Turning Waste into By-Product

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ARCS
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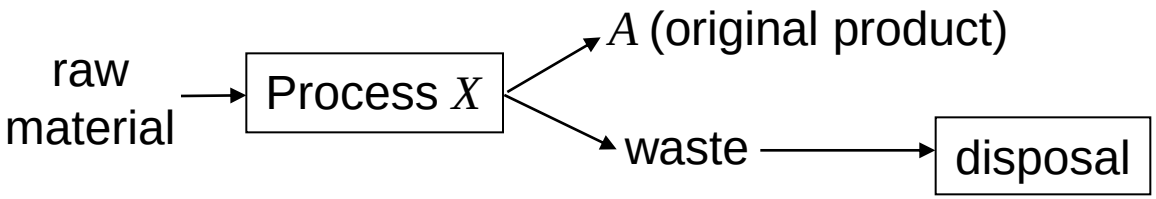
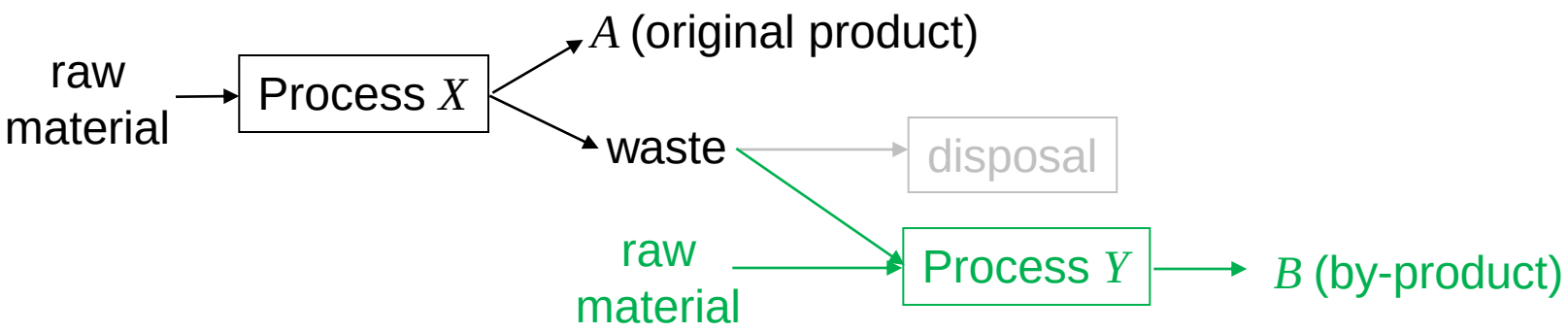
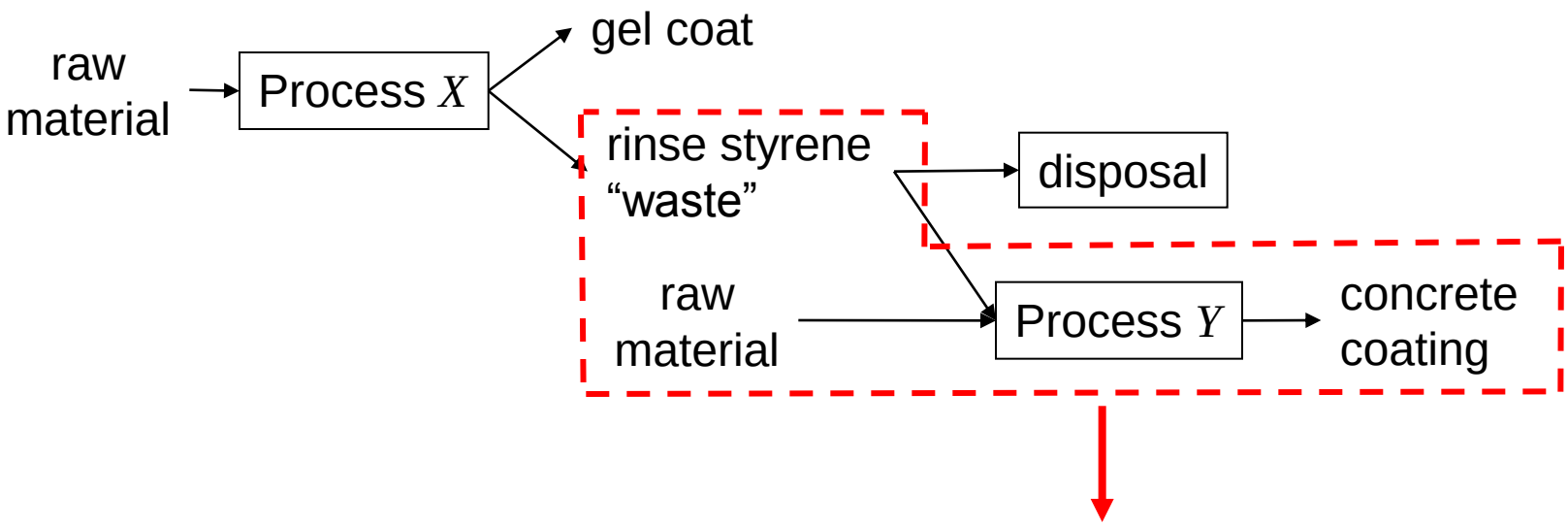
Typical Production Process



By-Product Synergy

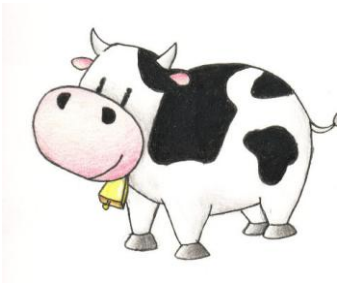


BPS: Cook Composites and Polymers



- Save disposal cost
- Incur processing cost
- Generate revenue
- Potentially reduce environmental impact

BPS: It's Been Around a While



Process X

beef (500 lbs)

"waste":
- tail (1)
- ears (2)
- hooves (4)
- organs (x1)
- blood (x2)
- ...

raw material

Process Y

"by-product":
- serum albumin (y1)
(macromolecular proteins, plywood adhesives, fertilizer, etc.)
- tallows (y2)
(chewing gum, frying oil, candles, crayons, soaps, PVC, jet engine lubricants, cough syrup, tranquilizers, dynamite, etc.)
- collagen (y3)
(vascular sealants, dental implants, marshmellows, lotions, shampoo, etc.)
- ...

Where’s the Beef?

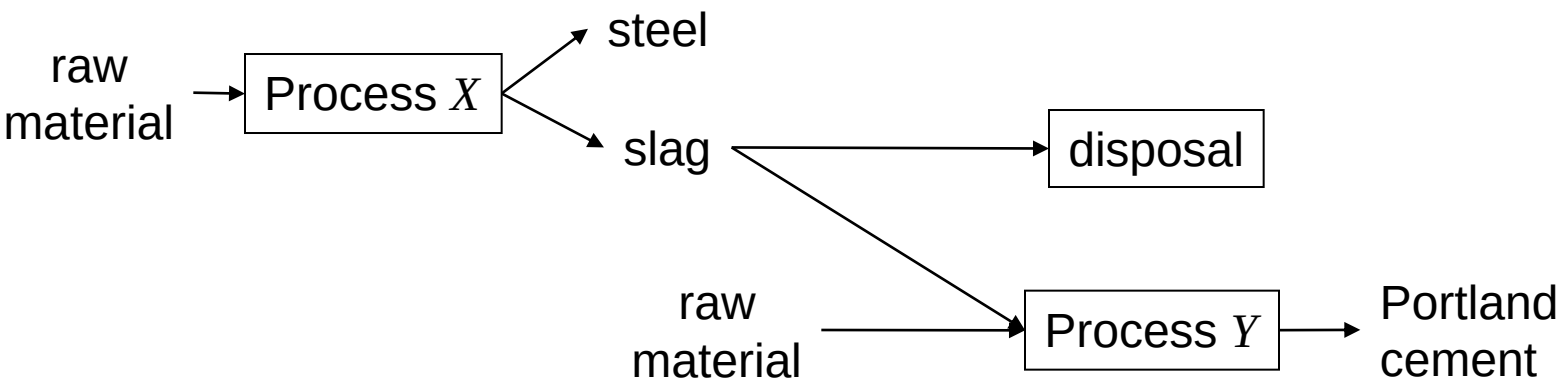
Macromolecular proteins, low-molecular-weight nutrients, carrier proteins for water-insoluble components, and other compounds necessary for in vitro growth of cells, such as hormones and attachment factors. Serum adds buffering capacity to the medium and binds or neutralizes toxic components in the growth milieu. Plywood adhesives, fertilizer, foam fire extinguisher, chemical fixer for dyes. Edible tallow is used in shortening for baked goods and in combination with vegetable oils for frying foods. Also used in chewing gum. Various industrial tallows: Top White Tallow, All-Beef Packer Tallow, Extra Fancy Tallow, Fancy Tallow, Bleachable Fancy Tallow, Prime Tallow,Special Tallow, No. 2 Tallow, A Tallow, Choice White Grease, Yellow Grease. Plastics, tires, candles, crayons, cosmetics, lubricants, soaps, fabric softeners, asphalt emulsifiers, synthetic rubber, linoleum (metallic stearate), PVC (calcium stearate), jet engine lubricants, carrier for pesticides and herbicides, wetting agents, dispersing agents, defoamers, solubilizers, viscosity modifiers. Synthetic motor oil, fed into gel cultures to produce antibiotics, high-performance coatings for planes and cars, food packaging, fishing line, acne medication, furniture, cosmetic gels, pharmaceutical additives, grease additives, toner adjuvants, antifoam agents, explosive additives, waterproofing agents. Lubricants in industrial processes. Rubber, textiles, ore floatation, corrosion inhibitors,metalworking lubricants. Emulsifiers, coating agents, textile sizers, lubricants, plasticizers, defoaming agents, lithium-based greases, textile lubricants, rolling and cutting oils, metal-machining lubricants. Sodium alkyl sulfates, ultimately made into detergents. A wide range of pharmaceuticals including cough syrups and lozenges, tranquilizers, eyewashes, contraceptive jellies and creams, ear drops, poison ivy solutions, solvent for digitalis and intramuscular injection, sclerosing solutions for treatment of varicose veins and hemorrhoids, suppositories, gel capsules. Solvent, sweetener, dynamite, cosmetics, liquid soaps, candy, liqueurs, inks, lubricants, antifreeze mixtures, culture nutrients for antibiotics. Aftershave preparations, shaving cream, toilet soap, toothpaste, sunscreens and sunblocks, dental floss, bath salts, bubble baths, body lotions, cleansing creams, moisturizing creams, external analgesics and counterirritants, shampoos, hair coloring preparations (bleaches, dyes, rinses, tints), hair dressings (brilliantines, creams, pomades), hair mousse, hair and scalp conditioners, hairspray, topical antibiotic preparations, hemorrhoidal preparations, pharmaceuticals for veterinary use, liquid household hard-surface cleaners, laundry aids (ironing and dry-cleaning spotting solutions), agricultural chemicals, automobile body polish and cleaners. Hemostats, vascular sealants, tissue sealants, orthopedic implant coatings, vascular implant coatings, artificial skin, bone graft substitutes, corneal shields, injectable collagen for plastic surgery, injectable collagen for incontinence treatment, meat casings, food additives, artificial dura maters, dental implants, wound dressings, antiadhesion barriers, platelet analyzer reagents, research reagents, antibiotic wound dressing, lacrimal plugs. Powdered gelatin, leaf gelatin, gelatin hydrolysate, instant gelatin, jellies, confectionery (jelly beans, jelly babies, gums, pastilles), aerated confectionery (marshmallows, meringues, nougats, fruit chews), caramels, sugarcoated almonds, desserts and dairy products (Bavarian creams, mousses, piecrusts, margarines, dietetic products, yogurts, ice creams and sorbets), clarification of wines (fining agent), decorations (garnishes, galantines, foie gras, eggs in jelly), gel reinforcement for cooked meats to improve slicing, gels for the liquor exuded from hams during cooking, gels to preserve pâtés, dietetic products (dietary breads, biscuits, powdered soups). Protective creams, beauty masks, lotions, shampoo basesHealth-pharmaceutical products. Soft capsules, hard-shell two-piece capsules, hemostatic sponges, biological adhesives, blood serum, binder in pills and suppositories. Binder for flammable substances in matches, binder to improve "crispness" of banknotes, coating for microparticles of self-copying papers,glues for paper and cardboard cartons, bookbinding glue, electrolyticsurface treatment of metals. Emulsion gelatin, dispersion gelatin, protective-layer gelatin, backing gelatin, baryta gelatin, modified gelatin.

Where’s the Beef?

“… the only industry in which some part of the cow is not used is concrete production.”

Macromolecular proteins, low-molecular-weight nutrients, carrier proteins for water-insoluble components, and other compounds necessary for in vitro growth of cells, such as hormones and attachment factors. Serum adds buffering capacity to the medium and binds or neutralizes toxic components in the growth milieu. Plywood adhesives, fertilizer, foam fire extinguisher, chemical fixer for dyes. Edible tallow is used in shortening for baked goods and in combination with vegetable oils for frying foods. Also used in chewing gum. Various industrial tallows: Top White Tallow, All-Beef Packer Tallow, Extra Fancy Tallow, Fancy Tallow, Bleachable Fancy Tallow, Prime Tallow,Special Tallow, No. 2 Tallow, A Tallow, Choice White Grease, Yellow Grease. Plastics, tires, candles, crayons, cosmetics, lubricants, soaps, fabric softeners, asphalt emulsifiers, synthetic rubber, linoleum (metallic stearate), PVC (calcium stearate), jet engine lubricants, carrier for pesticides and herbicides, wetting agents, dispersing agents, defoamers, solubilizers, viscosity modifiers. Synthetic motor oil, fed into gel cultures to produce antibiotics, high-performance coatings for planes and cars, food packaging, fishing line, acne medication, furniture, cosmetic gels, pharmaceutical additives, grease additives, toner adjuvants, antifoam agents, explosive additives, waterproofing agents. Lubricants in industrial processes. Rubber, textiles, ore floatation, corrosion inhibitors,metalworking lubricants. Emulsifiers, coating agents, textile sizers, lubricants, plasticizers, defoaming agents, lithium-based greases, textile lubricants, rolling and cutting oils, metal-machining lubricants. Sodium alkyl sulfates, ultimately made into detergents. A wide range of pharmaceuticals including cough syrups and lozenges, tranquilizers, eyewashes, contraceptive jellies and creams, ear drops, poison ivy solutions, solvent for digitalis and intramuscular injection, sclerosing solutions for treatment of varicose veins and hemorrhoids, suppositories, gel capsules. Solvent, sweetener, dynamite, cosmetics, liquid soaps, candy, liqueurs, inks, lubricants, antifreeze mixtures, culture nutrients for antibiotics. Aftershave preparations, shaving cream, toilet soap, toothpaste, sunscreens and sunblocks, dental floss, bath salts, bubble baths, body lotions, cleansing creams, moisturizing creams, external analgesics and counterirritants, shampoos, hair coloring preparations (bleaches, dyes, rinses, tints), hair dressings (brilliantines, creams, pomades), hair mousse, hair and scalp conditioners, hairspray, topical antibiotic preparations, hemorrhoidal preparations, pharmaceuticals for veterinary use, liquid household hard-surface cleaners, laundry aids (ironing and dry-cleaning spotting solutions), agricultural chemicals, automobile body polish and cleaners. Hemostats, vascular sealants, tissue sealants, orthopedic implant coatings, vascular implant coatings, artificial skin, bone graft substitutes, corneal shields, injectable collagen for plastic surgery, injectable collagen for incontinence treatment, meat casings, food additives, artificial dura maters, dental implants, wound dressings, antiadhesion barriers, platelet analyzer reagents, research reagents, antibiotic wound dressing, lacrimal plugs. Powdered gelatin, leaf gelatin, gelatin hydrolysate, instant gelatin, jellies, confectionery (jelly beans, jelly babies, gums, pastilles), aerated confectionery (marshmallows, meringues, nougats, fruit chews), caramels, sugarcoated almonds, desserts and dairy products (Bavarian creams, mousses, piecrusts, margarines, dietetic products, yogurts, ice creams and sorbets), clarification of wines (fining agent), decorations (garnishes, galantines, foie gras, eggs in jelly), gel reinforcement for cooked meats to improve slicing, gels for the liquor exuded from hams during cooking, gels to preserve pâtés, dietetic products (dietary breads, biscuits, powdered soups). Protective creams, beauty masks, lotions, shampoo basesHealth-pharmaceutical products. Soft capsules, hard-shell two-piece capsules, hemostatic sponges, biological adhesives, blood serum, binder in pills and suppositories. Binder for flammable substances in matches, binder to improve "crispness" of banknotes, coating for microparticles of self-copying papers,glues for paper and cardboard cartons, bookbinding glue, electrolyticsurface treatment of metals. Emulsion gelatin, dispersion gelatin, protective-layer gelatin, backing gelatin, baryta gelatin, modified gelatin.

BPS: Chapparal Steel / TXI



Research Question

1) What are the operational implications of implementing BPS (in a market setting)?
   - alternate form of waste disposal?
   - strategic joint decision-making?
2) How does competition affect the optimal operating policy?
3) What are the environmental implications?

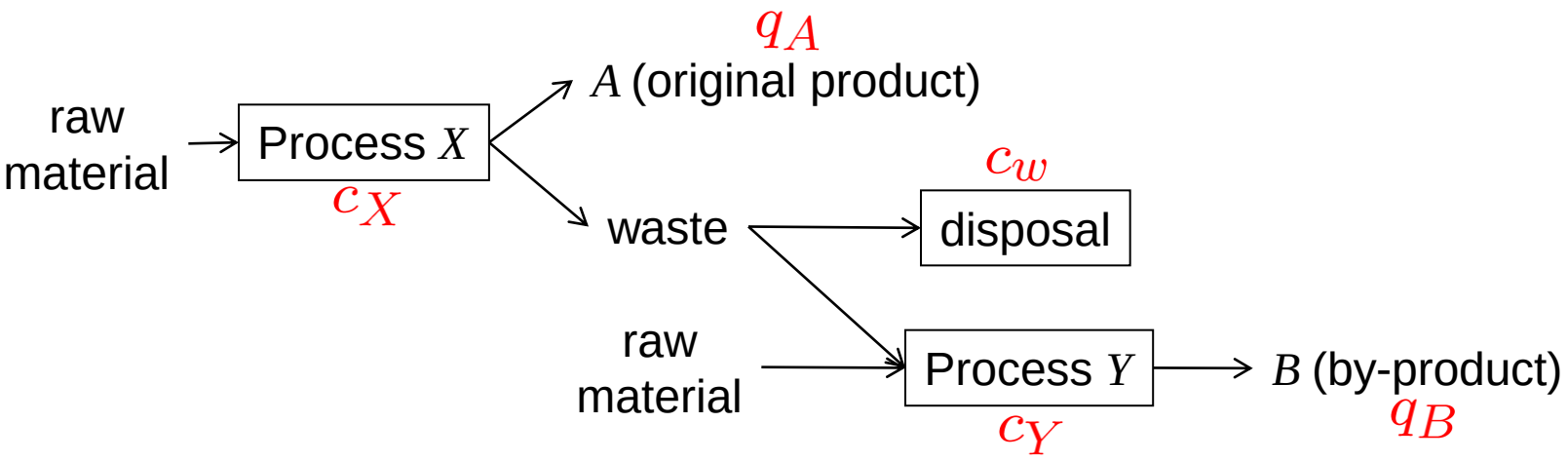
Literature

- **Operations**: Complementary to closed-loop supply chains, co-production
  - e.g., Debo, Toktay, and Van Wassenhove (2005), Guide and Van Wassenhove (2006), Atasu et al. (2008), Bitran and Leong (1992)

- **Environment**: Operational lens on industrial symbiosis
  - e.g., Ehrenfeld and Gertler (1997), Chertow (2000), Chertow and Lombardi (2005)

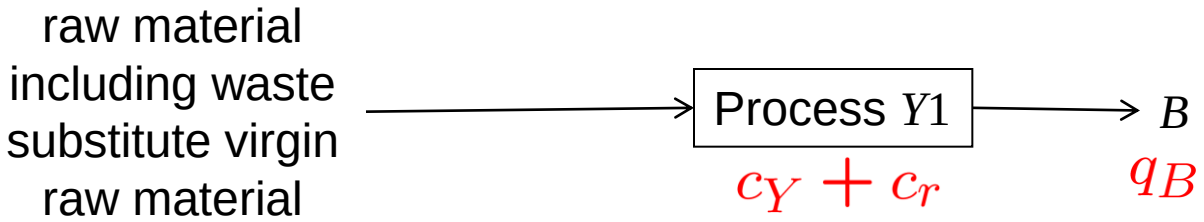
- **Economics**: Add operational detail to two-sided markets
  - e.g., Bulow, Geanokoplos, and Klemperer (1985), Chen and Ross (2007)

BPS process



One unit of A generates enough waste produce γ units of B.

Using virgin raw material to produce B



Monopoly / Monopoly

Market A:

$$p_A = a - q_A$$

Market B:

$$p_B = b - q_B$$

Firm 1 maximizes:

$$\max_{q_A, q_B} \pi = \underbrace{p_A q_A + p_B q_B}_{\text{revenue}} - \underbrace{(c_X + c_w) q_A}_{\text{cost of } A}$$

$$\underbrace{-(c_Y - \frac{1}{\gamma} c_w) \min\{q_B, \gamma q_A\}}_{\text{cost of } B \text{ using BPS method}} \underbrace{- (c_Y + c_r)(q_B - \gamma q_A)^+}_{\text{cost of } B \text{ using virgin raw material}}$$

Products *A* and *B* are "Subsidized"

$q_B \leq \gamma q_A$:

$$\pi = (p_A - (c_X + c_w))q_A + (p_B - \frac{1}{\gamma}(c_Y + c_w))q_B$$

product *B* is "subsidized" by c_w

$q_B > \gamma q_A$:

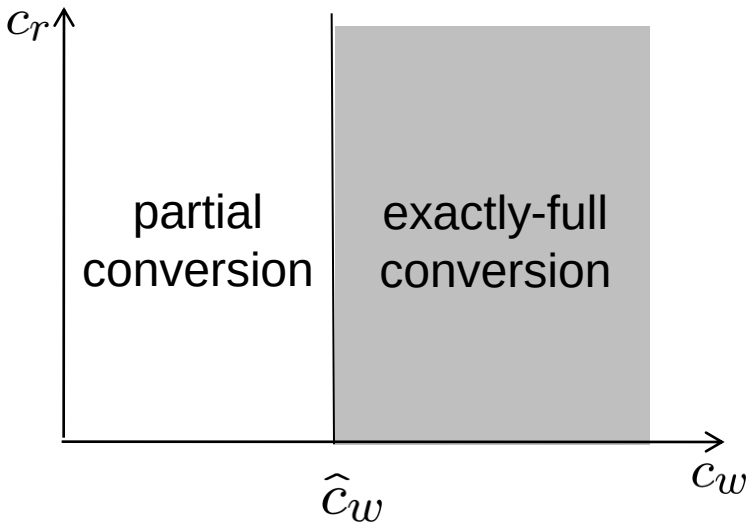
$$\pi = (p_A - (c_X - c_r))q_A + (p_B - \frac{1}{\gamma}(c_Y + c_r))q_B$$

product *A* is "subsidized" by c_r

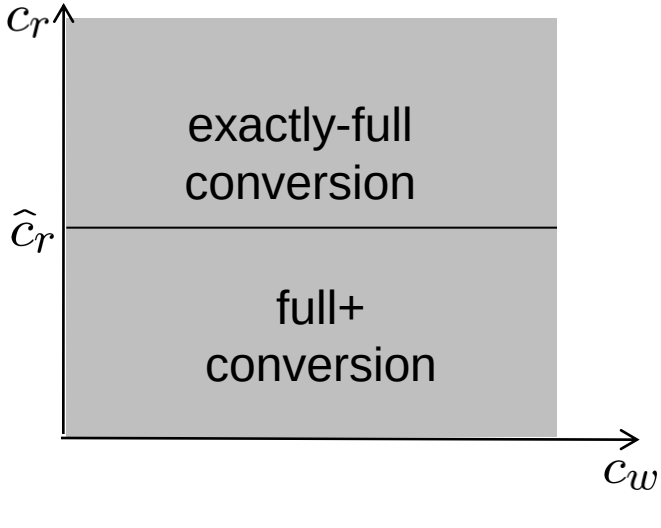
Three Operating Strategies

- Partial conversion: $q_B < \gamma q_A$
- Exactly-full conversion: $q_B = \gamma q_A$
- Full+ conversion: $q_B > \gamma q_A$

Optimal Operating Strategies Depend on "Subsidies"



a) $b - c_y < \gamma(a - c_x)$



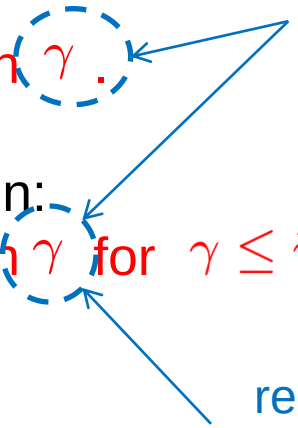
b) $b - c_y \geq \gamma(a - c_x)$

can manage as alternate form of waste disposal

requires strategically "overproducing" A

More Waste, More Profit

- Full+ conversion:
  - Profit increases in γ .
- Exactly-full conversion:
  - Profit increases in γ for $\gamma \leq \hat{\gamma}$.



represents efficiency of supplying raw material

represents efficiency of consuming waste

Monopoly / Price Competition

Market *A*: $p_A = a - q_A$

Market *B*: $p_B = c_b$

Assumption: The size of market B is large compared to what can be produced by the firm practicing BPS.

Assumption: $c_b \leq c_Y + c_r$

Result: If $c_b > c_Y - \frac{1}{\gamma} c_w$, BPS is profitable and exactly-full conversion is optimal. The optimal quantity of A is strictly greater than the monopoly quantity.

Result: The firm's profit increases in γ if and only if $c_Y < c_b$.

Duopoly / Price Competition

Market *A*: $p_A = a - q_{A1} - q_{A2}$

Market *B*: $p_B = c_b$

Should the firm license its BPS process to its competitor?

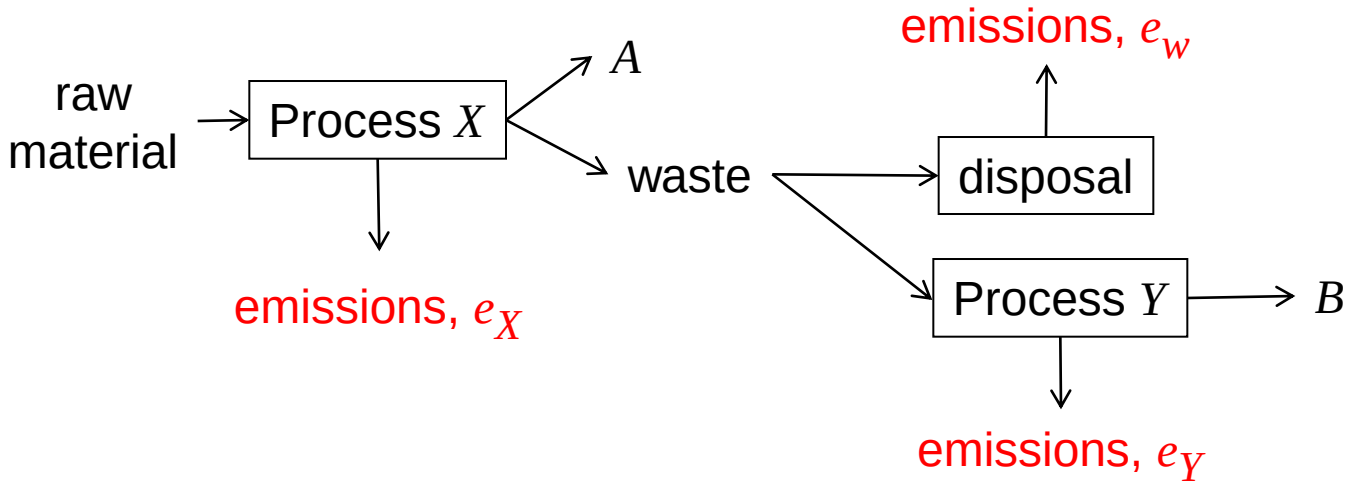
- Yes: gets license fee
- No: negates its cost advantage in market A

Result: If $c_b > c_Y - \frac{1}{\gamma} c_w$, the firm can increase profit by licensing its BPS process to its market A competitor for a license fee $\lambda = \frac{1}{\gamma} c_w + c_b - c_Y$ per unit of B produced.

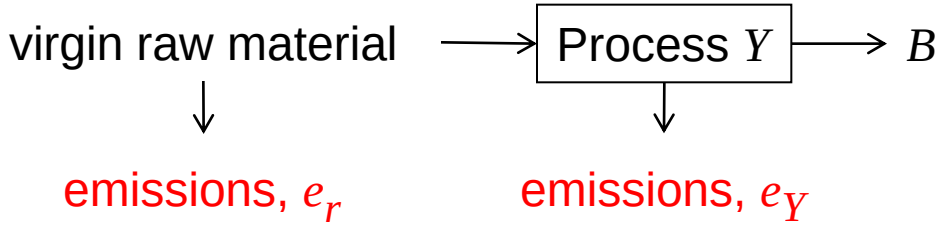
Result: The license fee decreases in γ .

Environmental Impact

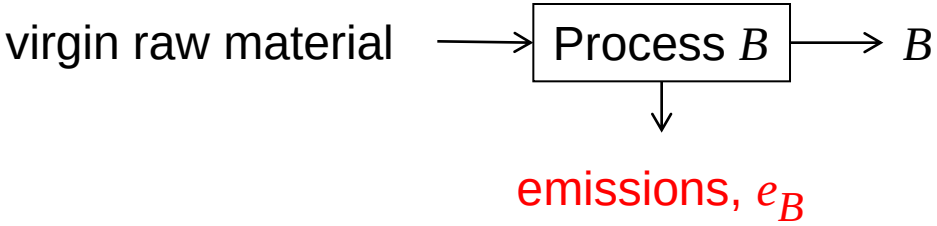
Firm 1: BPS process



Firm 1: Producing B using virgin raw material



Competitors in market B



Environmental Impact

	firm 1				market *A* competitor		market *B* competitors
	Process *X* e_X	Waste disposal e_w	Process *Y* (BPS) e_Y	Process *Y* (non-BPS) e_r	Process *X* e_X	Waste disposal e_w	Process *B* e_B
partial	0	-	+	0	0	0	-
full+	+	-	+	+	-	-	-
exactly-full	+	-	+	0	-	-	-

Firm 1's net emissions change can increase or decrease.

Competitors' emissions decrease.

Summary

- BPS links two markets through the production process of one firm
- Operational implications:
  - Two implementation modes: waste disposal vs. strategic
  - Increasing “waste” may increase profit
- Licensing BPS process can increase profits, reduce waste disposal
- Environmental implications
  - Competitors’ emissions decrease
  - BPS firm’s emissions change can increase or decrease
  - Net emissions impact controlled by the firm

Trash or Treasure?

- Sustainability:
  - *"[meeting] the needs of the present without compromising the ability of future generations to meet their own needs."*
- Externality = Waste
- Economics vs. Physical Systems
- Balance

Thank you!