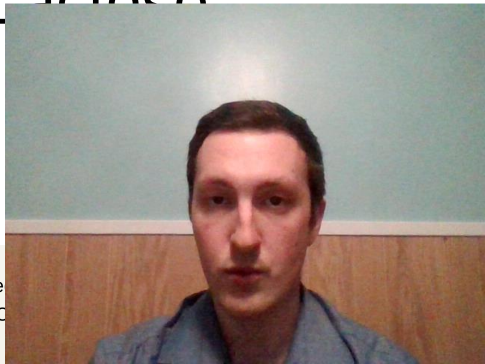


Powders produced from cheese whey

Whey protein

Whey powder

Lactose



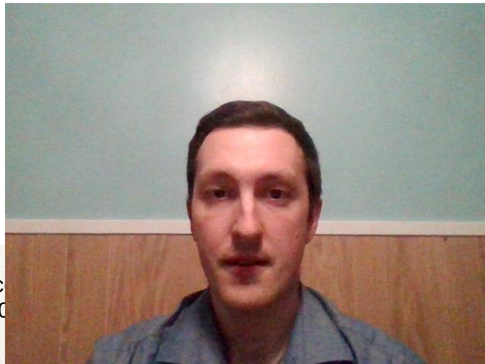
https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.amazon.com%2FOptimum-Nutrition-Standard-Protein-Chocolate%2Fdp%2FB000QSNYGI&psig=AOvVaw0LTzcULvCbjCAkXv8CL9Z-&ust=1602696329835000&source=images&cd=vfe&ve
https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.tradeindia.com%2Fproducts%2Flactose-powder-c5463041.html&psig=AOvVaw164bS4EhLqc2h_zJl1VAoq&ust=1602697586089000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCMjC
https://lifespa.com/whey-protein-best-breakfast-balance-weight-blood-sugar/

Low-value applications for GAW

- Land spreading
- Animal feed
- Wastewater treatment facility

→

- Environmentally unsustainable
- Expensive



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https://www.google.com/url?sa=i&url=http%3A%2F%2Friverdoghog.blogspot.c
time.html&psig=AOvVaw2Gx9KCkRupCLpIRSLBzPdd&ust=160269833033100
qFwoTCNCdzfGSsuwCFQAAAAAdAAAAABAG

GAW is difficult to treat

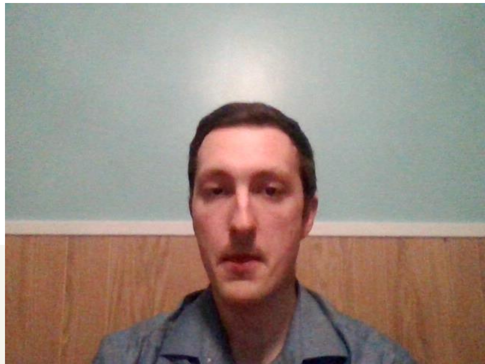
Why are cheese whey treatment methods not used for GAW?

- Low Protein
- Sticky
    - Hygroscopic lactic acid

http://oregondairy.org/wp-content/uploads/2014/04/4-2

Filtration + catalysis → 2 high-value products

Problem: Current GAW treatment methods are economically and environmentally unsustainable



Filtration + catalysis → 2 high-value products

<u>Problem:</u> Current GAW treatment methods are economically and environmentally unsustainable

<u>Goal:</u> Produce economically-viable high-value products from GAW

<u>Product 1 – Glucose-galactose syrup (GGS)</u>

- **Catalytic** lactose hydrolysis
- Test in **Ice Cream**

<u>Product 2 – milk minerals</u>

- **Filtration**

Glucose-galactose syrup

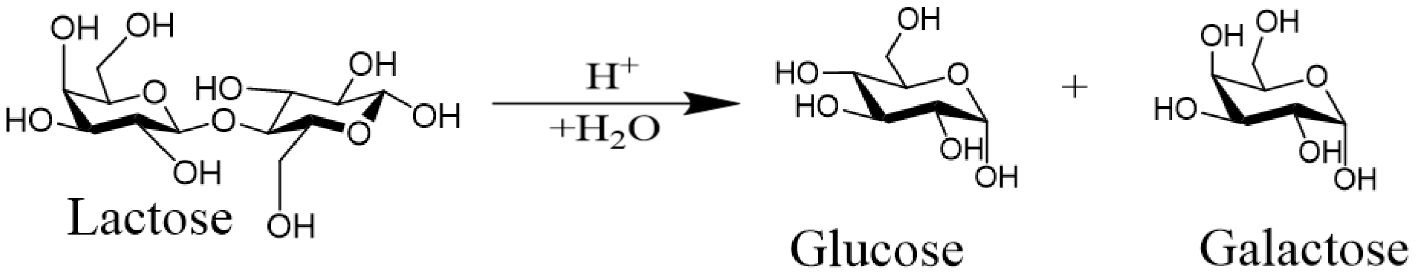
Glucose-galactose syrup produced by catalysis

Glucose-galactose Syrup (GGS)

- **Uses:** Sweetener
  - Could replace high fructose corn syrup (HFCS)
- **Price:** N/A
  - HFCS-42 is $510/ton
- **Note:** marketing advantages

https://www.ers.usda.gov/data-products/sugar-and-sweeteners-yearbook-tables/

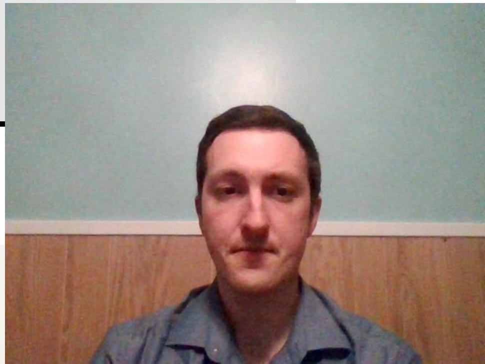
Lactose hydrolysis increases sweetness 4x



Acid-catalyzed lactose hydrolysis

- Increases sweetness
- More economical than enzymatic[1,2]

Sugar	Relative Sweetness
Sucrose (table sugar)	100
Lactose	16
Glucose	74
Galactose	60
High Fructose Corn Syrup 42	



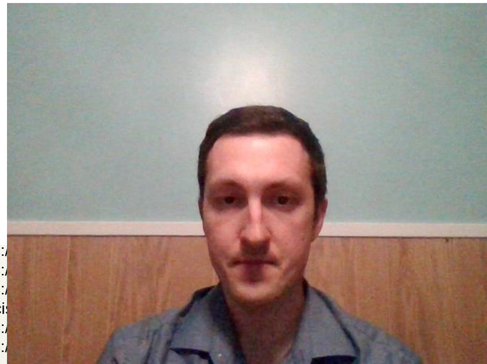
1. R. de Boer and T. Robbertsen, Neth. Milk Dairy J., 1981, 35, 95–111.
2. M. R. Okos, E. A. Grulke & A. Syverson, *J. Fd Sci.* **43** (1978) 566-571.

https://owlsoft.com/pdf_docs/WhitePaper/Rel_Sweet.pdf

GGS improves flavor in dairy and bakery products

Food made with GGS replacing some sugar	Result
Ice cream	Reduced off-flavors[2], smoother[3], softer[3], better overall[2]
Soft-serve	Reduced off-flavors, better overall[4]
Bread/bakery	Better overall[1,5]

- **Note:** marketing advantages (“green”, “no corn syrup,” “reduced waste”, “no added sugar”)



Alsaed, AK *et al.* “Utilization of Labneh Whey Lactose Hydrolyzed Syrup in Baking and Confectionery.” Pakistan Journal of Nutrition, 2012.
Arndt EA *et al*. “Development of Hydrolyzed and Hydrolyzed-Isomerized Syrups from Cheese Whey Ultrafiltration Permeate and Their Utilization in Ice Cream.” Journal of Food Science, 1989
Rothwell, J. “Uses for dairy ingredients in ice cream and other frozen desserts.” Journal of the Society of Dairy Technology, 1984.
Rexroat, TM. “Acceptance of Frozen Desserts Made with Concentrated, Decolorized, Deionized Hydrolyzed Whey Permeate.” Journal of Dairy Science, 1985
Ogunrinola, OA, *et al.* “Functional Properties of Hydrolyzed Whey Permeate Syrups in Bread Formulations.” Journal of Food Science, 1988.

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Pilot plant separates and produces products

- Industrial filtration operations
  - Nanofiltration, ultrafiltration, microfiltration, and reverse osmosis
  - Allows separation of brine and livestock feed
- Spray dryer
  - Produces powder products
  - We produced milk minerals from filtered GAW in the spray dryer

Filter unit

Filtration system

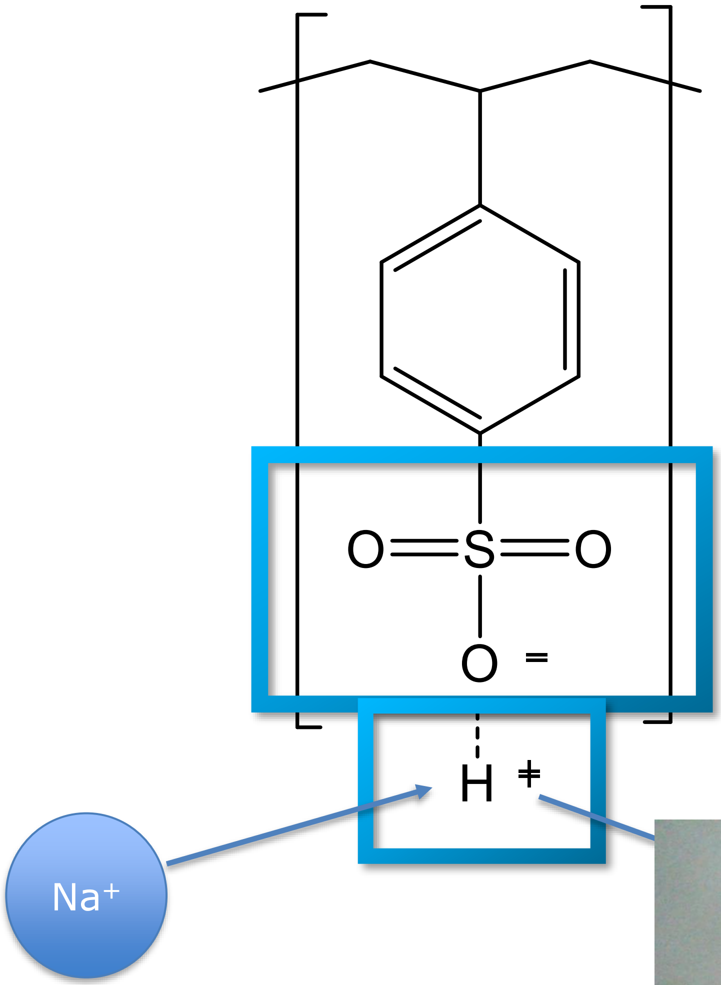
MF retentate

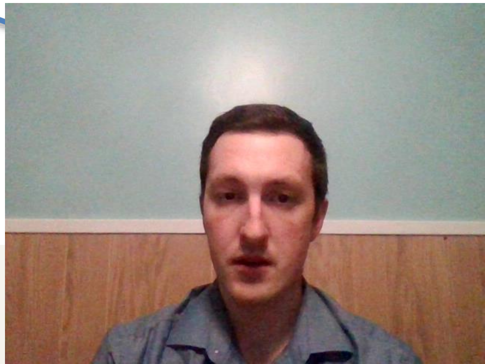
Spray drye

Ion exchange resins remove salt and NPN

- Laboratory-scale ion exchange resins used

- Ion exchange resins adsorb:
  - Ions
  - NPN
  - Other impurities

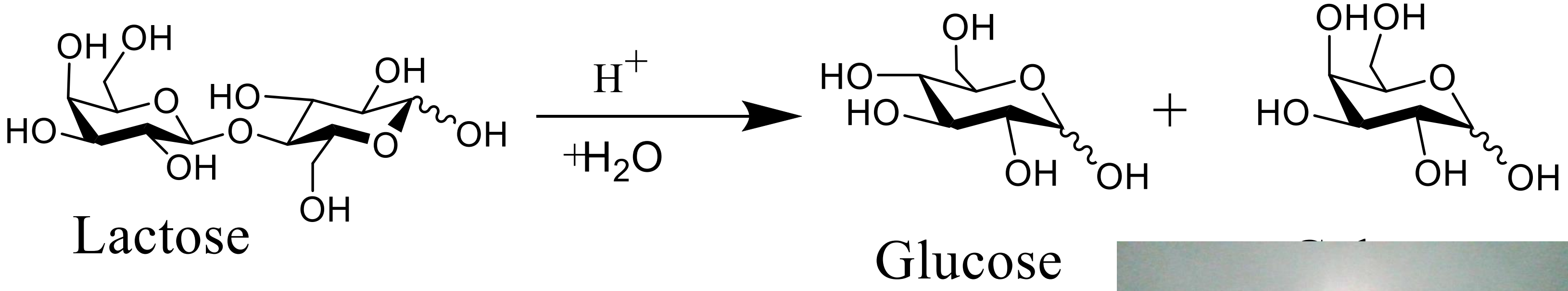


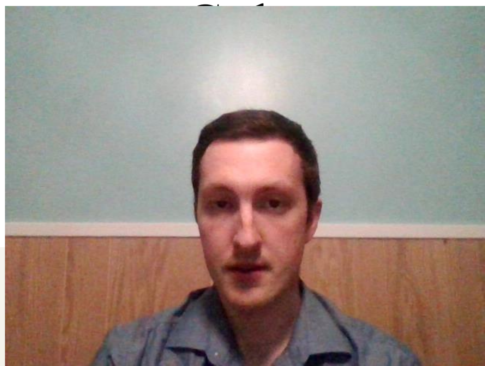


1. Delbeke, R. “Purification of an ultrafiltration permeate with adsorbent and ion-exchange resins.” Netherlands Milk and Dairy Journal, 1979.

High yields in laboratory-scale reactor

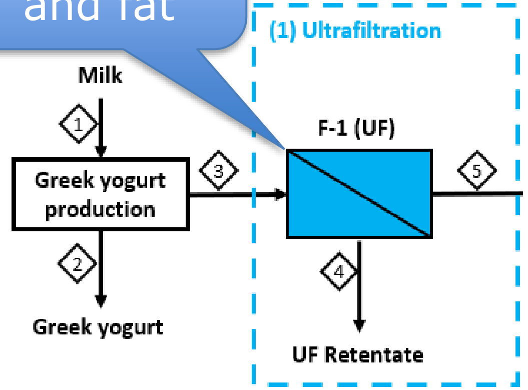
Lactose conversion	Glucose and Galactose Selectivity	Glucose and Galactose Yield
90%	99%	90%

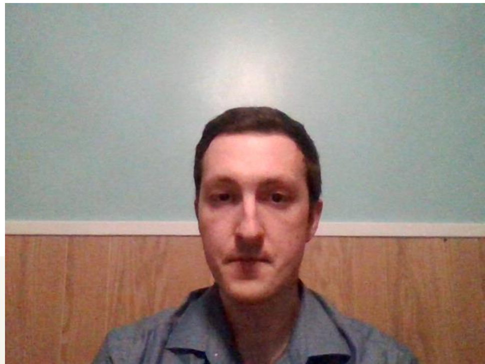


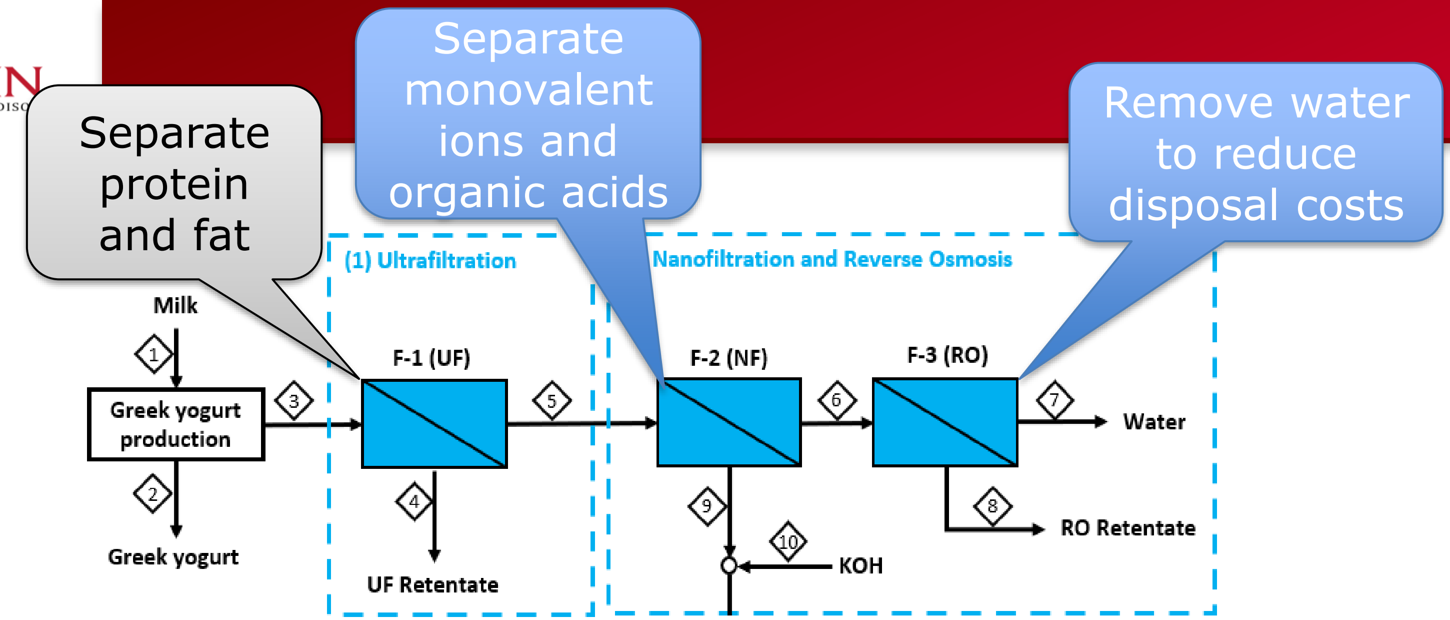


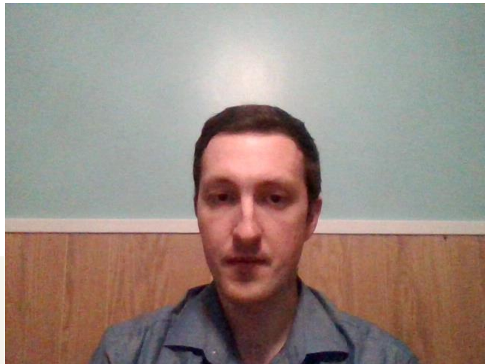
Process Flow Diagram

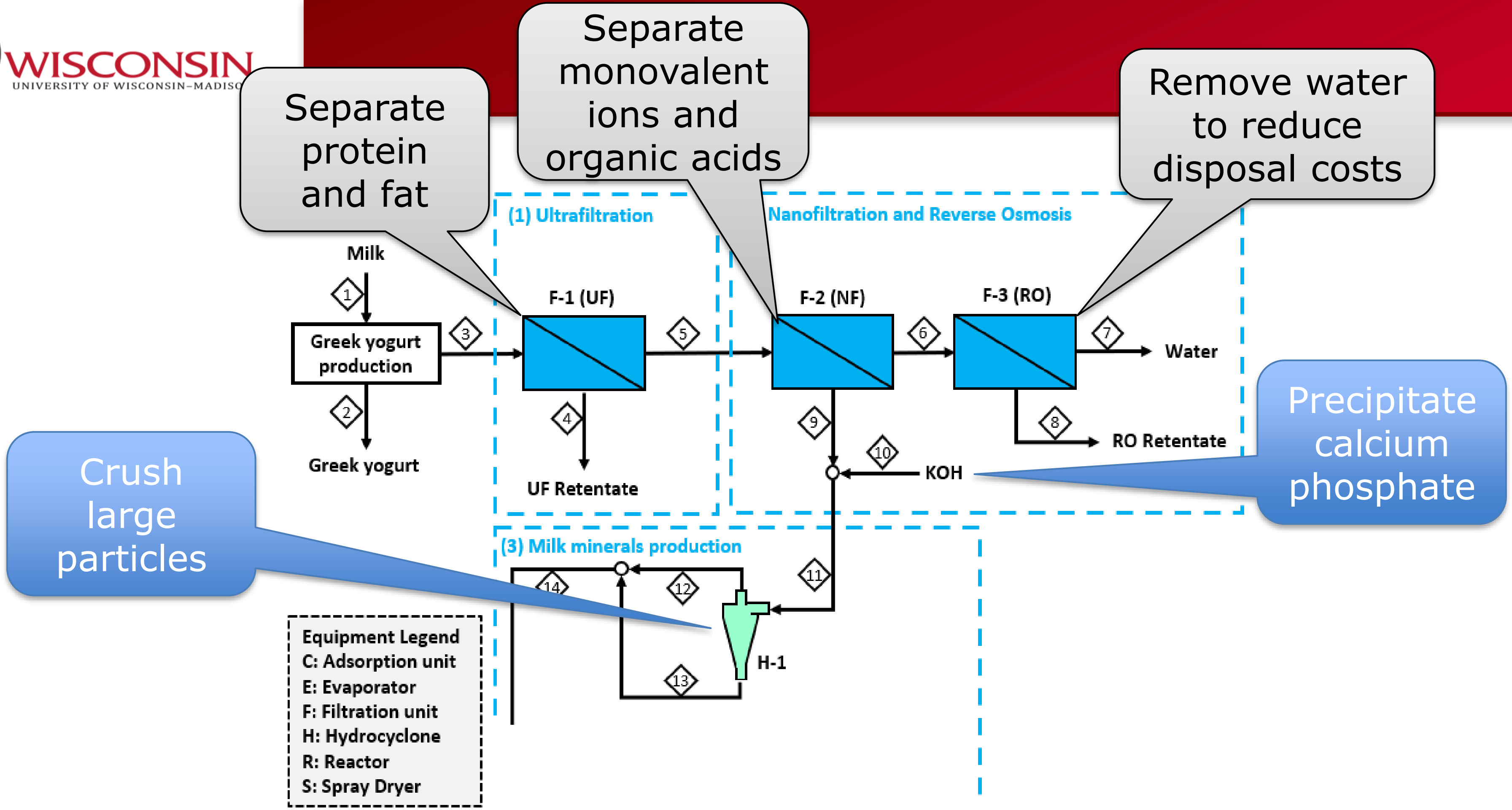
Separate protein and fat






Separate protein and fat
Separate monovalent ions and organic acids
Remove water to reduce disposal costs
(1) Ultrafiltration
Nanofiltration and Reverse Osmosis
Milk
1
Greek yogurt production
2
Greek yogurt
3
F-1 (UF)
4
UF Retentate
5
F-2 (NF)
6
F-3 (RO)
7
Water
8
RO Retentate
9
10
KOH

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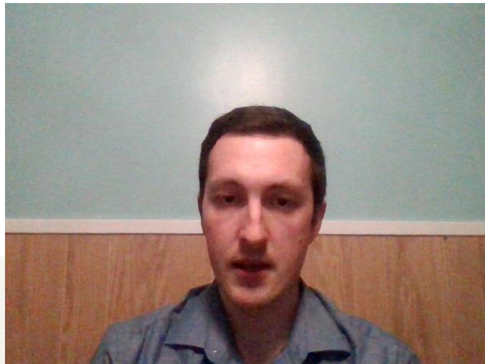
Nanofiltration and Reverse Osmosis
Milk
Greek yogurt production
Greek yogurt
F-1 (UF)
F-2 (NF)
F-3 (RO)
Water
RO Retentate
UF Retentate
KOH
Precipitate calcium phosphate
Crush large particles
(3) Milk minerals production
H-1
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Equipment Legend
C: Adsorption unit
E: Evaporator
F: Filtration unit
H: Hydrocyclone
R: Reactor
S: Spray Dryer



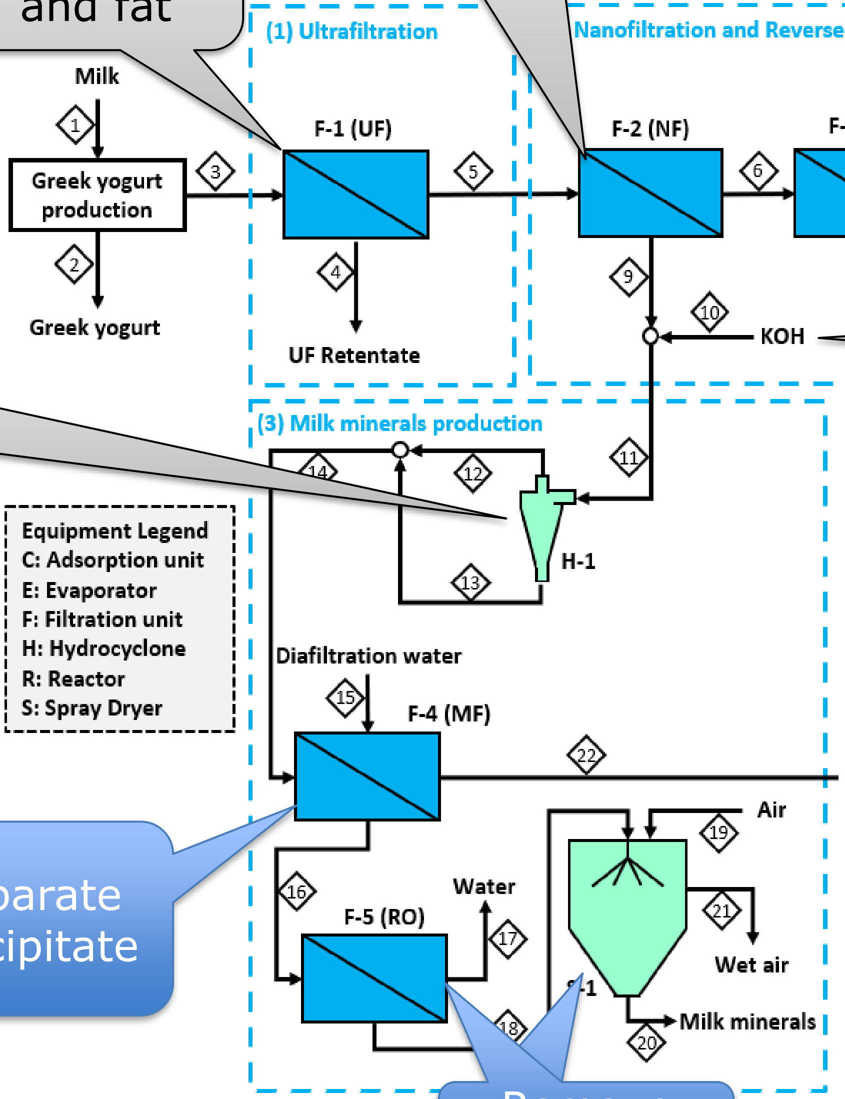
Separate protein and fat

Separate monovalent ions and organic acids

Remove water to reduce disposal costs

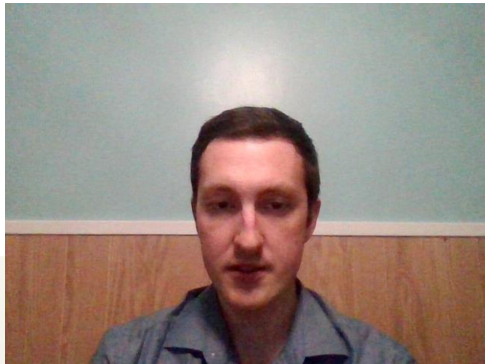
Precipitate calcium phosphate

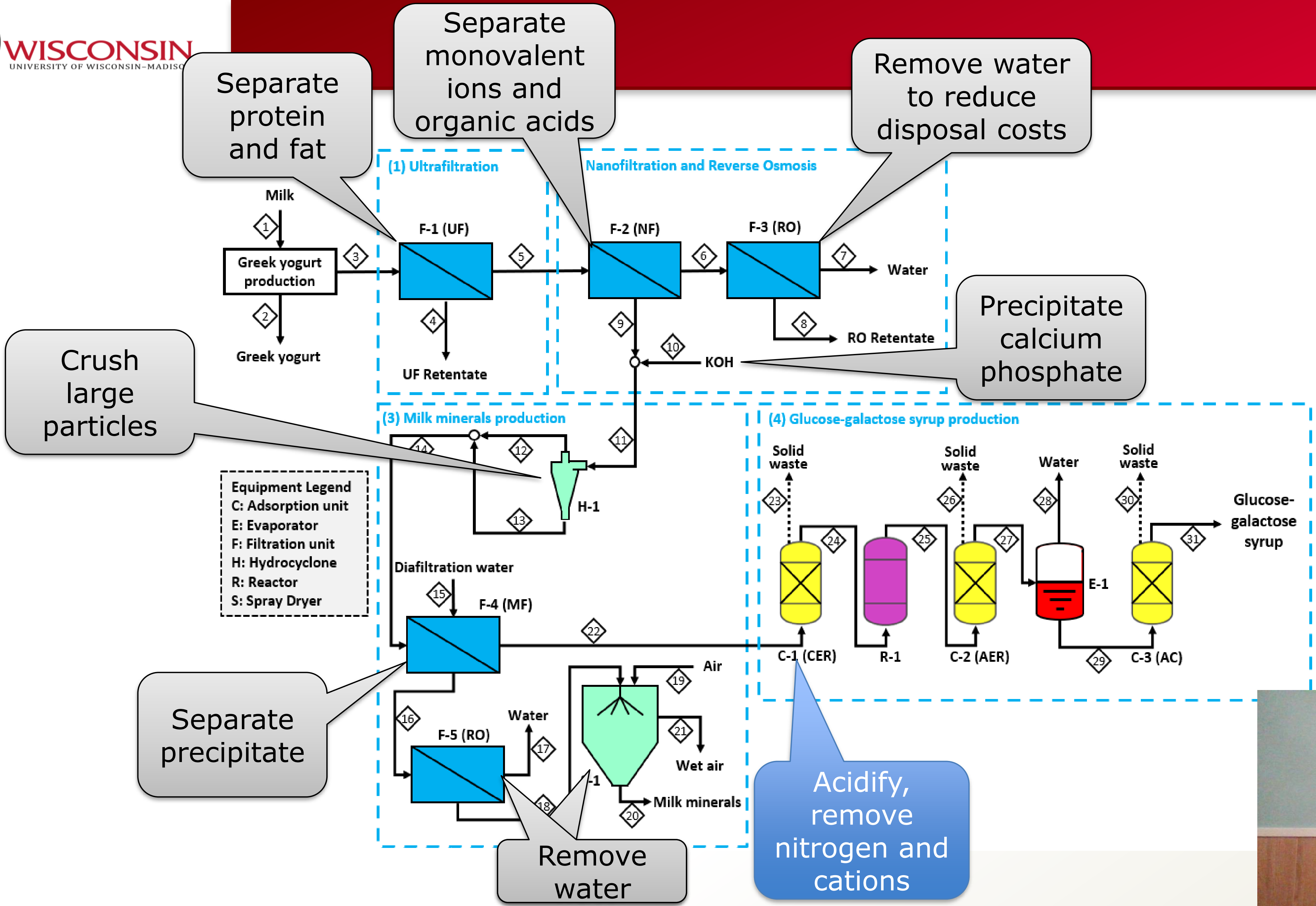
Crush large particles



Separate precipitate

Remove water

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Milk
Greek yogurt production
Greek yogurt
F-1 (UF)
UF Retentate
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F-3 (RO)
Water
RO Retentate
KOH
Precipitate calcium phosphate
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(3) Milk minerals production
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H: Hydrocyclone
R: Reactor
S: Spray Dryer
Diafiltration water
F-4 (MF)
F-5 (RO)
Water
Air
Wet air
Milk minerals
Separate precipitate
Remove water
(4) Glucose-galactose syrup production
Solid waste
Solid waste
Water
Solid waste
Glucose-galactose syrup
E-1
C-1 (CER)
R-1
C-2 (AER)
C-3 (AC)
Acidify, remove nitrogen and cations
1
2
3
4
5
6
7
8
9
10
11
12
13
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15
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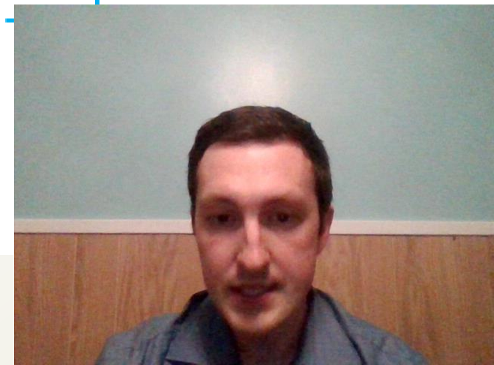

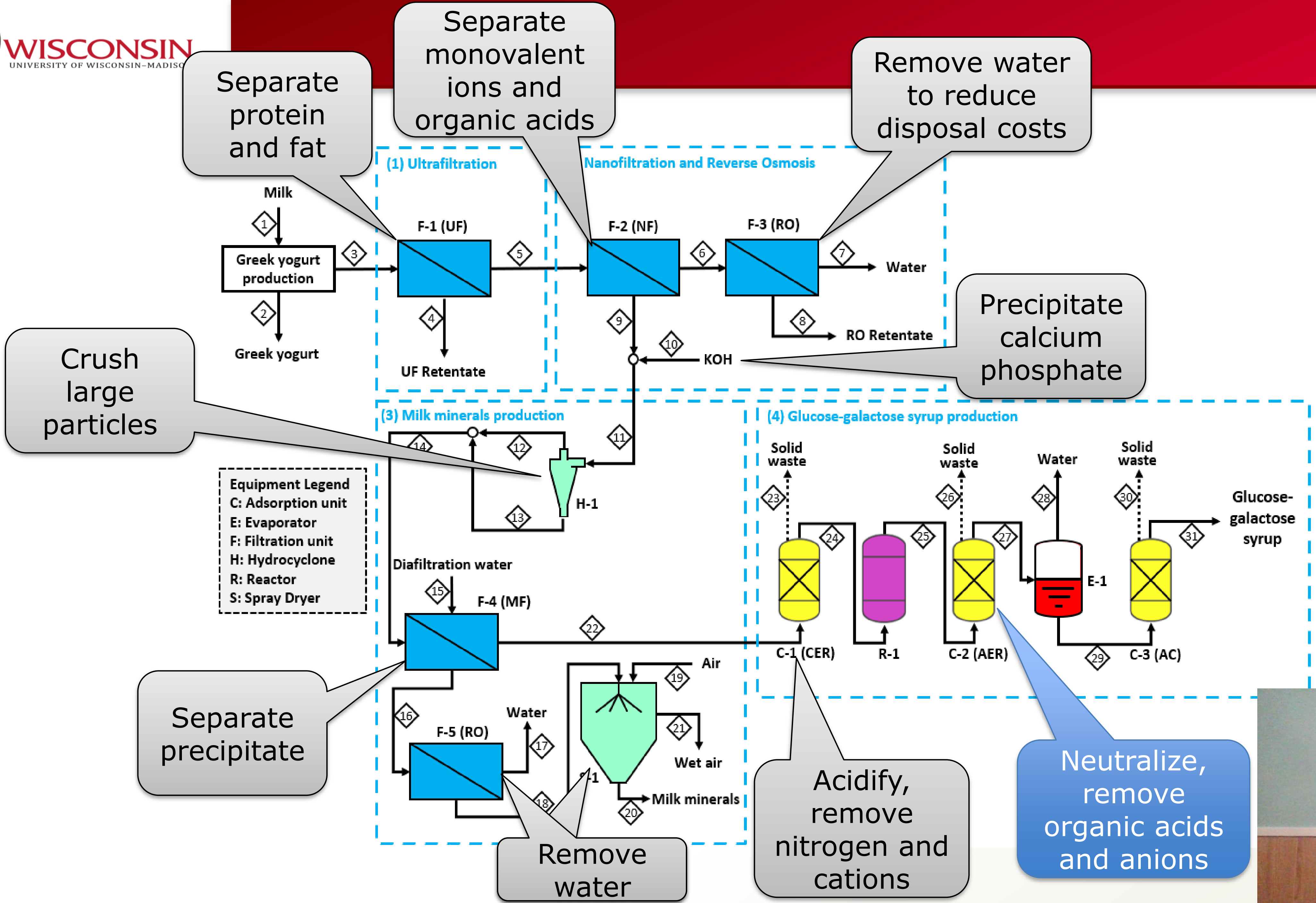
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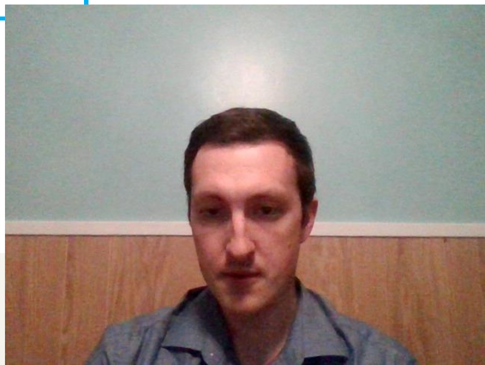
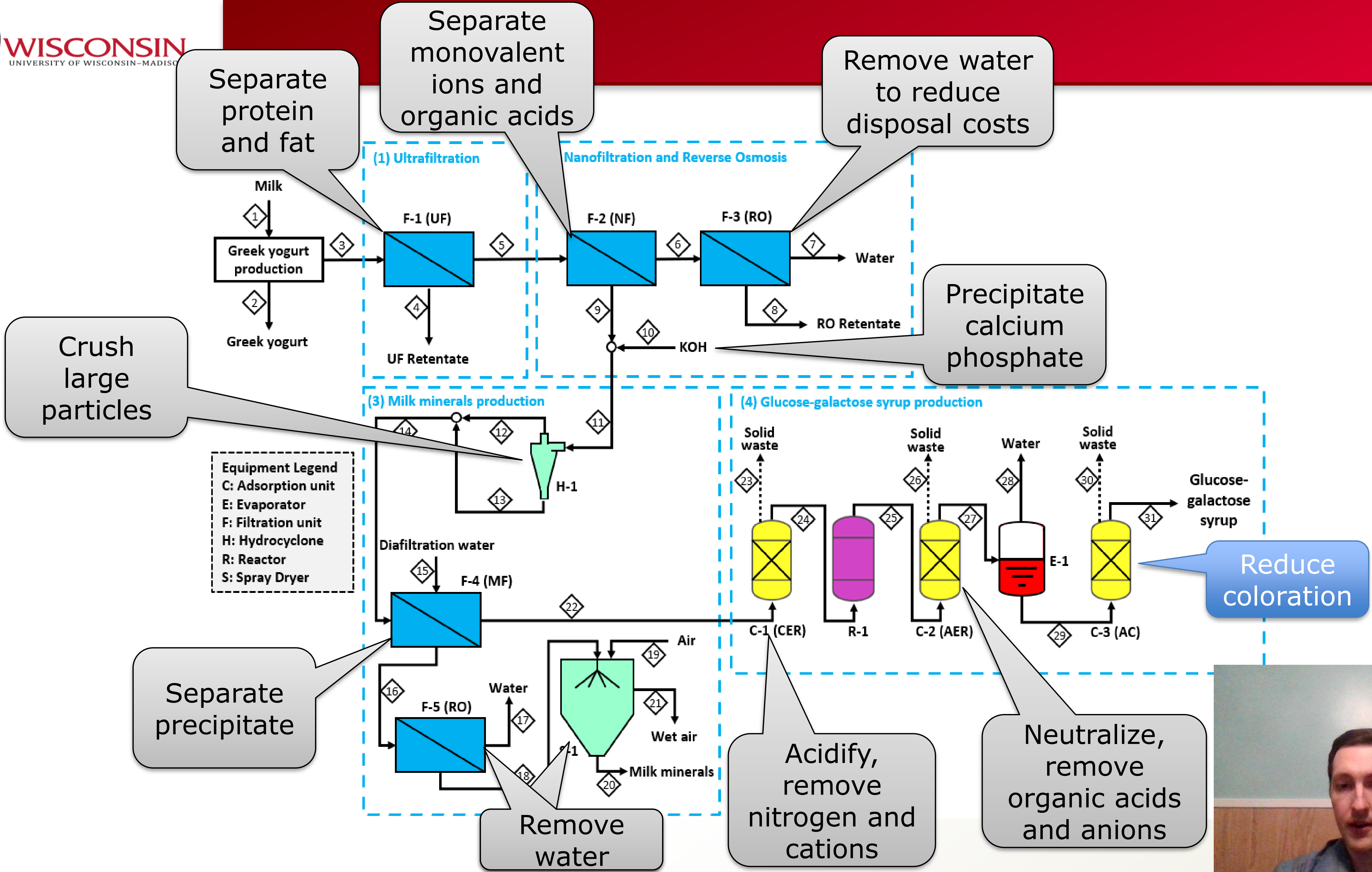
Diafiltration water
F-4 (MF)
Separate precipitate
F-5 (RO)
Water
Air
Wet air
Milk minerals
Remove water
(4) Glucose-galactose syrup production
Solid waste
Solid waste
Water
Solid waste
Glucose-galactose syrup
E-1
C-1 (CER)
R-1
C-2 (AER)
C-3 (AC)
Acidify, remove nitrogen and cations
Neutralize, remove organic acids and anions

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Water
Air
Wet air
S-1
Milk minerals
Separate precipitate
Remove water
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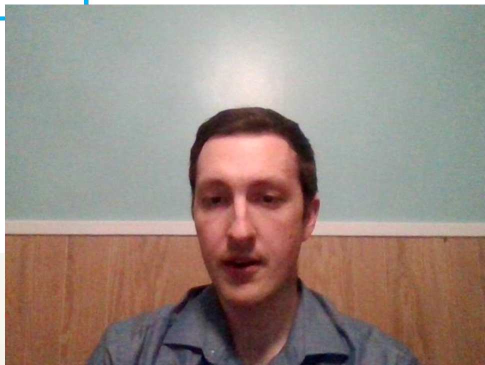
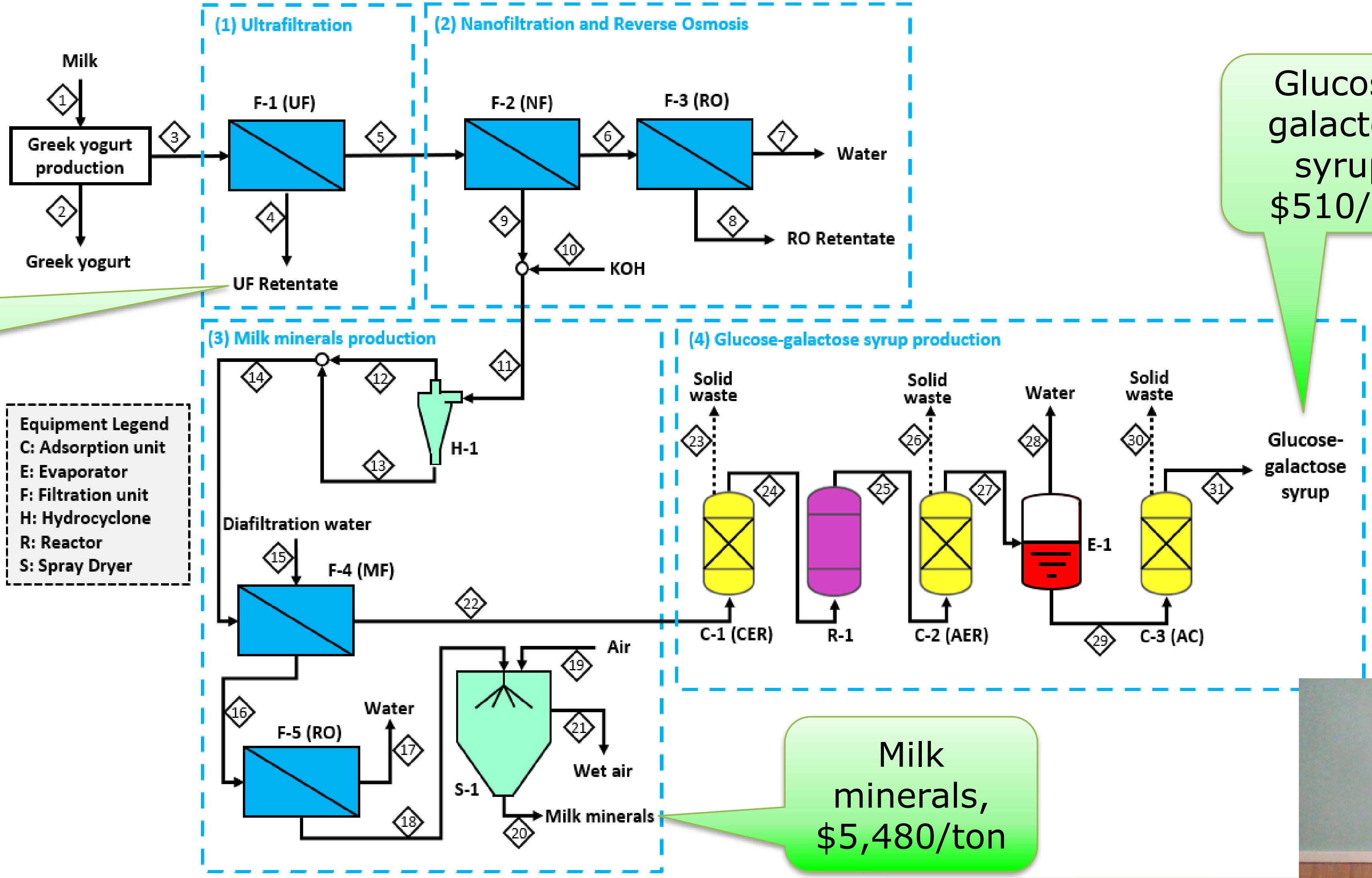
Solid waste
Solid waste
Water
Solid waste
Glucose-galactose syrup
E-1
C-1 (CER)
R-1
C-2 (AER)
C-3 (AC)
Reduce coloration
Acidify, remove nitrogen and cations
Neutralize, remove organic acids and anions

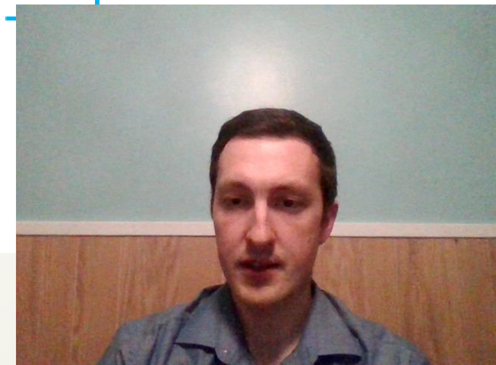




Sell as animal feed, $110/ton

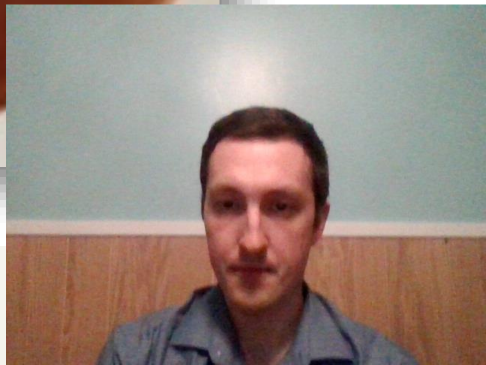
Glucose-galactose syrup, $510/ton

Milk minerals, $5,480/ton



Fixed off flavors, GGS tastes good!

- Made 800 mL of GGS
- Fixed fish and sulfur flavors
- Now GGS tastes great!
  - Like maple syrup



Tested GGS in ice cream

- 3 soft serve ice cream batches
  - Control (no GGS)
  - Test 1 (25% of sucrose replaced with GGS)
  - Test 2 (50% of sucrose replaced with GGS)
- Normalized to same freezing point
- Evaluated by 2 person expert panel

https://www.car

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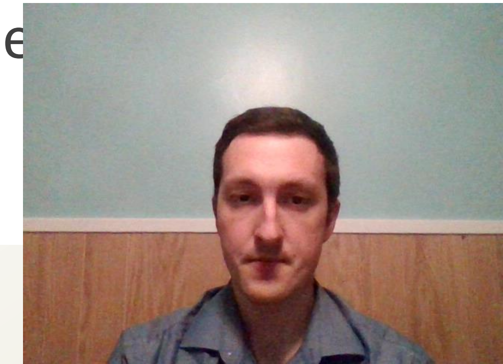
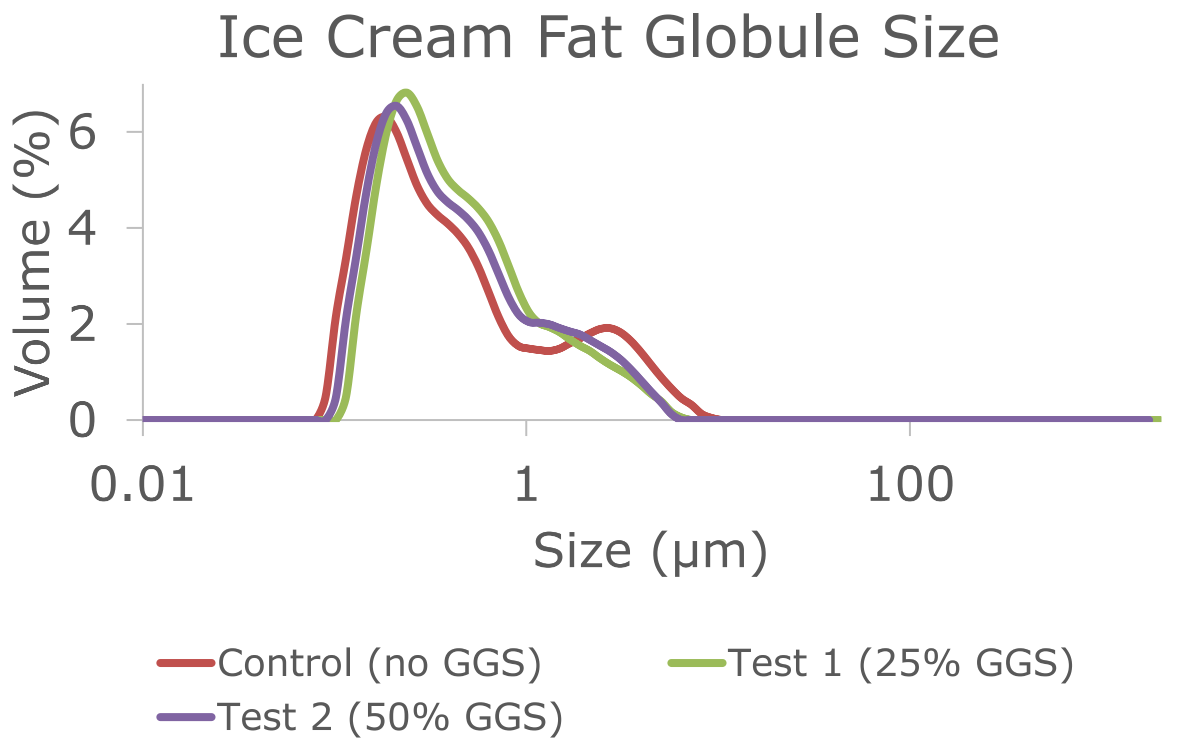
Soft serve w/GGS tastes good

	Flavor	Cooked	Unnatural Flavor	Icy	Weak
Control	**2**	1	**0**	4	3
25% GGS	**3**	2	**2**	3	2
50% GGS	**4**	2	**3**	4	2

- Unnatural flavor was slight caramel
- 0s for 18 descriptors, including:
  - acid, syrup flavor, greasy, gummy, low flavoring, low swee



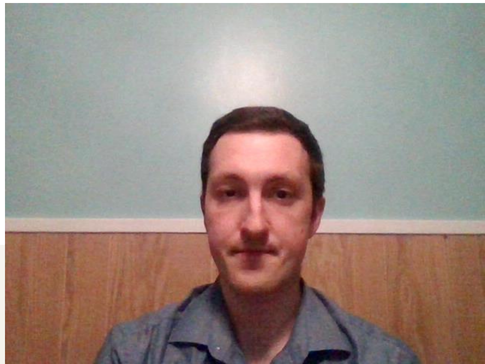
GGS does not affect ice cream properties



Soft Serve Batch	Mean Size (µm)	Std. Dev (µm)
Control (no GGS)	45.1	24.3
Test 1 (25% GGS)	51.0	22.2
Test 2 (50% GGS)	43.3	21.0

Economic analysis shows viability

Assumption	Value
GAW Feed price ($/ton)	0
GAW Feed (tons/day)	1,000
GAW disposal cost ($/ton)	16[1]
Contingency (%)	40
Plant life (years)	30



1. M. Quast. Personal Communication, **2019**

High revenue compared to costs

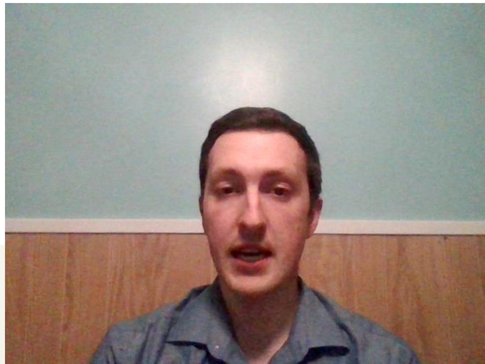
Product	Value ($/ton)	Flow (tons/day)	Value ($ million/year)
GAW disposal credit	16	1,000.0	5.3
GGS (wet basis)	510	54.6	9.2
Milk minerals	5,480	1.6	3.0
UF retentate (sold as animal feed)	110	52.1	1.9
Total Revenue			**19.3**

Capital costs	**33.5**	**$ million**
Operating costs	**5.8**	**$ million/yr**
Income tax	**2.7**	**$ million/yr**
After tax net revenue	**10.2**	**$ million/yr**

35.5% IRR achieved

- Discounted Cash Flow Rate of Return analysis (DCFROR)
  - Accounts for present vs future value of money

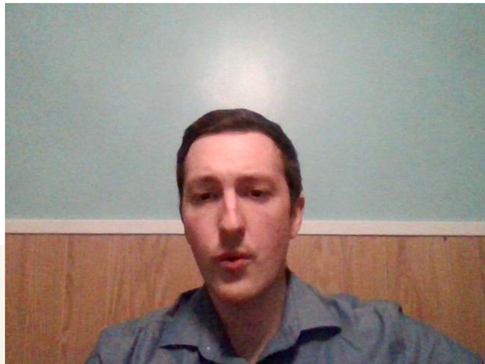
Capital costs ($ million)	33.5
After tax net revenue ($ million/yr)	**10.2**
IRR (%)	**35.5**



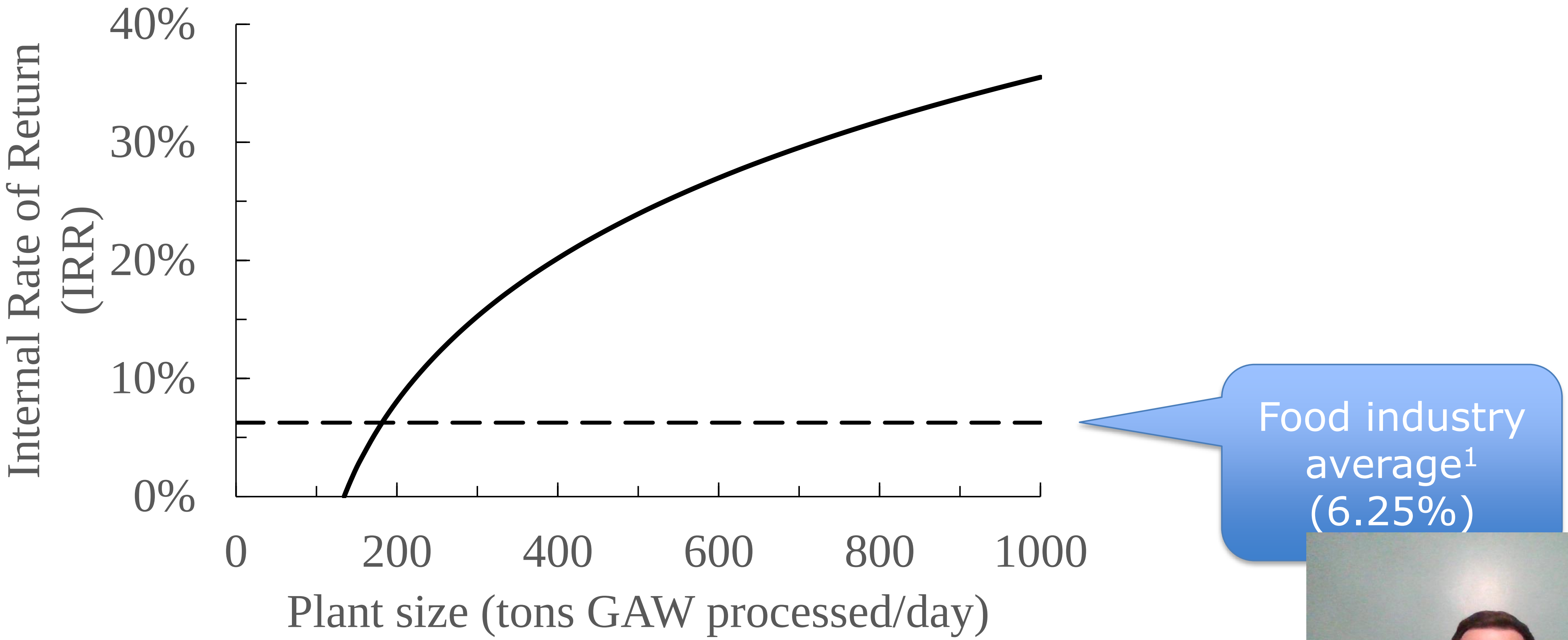
21.7% IRR if no current GAW disposal costs

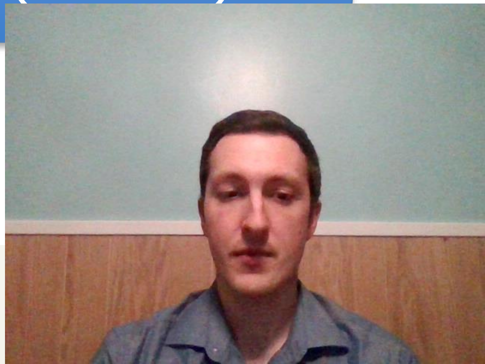
- Discounted Cash Flow Rate of Return analysis (DCFROR)
  - Accounts for present vs future value of money

Capital costs ($ million)	33.5
After tax net revenue ($ million/yr)	**10.2**
IRR (%)	**35.5**
IRR without GAW disposal credit (%)	**21.7**



Market-average profitability at 200 tons/day GAW

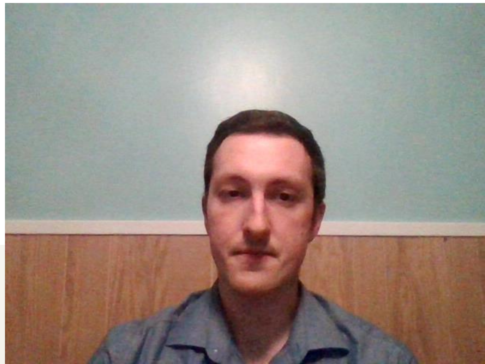




1. https://eresearch.fidelity.com/eresearch/evaluate/fundamentals/keyStatistics.jhtml?stockspage=keyStatistics&symbols=GIS&output=print

Next Steps in Technology Development

- Scale up to pilot-scale
  - Jarryd Featherman heads this
  - Goal: produce >1 gal/month of GGS
- Use this technology in other low-value dairy streams
  - can be adapted to any stream with lactose
  - de-lactosed permeate, other acid whey, etc.
- Find industrial collaborators interested in using or commercializing the technology



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- Patent application filed

  - Huber, George W., Scott A. Rankin, and Mark J. Lindsay. "Method of converting lactose-containing dairy by-products into monosaccharides." U.S. Patent Application No. 15/926,461.

- 2 publications

  - Lindsay, Mark J., et al. "Production of monosaccharides and whey protein from acid whey waste streams in the dairy industry." *Green Chemistry* 20.8 (2018): 1824-1834.
  - Lindsay, Mark J., et al. "Catalytic Production of Glucose-Galactose Syrup from Greek Yogurt Acid Whey in a Continuous Flow Reactor." *ChemSusChe*

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Questions?

LE MARS IA
LE MARS · IA 1869
Ice Cream Capital OF THE WORLD

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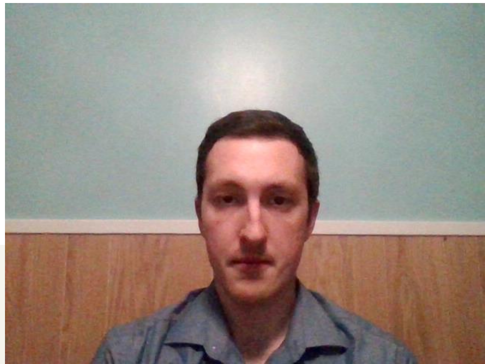
A FAMILY COMPANY
Wells
SINCE 1913



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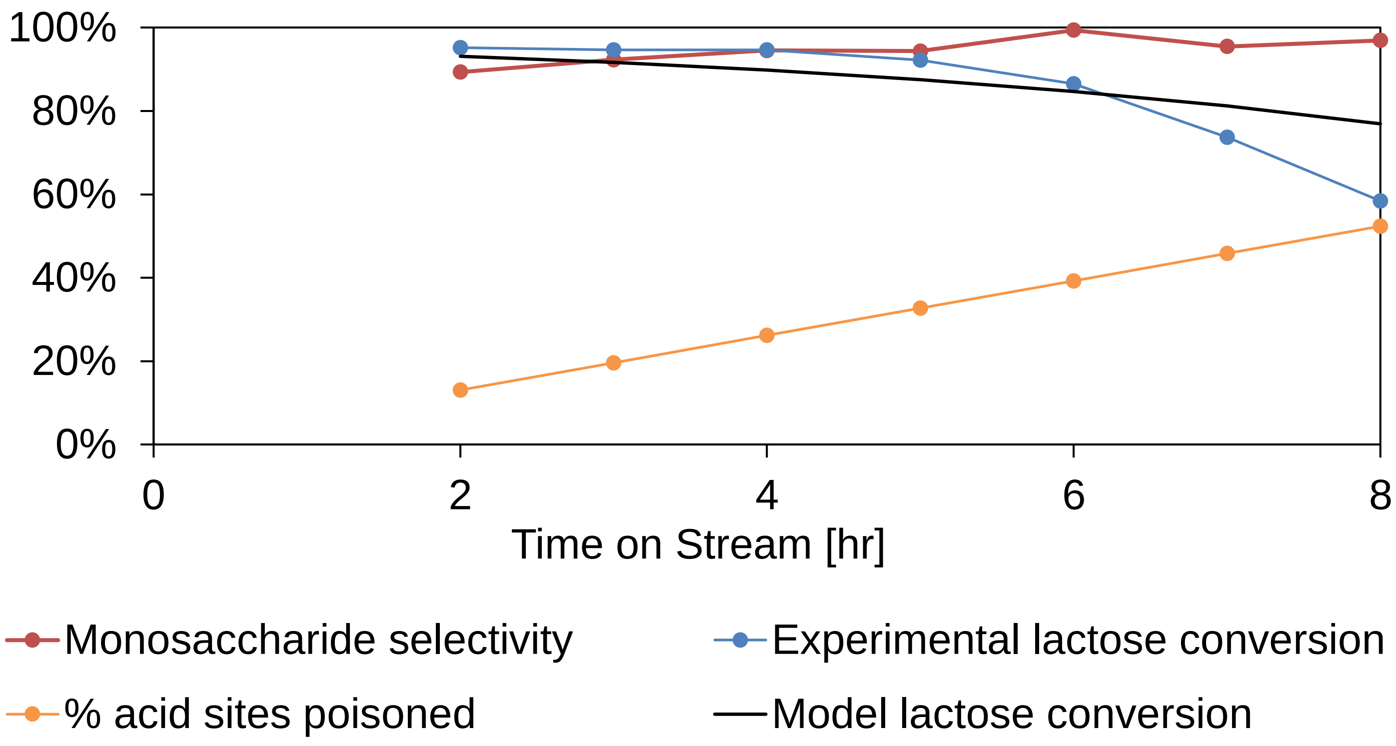
https://universityresearchpark.org/2015/federal-funds-to-bolster-food-manufacturing-biotech-headed-to-madison-region/
https://wellsenterprisesinc.com/about/history
https://www.lemarsiowa.com/

Rapid catalyst deactivation

- 1 demineralization step
- 4 hours at >80% lactose conversion



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Capital costs

Row	Process Area	Calculation method	Installed Cost ($ million)
1	1. UF		2.0
2	2. NF and RO		2.8
3	3. Milk minerals production		2.8
4	4. GGS production		6.1
5	**ISBL**	=1+2+3+4	**13.6**
6	Other OSBL (Storage ect.)		0.7
7	Warehouse	4.0% of ISBL	0.5
8	Site Development	9.0% of ISBL	1.2
9	Additional Piping	4.5% of ISBL	0.6
10	**Total Direct Costs (TDC)**	=5+6+7+8+9	**16.7**
11	Prorateable Expenses	10.0% of TDC	1.7
12	Field Expenses	10.0% of TDC	1.7
13	Home Office & Construction Fee	20.0% of TDC	3.3
14	Project Contingency	40.0% of TDC	6.7
15	Other Costs (Start-Up, Permits, etc.)	10.0% of TDC	1.7
16	**Total Indirect Costs**	=11+12+13+14+15	**15.0**
17	**Fixed Capital Investment (FCI)**	=10+16	**31.8**
18	Land & Working Capital	5.5% of FCI	1.7
19	**Total Capital Investment (TCI)**	=17+18	**33.5**

- Aspen Plus process simulation software and industry quotes used for capital and utility costs

Operating costs

Raw Material	amount	unit	Price	Unit	$ million/yr
Sulfuric acid (98% food grade)	13	tons/day	200	$/ton	0.83
sodium hydroxide	5	tons/day	350	$/ton	0.59
Ion exchange resins					0.02
Filter replacements and CIP					2.07
RO retentate disposal	100	tons/day	16	$/ton	0.53
Process water	440	tons/day	0.29	$/ton	0.00
Low Pressure Steam	4,859	kw	1.90E-6	$/kJ	0.26
Cooling Water	264	kw	2.12E-7	$/kJ	0.00
Grid Electricity	16	kw	0.0691	$/kWh	0.37
Total Variable Operating Costs					**4.15**

Position	Salary	# Required	Total	$ million/yr
Plant engineer	$ 91,283	1	$ 91,283	
shift operators	$ 47,333	10	$ 454,397	
Total Salaries			$ 545,680	0.55
Labor Burden (90%)			$ 491,112	0.49
Maintenance	3.0% of ISBL		$ 409,525	0.41
Property Insur. & Tax	0.7% of FCI		$ 222,406	0.22
Total Fixed Operating Costs				**1.67**
Total Operating Costs				**5.81**