CO_2 Utilization

Kaitlyn Hansen
Joseph Hernandez
James Shelton

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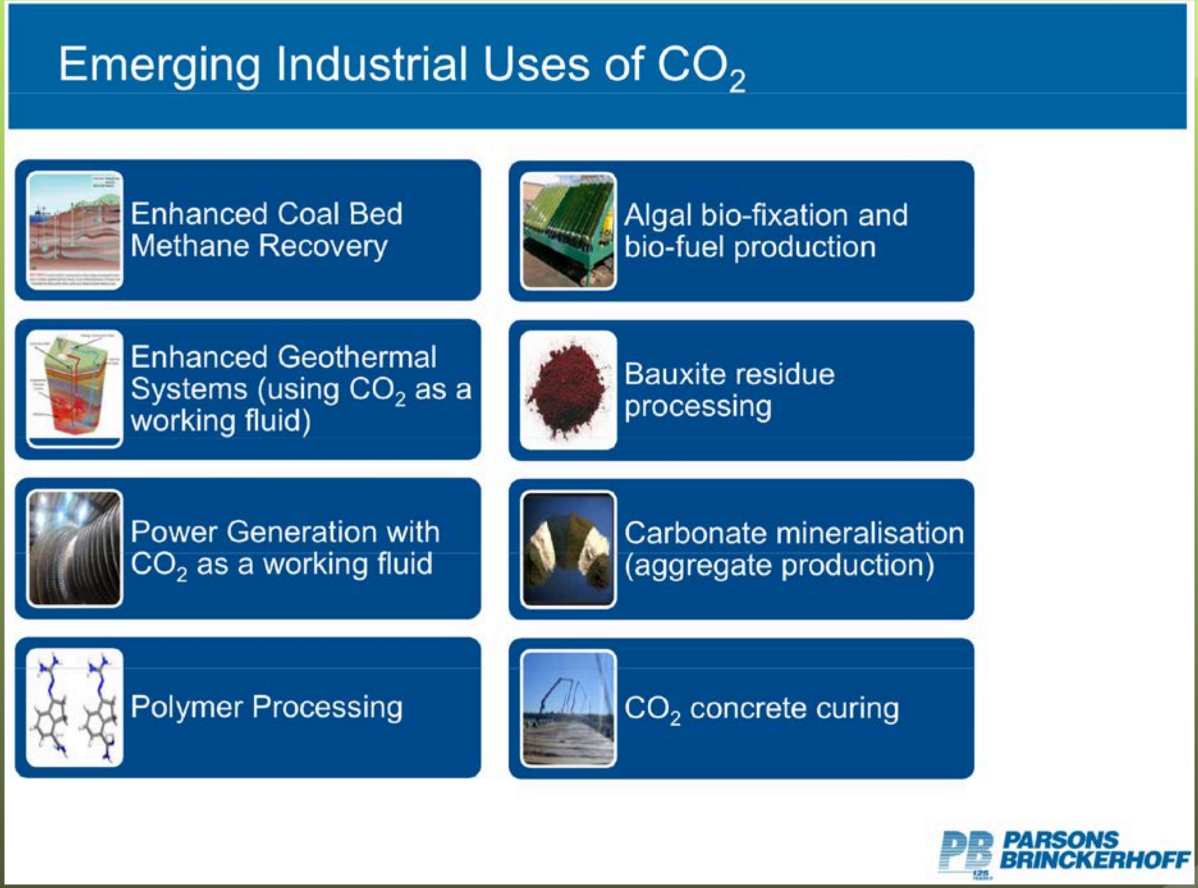
Carbon Dioxide (CO_2) Uses



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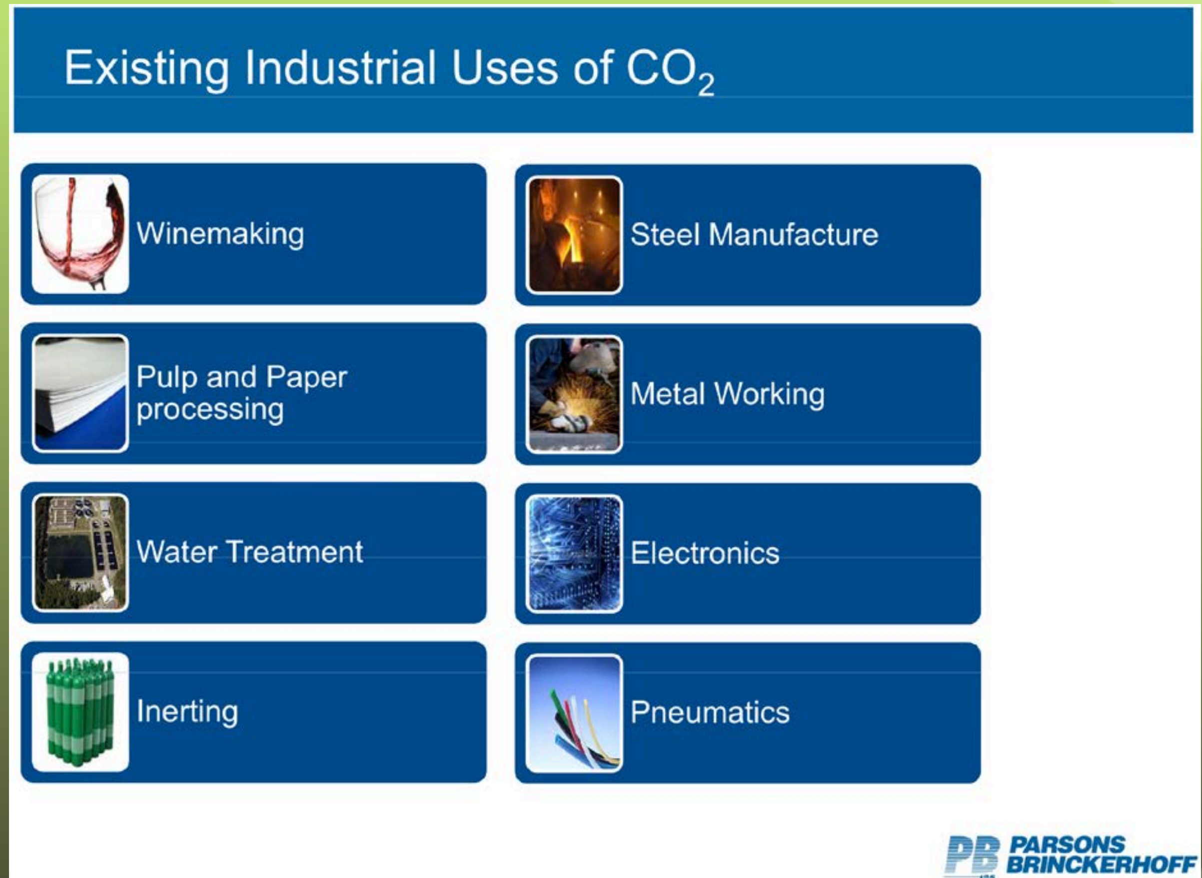
Carbon Dioxide (CO_2) Uses cont.



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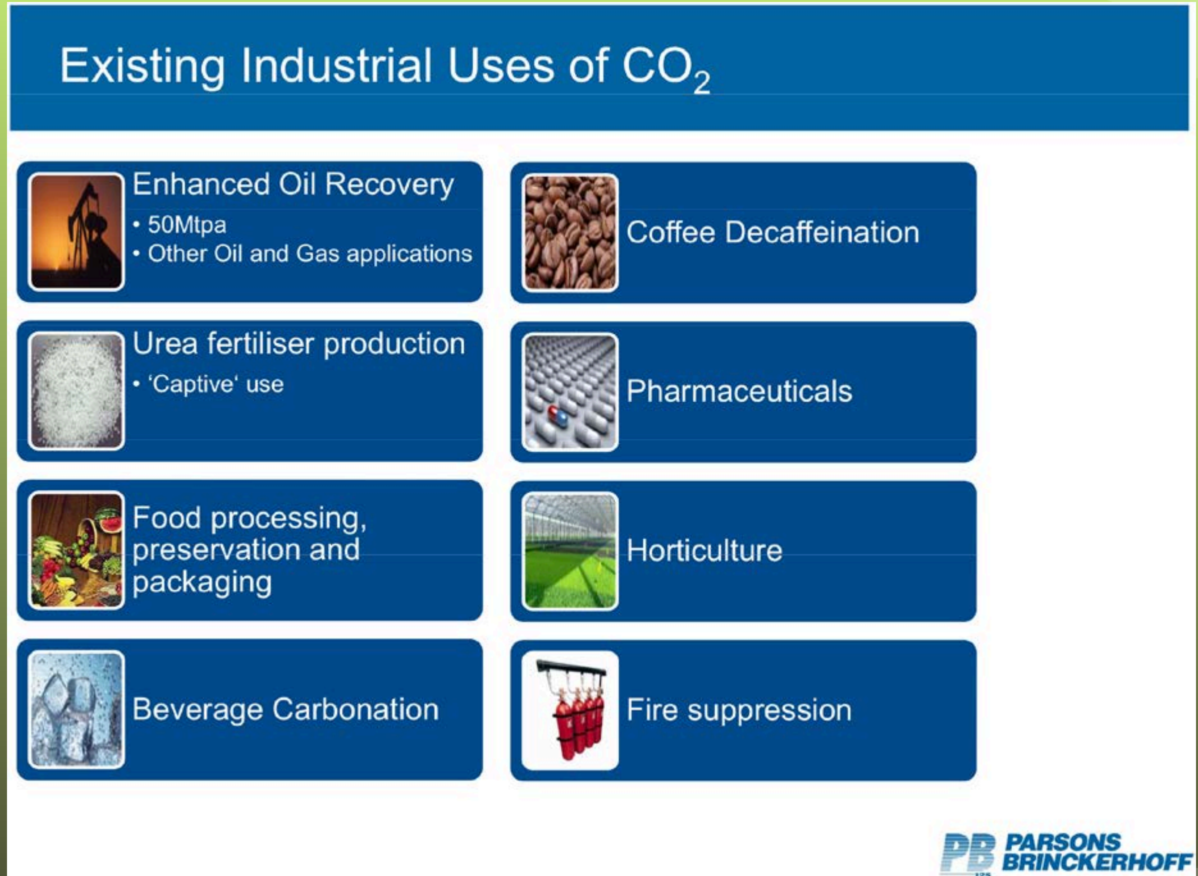
Carbon Dioxide (CO_2) Uses cont.



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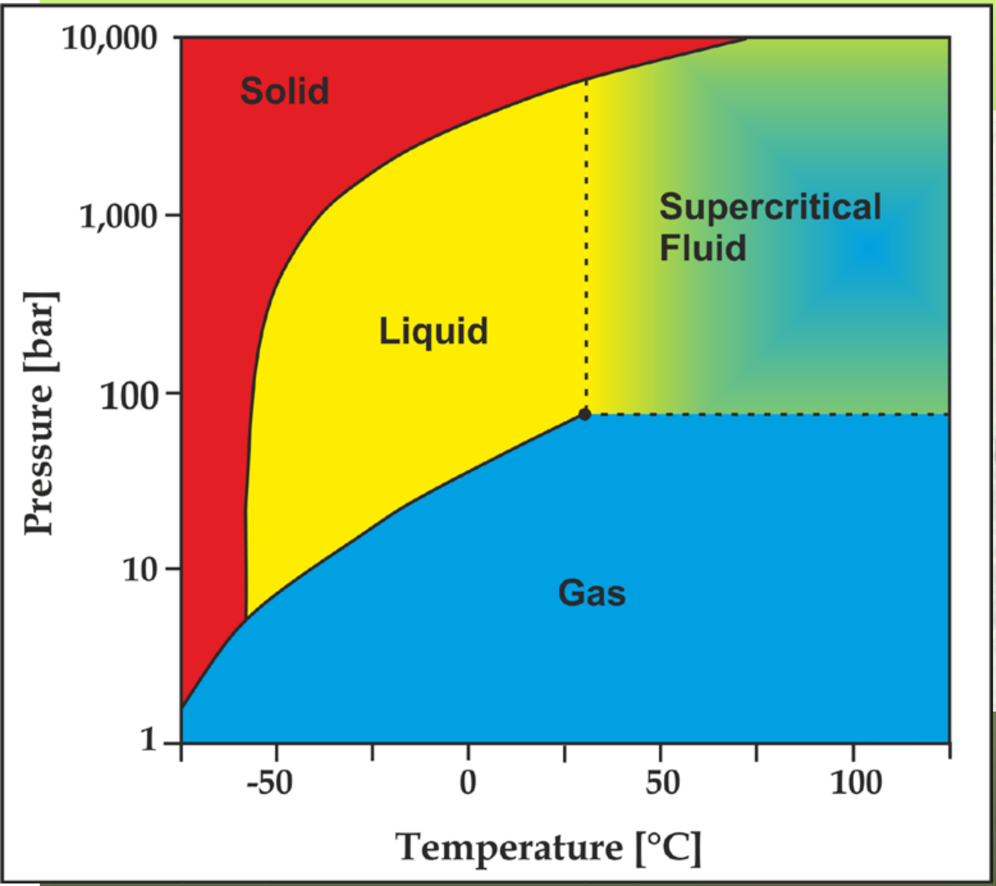
Outline

- Supercritical Fluids
- Decaffeination
- Beverage Carbonation
- Cryogenic Freezing
- Water Treatment

Supercritical Fluids



Phase Diagram of Carbon Dioxide

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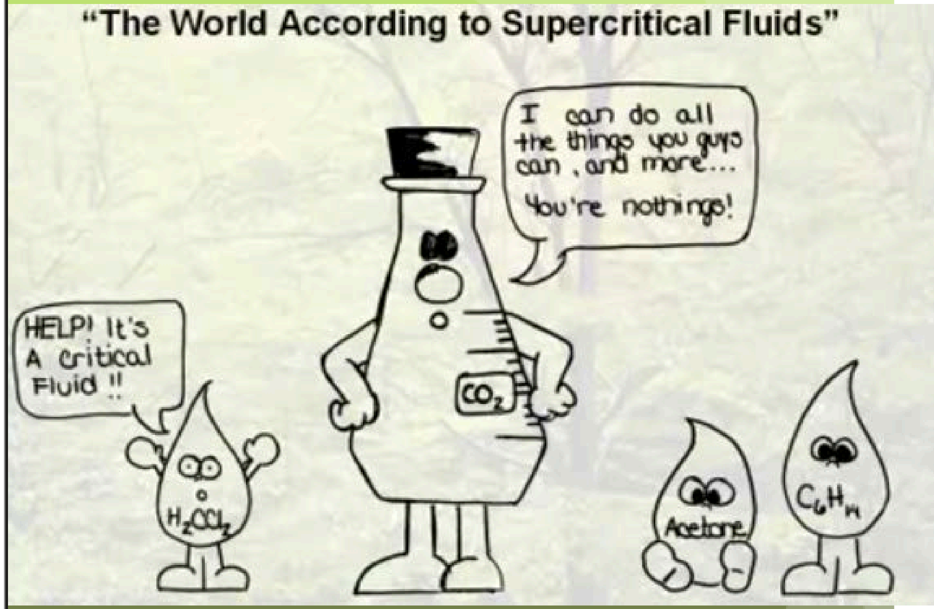
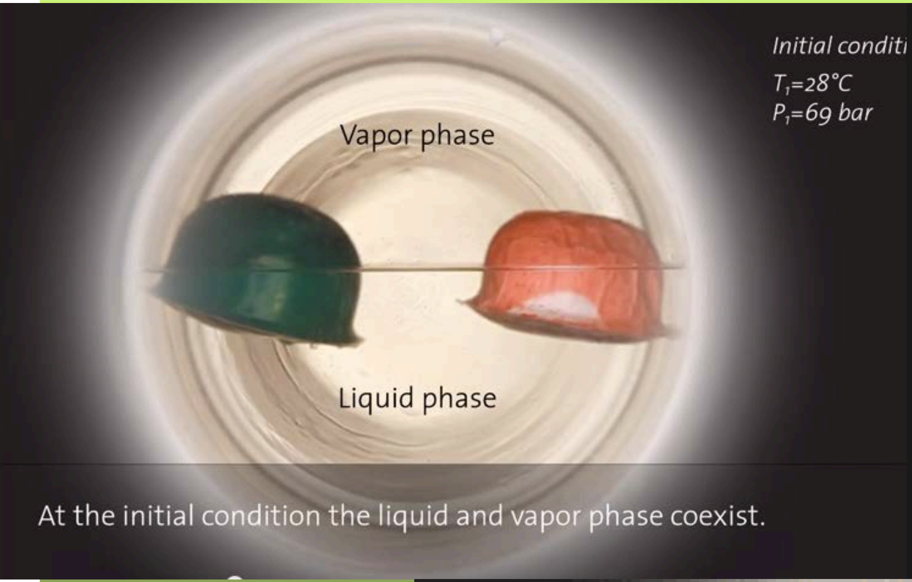
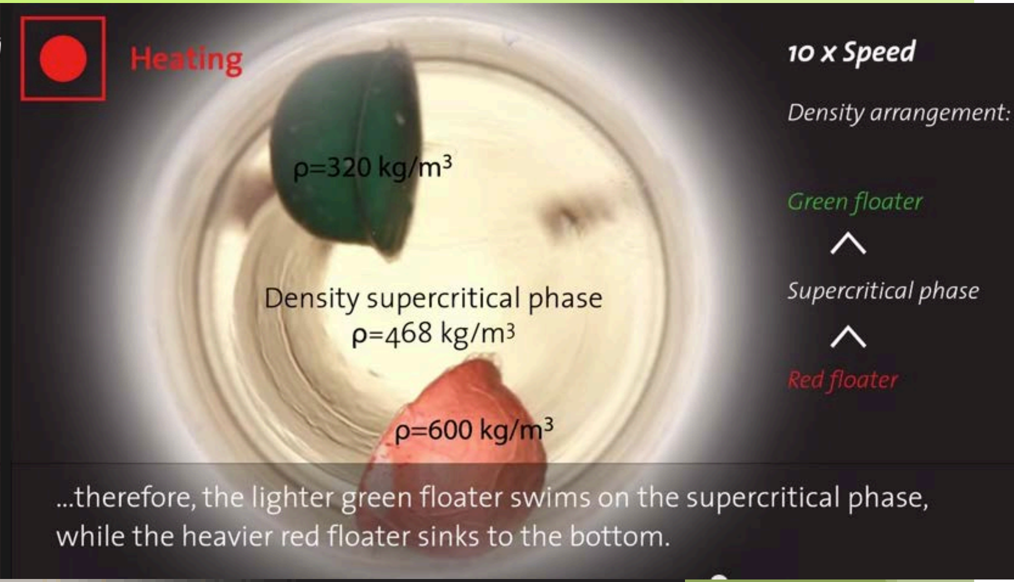


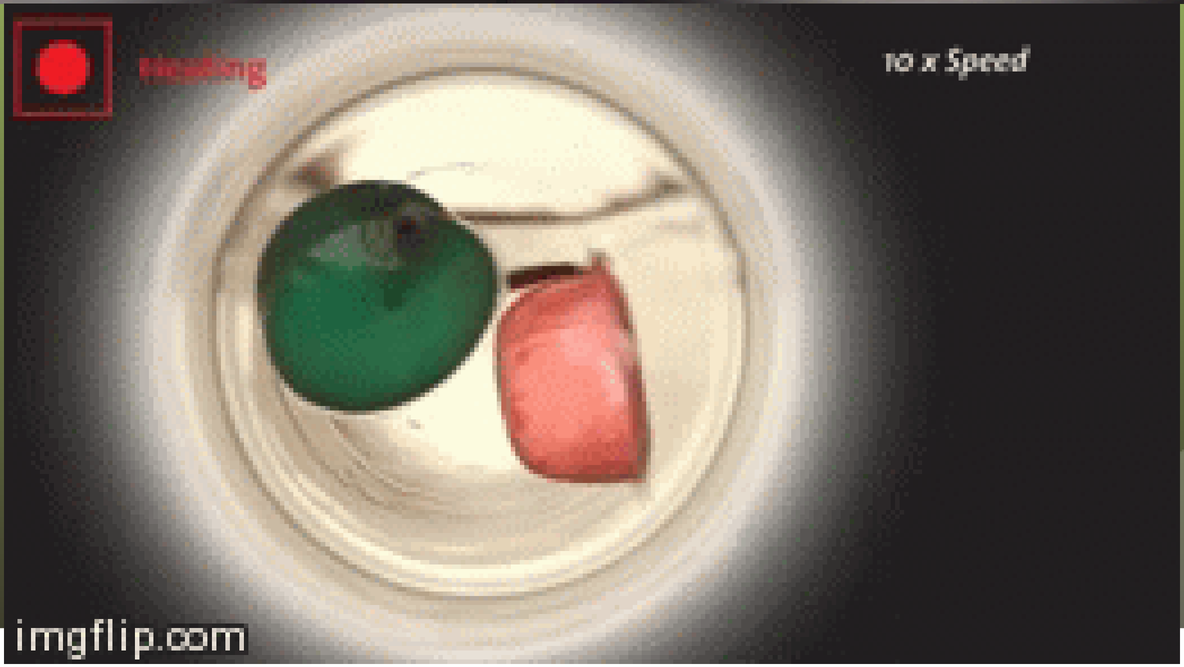
What Is Supercritical Carbon Dioxide? Applied Separations, Inc., 5 Aug. 2010. Web. 21 Apr. 2015.

Supercriticality

Reference: at end of presentation







CO_2 vs. Other Supercritical Fluids

Solvent	Critical Temperature (°C)	Critical Pressure (bar)
Carbon Dioxide	31.1	73.8
Chlorotrifluoromethane	28.9	39.2
Propane	96.7	42.5
Cyclohexane	280.3	40.7
Toluene	318.6	41.1
Perchloroethylene	347	47.6
Methylene Chloride	237	61
Water	374.2	220.5

Reference: at end of presentation

- Dry Cleaning
- Spray Paint
- Coffee Decaffeination

- Perchloroethylene
- Chlorofluorocarbon or propane
- Water, Methylene Chloride

Choose CO_2 as a SC Fluid

Reference: at end of presentation

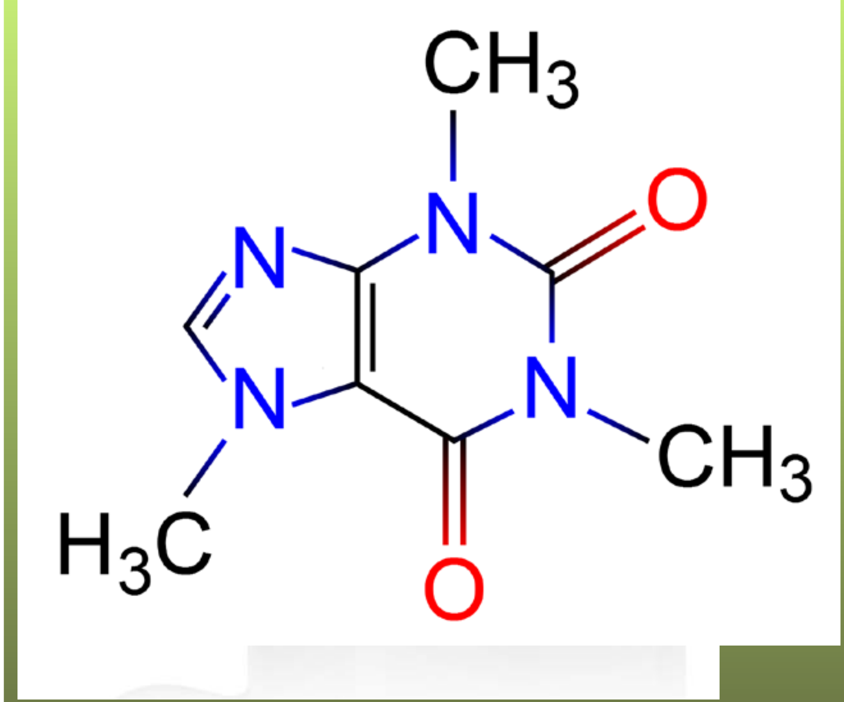
- Safe, environmentally friendly
- Recyclable
- Inexpensive/readily available
- No residue
- Mild conditions for supercriticality
- Tunable
- Servicing the environment by using CO_2

Venus's atmosphere is 96.5% CO_2 and the average temperature and pressure are 467ºC & 93 bar, meaning the atmosphere on Venus is made up of supercritical CO_2!

Market for Coffee

- The coffee industry is valued at $100 billion annually; $19 billion just in the US
  - Largest worldwide commodity after crude oil
- Worldwide, we drink 500 billion cups of coffee per year
- Decaffeinated coffee accounts for about 12% of worldwide consumption
- Certified coffee farms dropped from 43% to 24% between 1996 and 2010 because of demand
- There are about 1,200 chemical compounds in coffee with about half contributing to flavor

Coffee Decaffeination



Caffeine Molecule

- Caffeine is a nonpolar, hydrophilic molecule
- Water as a solvent
- Organics as solvents
- Supercritical CO_2 is tunable
  - Selectively dissolve caffeine
  - Increasing pressure increases the density and makes the supercritical CO2 simulate greater polarity

Water as a Solvent—Swiss Water Process

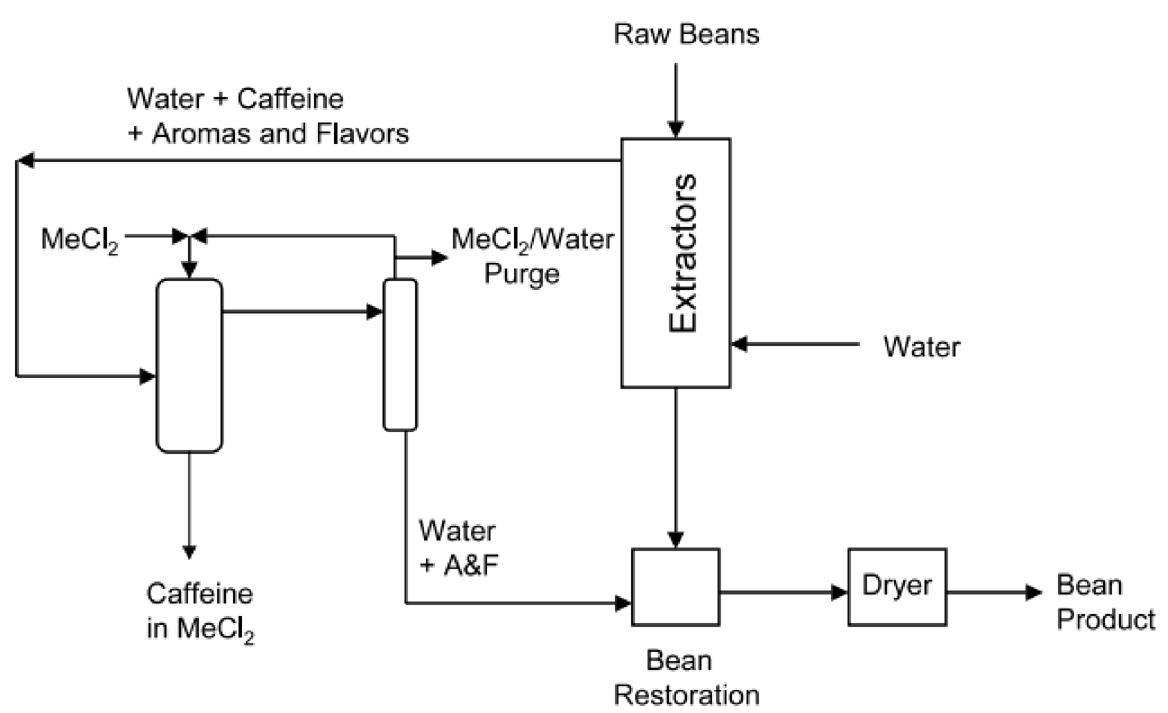


Fig. 1. Conventional 'water process' for decaffeination of coffee beans.

- Uses clean water
- Wastes a set of coffee beans

Reference: at end of presentation

Beans amount to 95% of cost

- Water waste is a major source of "anti-greenness"

Table 2.1 Physical input/output table for 1 ton of green bean input (simplified)

Input		Output	
Item	Physical amount	Item	Physical amount
Green beans	1,000 kg	Green beans grade A	430 kg
Water	0.035 m^3	Green beans grade B	370 kg
Electric energy	40 kWh	Green beans grade C	60 kg
		Green beans grade D	55 kg
		Green beans for local market	75 kg
		Dust	2 kg
		Weight loss	8 kg
		Waste water	0.035 m^3

Reference: at end of presentation

Supercritical CO_2 Decaffeination

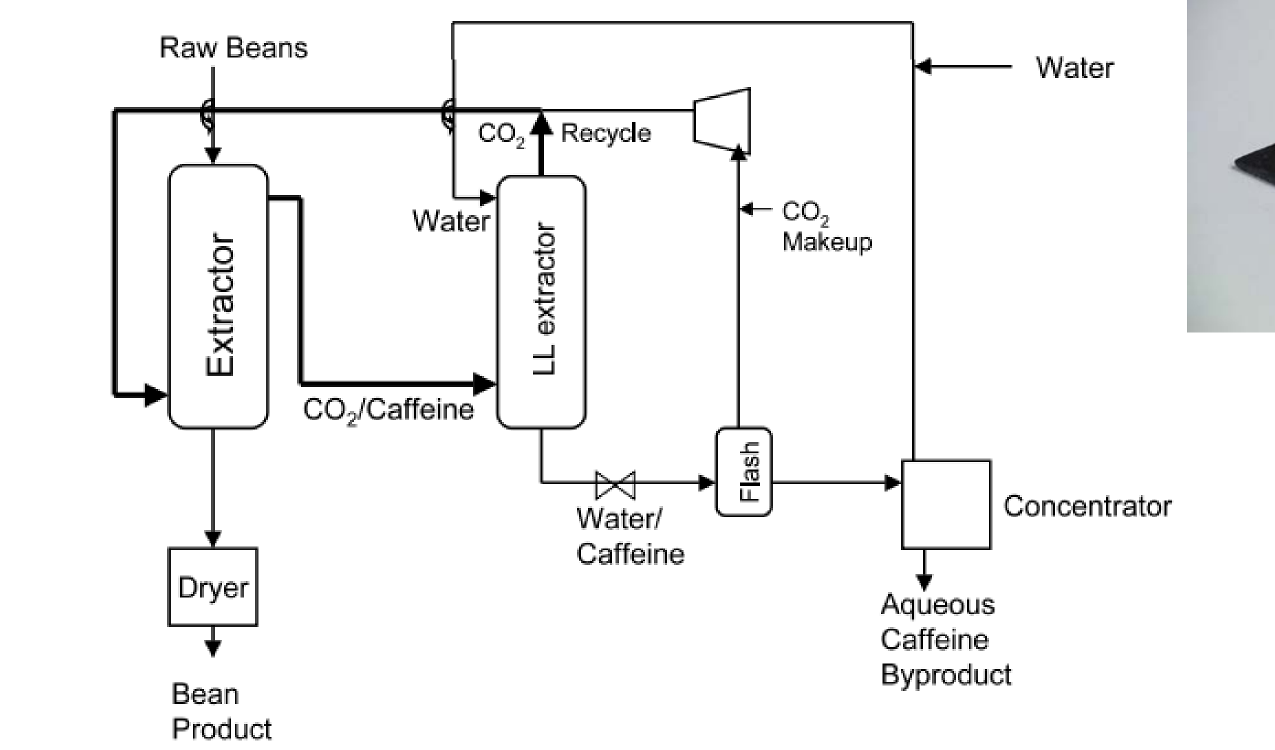


Fig. 2. Decaffeination of coffee beans using supercritical CO_2. $MeCl_2$ refers to methylene chloride.

Without the use of water, extraction will result in solid caffeine byproduct when CO_2 is depressurized into a gas.

Reference: at end of presentation

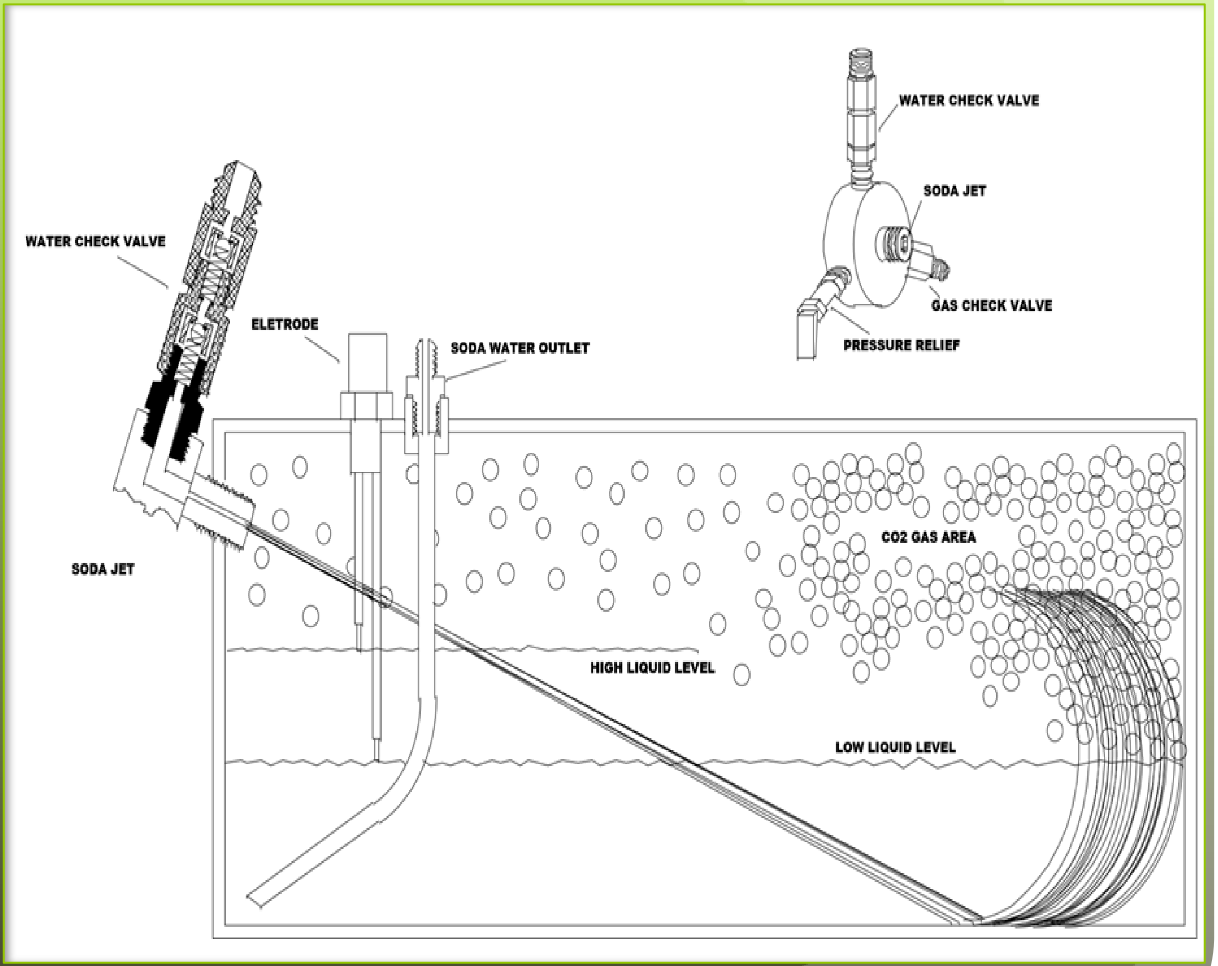
Market for Beverage Carbonation

- Dominant use of CO_2 in the food industry
- Solution of carbon dioxide gas in liquid water
- **Why?**
- Creates "bubbly effect"
- Acts as a preservative

Reference: at end of presentation

Carbonation Process

- Carbonator or Saturator used to carbonate water
- Carbonated water mixed with syrups and additives



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Cryogenic Freezing

- Defined as freezing at -75F or below.
- CO_2 injected as high pressure liquid
- Instantly expands into gas and tiny solid particles called "snow"
- Solids are driven into surface of the food
- The refrigeration effect occurs due to the latent heat of sublimation

Reference: at end of presentation

Cryogenic Freezing vs. Mechanical Freezing

	Cryogenic Freezing	Mechanical Freezing
Investment Costs	Lower cost of capital equipment and simpler, inexpensive installation.	Higher cost of capital equipment and complex and costly installation.
Operating Costs	Higher energy cost with liquid nitrogen or carbon dioxide as energy source.	Generally lower energy cost.
Maintenance Costs	Low: • High uptime • Low maintenance requirements • Reduced cleaning requirements	High: • All parts of a mechanical refrigeration system consisting of three major pieces: high horse-power compressor, condenser, evaporator, and refrigerant storage must be inspected annually. • Ammonia refrigeration systems with 10,000 pounds or more of ammonia are a covered process subject to the requirements of the OSHA Process Safety Management Standard (PSM) 1910.119.
Freezing Temperatures	Typically, -160°F or lower for Liquid N_2 and -80°F for liquid CO_2.	Typically -30°F
Food Quality	Rapid freezing reduces dehydration loss to less than 1%, thus preserving texture and flavor. Product does not stick to belt.	Slower freezing, up to 3 to 4 times longer than cryogenic freezing, can result in surface dehydration and weight loss and does not allow the successful preparation of Individually Quick Frozen (IQF) products. Product tends to stick to belt.
Environmental Considerations	Environmentally friendly way of freezing food.	Ammonia is a great refrigerant but it is highly toxic.

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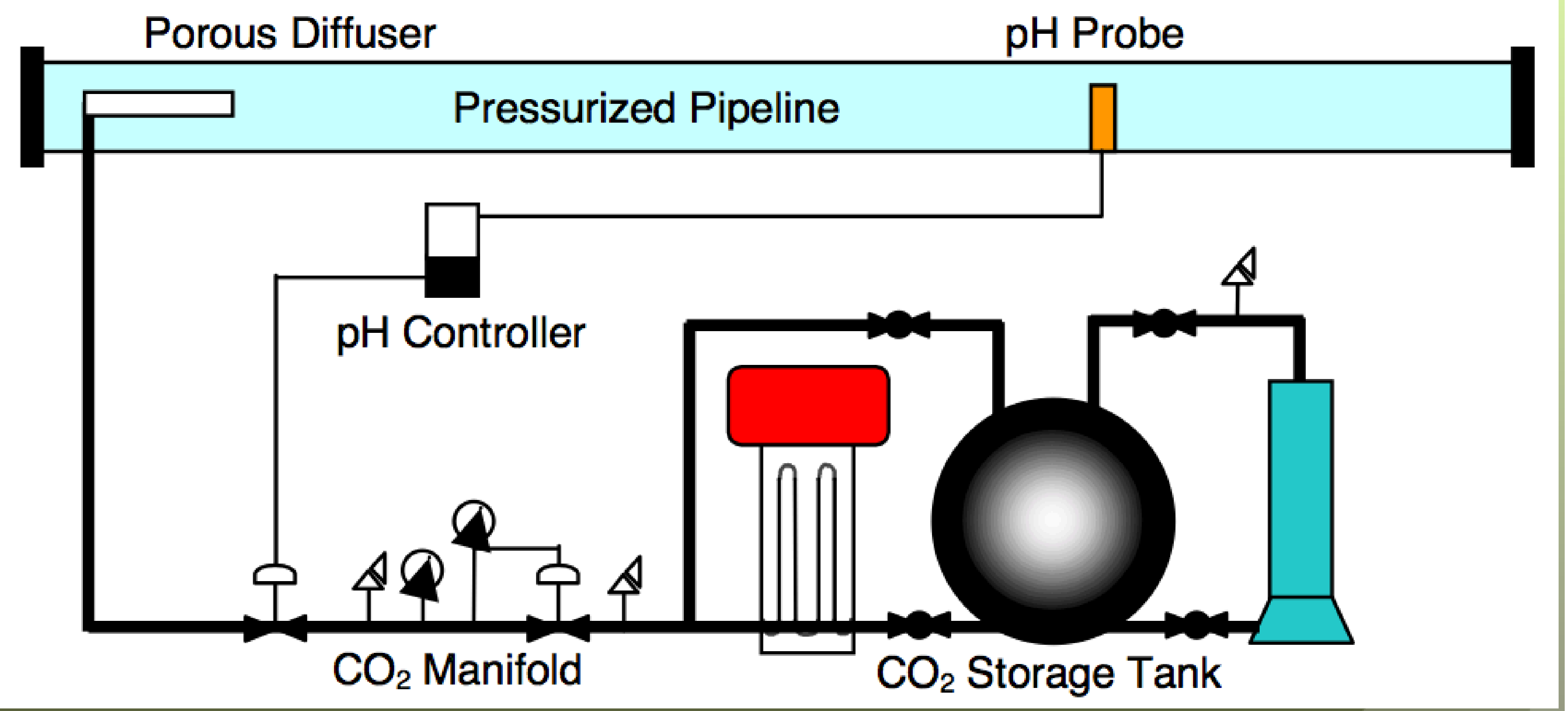
CO_2 Water Treatment: pH Control



- CO_2 is inert & non-corrosive
- Gradual pH level changes vs. rapid strong acid changes
- Secondary products are safe for the environment vs. mineral acids

Summary

- Abundant source of CO_2 in atmosphere
- Various uses for CO_2
- All greener methods than current methods
  - Readily available
  - No hazardous byproducts during usage
  - Can be used with existing systems and materials

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