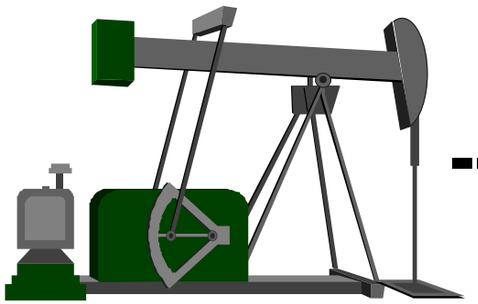
Biorefining Opportunities for the Dairy Industry

Mark R. Etzel
University of Wisconsin

Analogy to crude-oil refining



distillation
catalytic cracking
catalytic reforming

----------> refined products
(gasoline, jet fuel)

biological
processing

----------> refined products
(proteins, sugars)

US consumption & price

- **Petroleum**
  - 1140×10^9 L/yr
  - $0.25/L (crude oil)
  - $285 billion

- **Milk**
  - 62×10^9 L/yr (5 %)
  - $0.36/L (144 %)
  - $22 billion (8 %)

Refinery concepts

- Revenues from generating multiple pure products are greater than revenues from generating one pure product and an impure product

- Shifting between products day-to-day matches output to changing consumer demands and market values

Petroleum example

	L/yr	$/L (w/o taxes)	$/yr
Jet fuel (% crude oil)	96×10^9 (8 %)	0.27 (108 %)	26×10^9 (9 %)
Gasoline (% crude oil)	500×10^9 (44 %)	0.34 (136 %)	170×10^9 (60 %)

Milk composition

- Water 86.6 %
- Lipids 4.1 %
  - Triglycerides 3.9 %
  - Diglycerides 0.1 %
  - Phospholipids 0.05 %
- Protein 3.5 %
  - Caseins 2.8 %
  - Whey 0.7 %
- Lactose 5.0 %
- Ash 0.8 %

Current dairy product prices

Component	$/kg	$/L-milk	% Milk
Butter	5.40	0.22	61
Cheese	4.80	0.48	133
Dry whey	0.65	0.06	17
Total			211

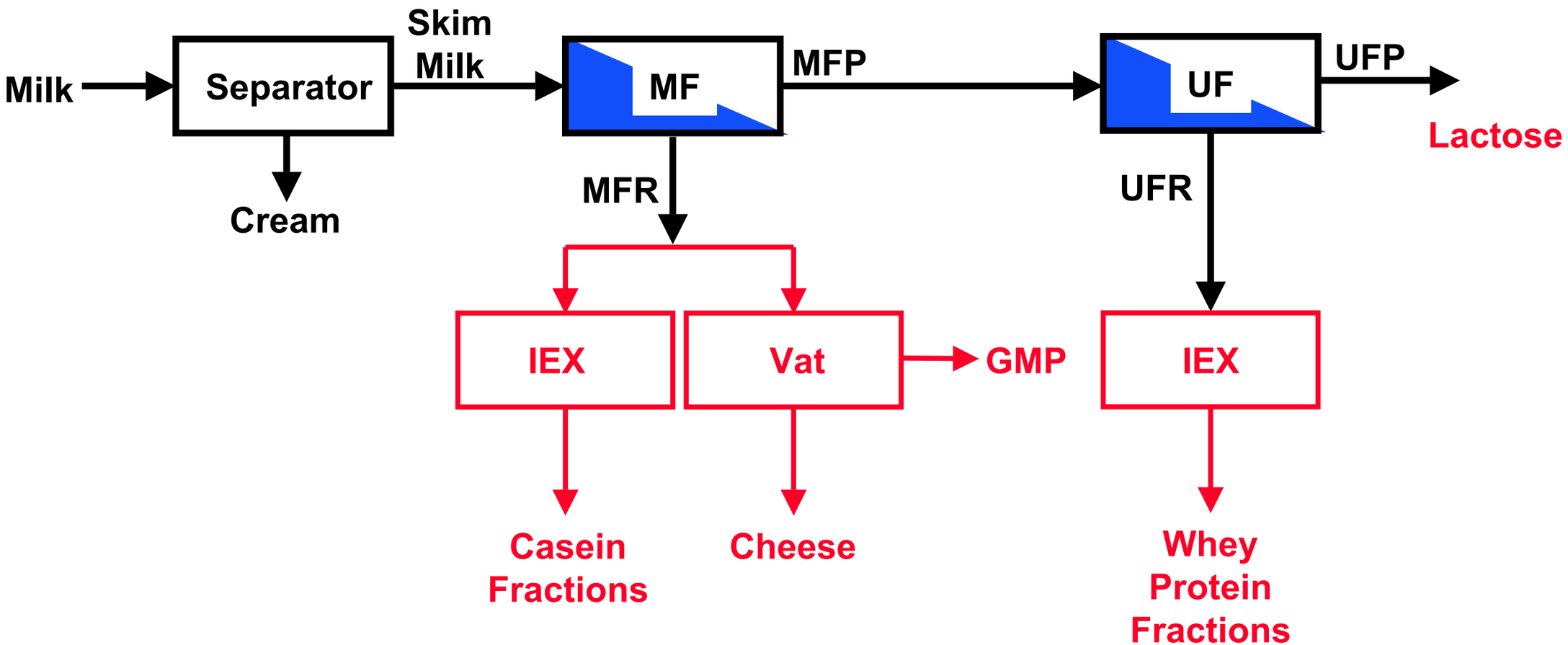
Major dairy proteins

whey	β-lactoglobulin
	α-lactalbumin
	serum albumin
	immunoglobulins
	glycomacropeptide
	lactoferrin
	lactoperoxidase
caseins	κ-casein
	β-casein
	α_s-caseins

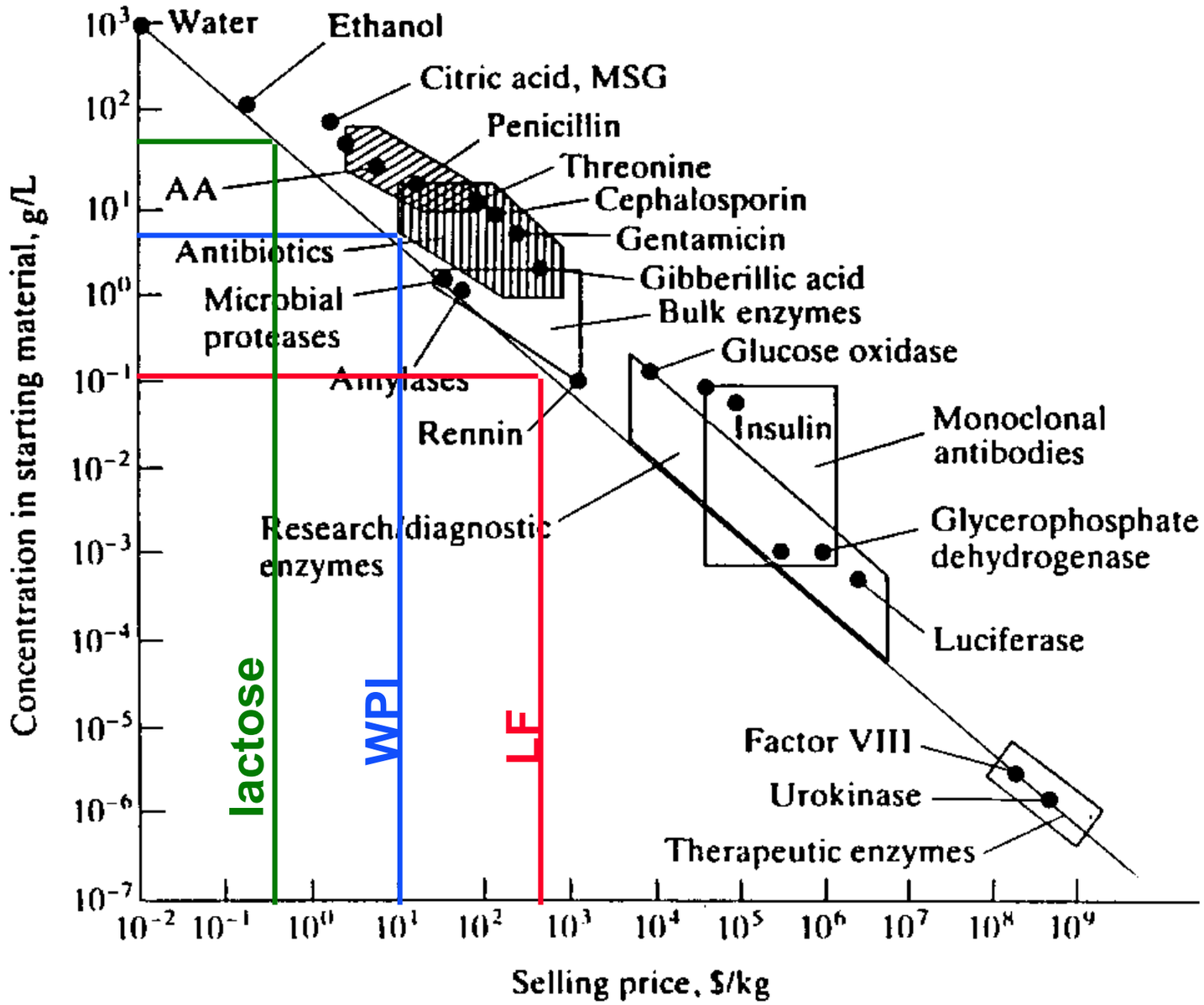
Properties of proteins in milk

Protein	(kg/mol)	g/L	pI
β-lactoglobulin	18	3.2	5.4
α-lactalbumin	14	1.2	4.4
serum albumin	66	0.4	5.1
immunoglobulins	150	0.7	5-8
lactoferrin	77	0.1	7.9
lactoperoxidase	78	0.03	9.6
κ-casein	19	3.3	5.8
β-casein	24	9.3	5.2
α_s-caseins	24	13	4.9/5.3

Example milk biorefinery



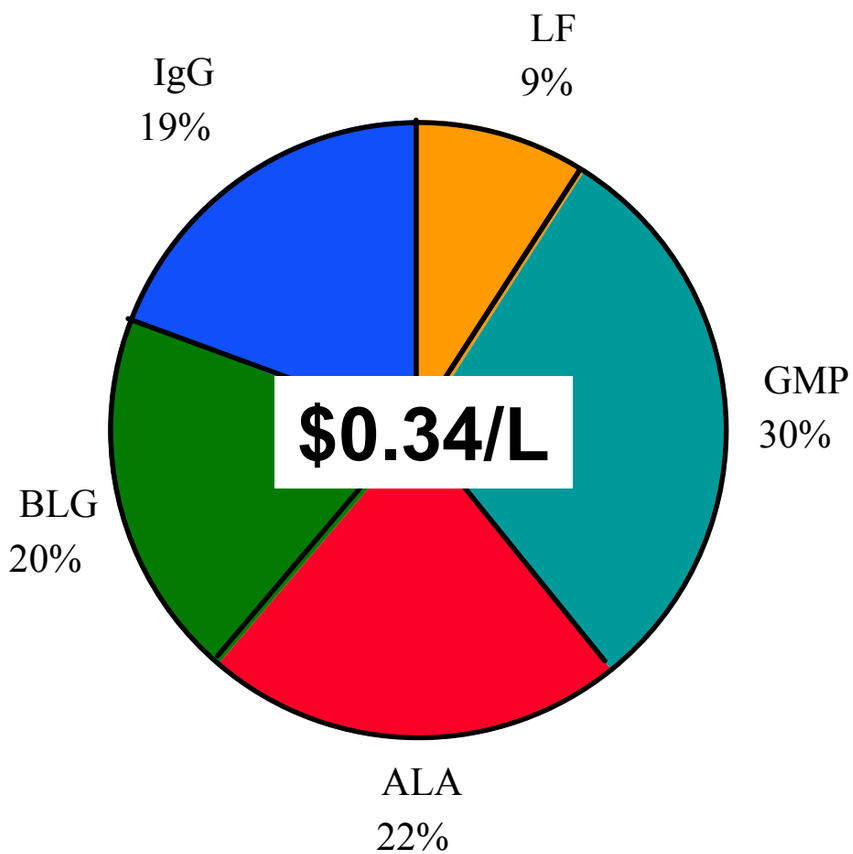
Cost of separation processes



Biorefinery whey protein prices

Component	$/kg	$/L-milk	% Milk
Lactoferrin	300	0.030	8
Glycomacropeptide	70	0.11	31
Alpha-lactalbumin	60	0.072	20
Beta-lactoglobulin	20	0.064	18
Immunoglobulin	90	0.063	18
Total		0.34	95

Whey protein value



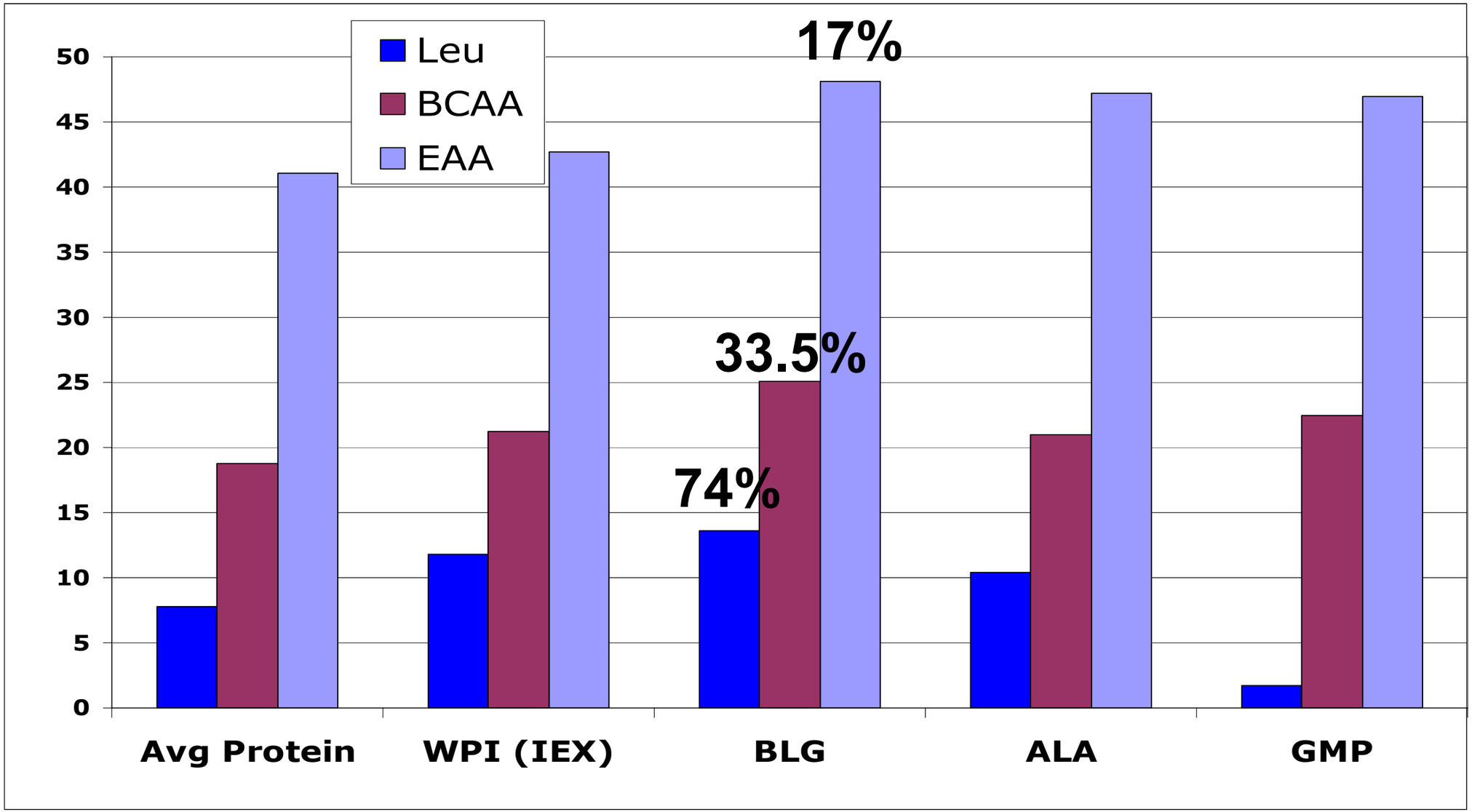
28×10^9 L/yr whey (USA)
$\$9.5\times10^9$/yr whey (USA)

Increased protein diets

Diets high in EAAs, BCAAs & Leu:

- **Fight obesity and diabetes**
- **Reduce appetite**
- **Stimulate MPS**
- **Reduce insulin titers**
- **Reduce blood lipid titers**

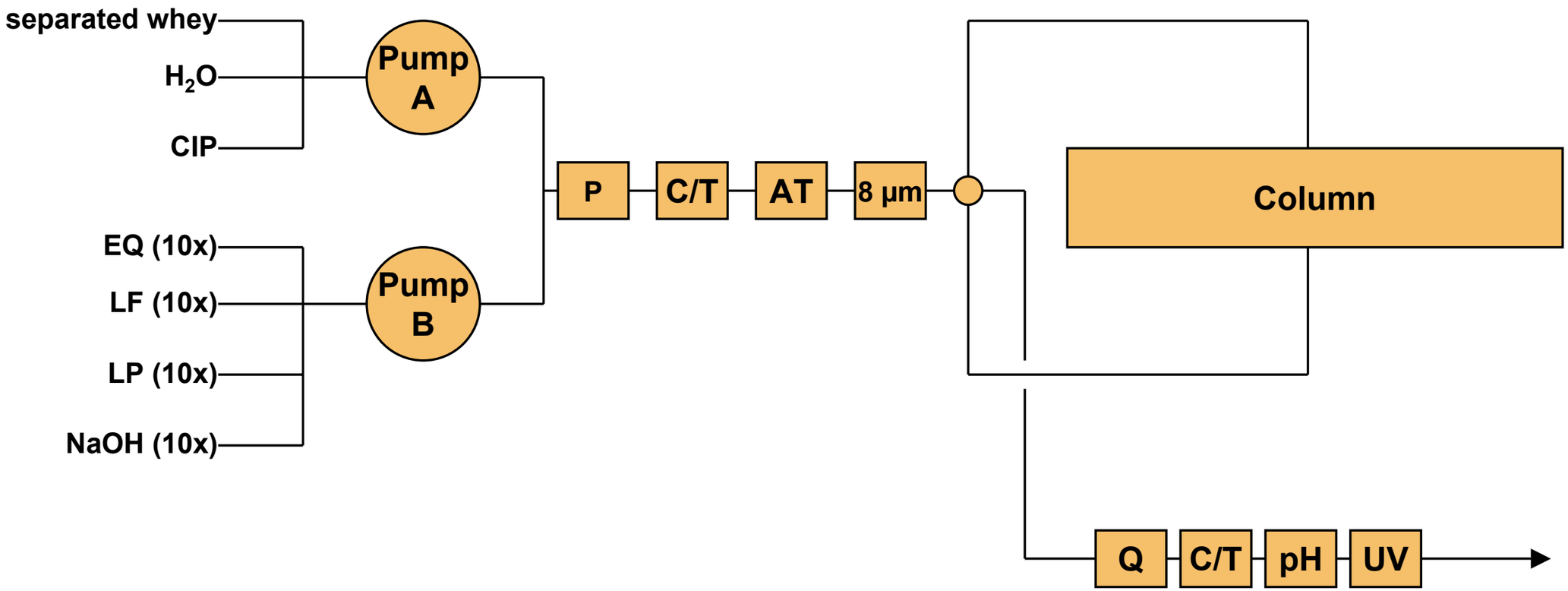
Dairy proteins



Bioprocess chromatography column

Bioprocess system controller

Chromatography flow sheet



Biorefinery dairy product prices

Component	$/kg	$/L-milk	% Milk
Butter	5.40	0.22	61
Cheese	4.80	0.48	133
Protein Fractions	20-300	0.34	95
Lactose	0.52	0.026	7
Total	1.84	0.16	296

Lactose biorefinery products

- Lactose derivatives
  - Glucose & galactose
  - Lactulose (fructose-Gal)
  - Lactitol (sorbitol-Gal)
  - Tagatose (derGal)
  - Lactobionic acid (gluconic acid-Gal)

- Lactose synthesis
  - Oligosaccharides (e.g. siallylactose)
  - Polysaccharide gums (xanthan, Lactan)

Sugar substitutes

Compound	GI	Sweetness	Calories (kcal/g)
Lactose	46	20	4
Glucose	100	75	4
Galactose	23	35	4
Lactulose	0	55	0
Lactitol	6	40	2.0
Tagatose	3	92	1.5

Applications -- Beverages

— Other drink sales replacing milk sales:

- Carbonated soft drinks = $63 billion (1% growth)
- Juice and juice drinks = $20 billion (0% growth)
- Functional beverages = $11 billion (11% growth)
- Bottled water = $8 billion (12% growth)
- Milk = $12 billion (0% growth) (least expensive!)

— Fortify non-dairy beverages with milk sugars and proteins that have special medical benefits and unique functional properties

Conclusions

1.) New dairy biorefinery products: fractionated and converted proteins, sugars, and lipids to increase revenues and flexibility.

2.) Applications in beverages:

Non-dairy beverages = $102 billion (3% growth)

3.) “Reduced-calorie” and “high-protein” beverages vs. soft drinks and juices (healthy vs. not healthy).