



*the **energy** of innovation™*

Advanced Energy and Water Systems for Bioprocessing Plants

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Presentation Overview

Section 1 – Historical Perspective

Section 2 – Modern Ethanol Plant

Section 3 – Energy Trends

Section 4 – Water Trends



History of ethanol industry

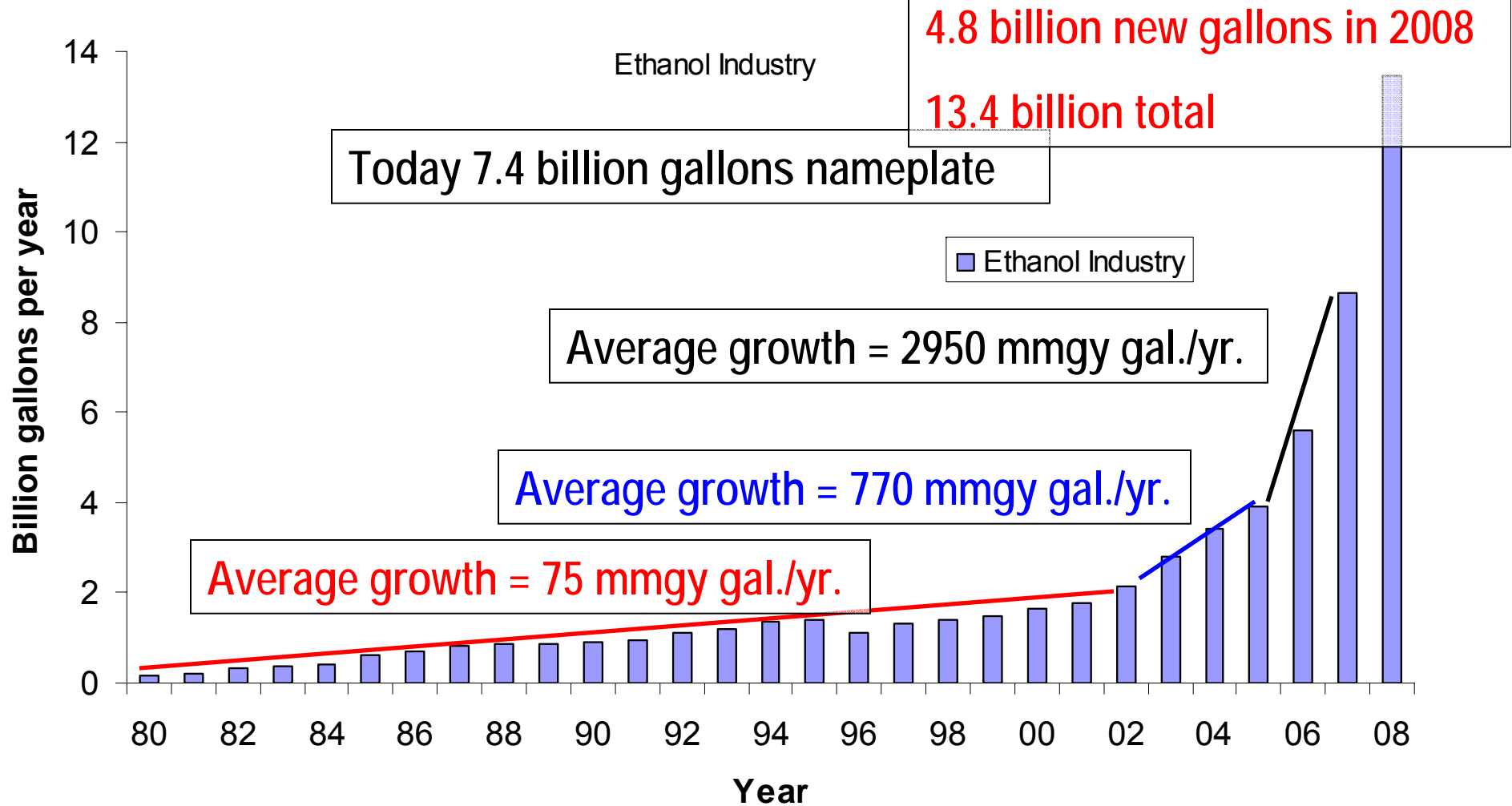
- Early 1980's <1 mmgpy
 - 1980: \$3.60/gal - NREL
- Today 50 mmgpy and 100 mmgpy plants
 - 2004: \$1.00/gal – NREL
 - 2006: \$1.50/gal – Bank number
 - \$2.45 corn, \$8 gas, labor, maintenance, capital
- 100 mmgy most popular size today
 - Ethanol: 2.8 gal/bushel corn
 - DDGS: 18 lbs/bushel corn
 - Over 36 million bushel corn/plant
 - 240,000 acres corn (150 bu/acre)





Ethanol Production Growth in the U.S.

Operating and under construction





Modern plant energy numbers

- Energy consumption dry grind ethanol plant
 - 20,000 BTU per gallon to produce fuel grade ethanol
 - Minimum energy demand fixed by distillation energy
 - Opportunity for additional heat integration
 - Cascade distillation
 - More capital expense
 - Lower up-time due to more complicated system
 - 12,000 BTU per gallon to dry 100% of DDGS
 - Most expensive energy here
 - Difficult to use energy cascade
 - 0.75 kW electrical for 100% dry DDGS
- 3 to 4 gallons water per gallon ethanol



“New” energy systems

- On-site electrical production
 - Steam let-down turbine
 - Using current steam pressure
 - Good for 20% of electrical demand
 - Steam let-down turbine
 - Using high pressure boiler 400psi
 - Good for another 20% of electrical demand
 - Steam let-down turbine to run the entire plant
 - Theoretical 3100 BTU steam pressure/gallon
 - 83% boiler efficiency
 - Actual will be higher because of 2nd law of thermodynamics



“New” energy systems

- Solids fuel burners
 - Fiber ~ 8000 BTU/lb bone dry
 - Stover ~ 7500 BTU/lb bone dry
 - Bubbling bed system
 - Used primarily for coal-to-steam
 - Can be used for other solid fuels
 - Corn stover or other biomass types
 - Lincolnway and CVEC plants
 - Producer gas system
 - Pyrolysis-to-steam
 - Friendly to biomass fuels
 - Little Falls, MN; St Joseph, MO
- Increased emissions are a reality to deal with
 - No fuel burns as clean as CH₄
 - **SOx, NOx, PM**, CO and VOC
 - CO₂ emissions higher because fuel pre-oxidized



“New” energy systems

- Integrated dryer/boiler
 - Superheated steam to ring dryer
 - Energy production acts at TO for emission control
 - ~6 second residence time DDGS in ring
 - Saturated or near saturated steam from dryer
 - Integration of waste dryer steam for augmentation of plant steam needs
 - Ethanol + drying cost estimate 26,000 BTU/gallon
- Water use potentially 1.5 gallons/bushel
 - Recover water from dryer back in process
- Highly integrated system
 - Reliability not proven
 - “Downtime costs the industry more than anything else”



“New” energy sources

- Stover for dry grind steam demand = ~15 lbs/bushel
 - ~30% of stover for acreage supplying plant
- Dry fractionation
 - 20,000 BTU for ethanol production
 - 4,000 BTU for drying 100% HPDDGS
 - ~4.7 lbs fiber per bushel
 - ~4 lbs “solubles” per bushel
- Fiber
 - Combustion equivalent of ~9,600 BTU/gallon
- Anaerobic digestion
 - “Thin stillage” digestion ~8,000 BTU/gallon
- Remaining energy need
 - $24,000 - 17,600 = 6,400$ BTU/gallon
 - Can be met with ~1 lbs/gallon stover (or less)
 - ~3 lbs/bushel processed
 - ~5% of stover for acreage supplying plant



Anaerobic digestion

- Consortium culture
 - Converts organic matter to $\text{CH}_4 + \text{CO}_2 + \text{H}_2\text{O}$
 - Many different bacteria species acting synergistically
 - The end-products of one class of bacteria are used by next class
- Upflow Anaerobic Sludge Blanket (UASB)
 - Hydraulic Retention Times (HRT) measured in hours
 - 8 to 12 hours
 - Load rates generally 10+ g/L/day COD (max 16 g/L/day)
 - Cannot handle suspended solids well
- Big Volume Fermenters (BVF)
 - HRT generally measured in days
 - 15 to 20 days common
 - Need large HRT because culture moves with water
 - Washout a problem with shorter HRT
 - Load rates generally 1 g/L/day COD
 - More tolerant to suspended solids



“New” energy sources

- “Closed loop” feedlot systems
 - Feed wet DDGS to on-site cattle production feedlot
- Anaerobic digestion for energy need
 - Need ~4 lbs digestible material per gallon processed
 - Digestion of thin stillage will account for 1.4-2.2 lbs
 - Feedlot produces 5 to 6 lbs solids per animal per day
 - Digest manure only need 0.73 head per gallon per day
 - 10 MMGY facility would need ~20,000 head lot
 - Digest thin stillage and manure need 0.36 head per gallon per day
 - 10 MMGY facility would need ~10,000 head lot
- Due to size of feedlot this is restricted to smaller facilities



“New” energy sources

- Issues with anaerobic digestion
 - Water after digestion, what to do with it
 - Probably can't take it back to the plant
 - Need a place to discharge this
 - Irrigation only practical half of the year or less
 - Takes plant out of zero discharge status
 - H₂S production
 - Virtually all SO₄²⁻ converted to H₂S
 - Need to scrub biogas prior to combustion
 - NH₃ production
 - In BVF proteins converted to NH₃
 - Need to find proper place to put water



Water use in perspective

- Dairy cow uses 35 gallons of water a day
- Feedlot animal uses 15 gallons of water a day
- Human uses 150 gallons of water a day
- 100 million gallon ethanol plant uses enough water to irrigate about 800 acres of corn in Kansas
- Gallon of ethanol requires 3 to 4 gallons of water
- Gallon of gasoline requires ~8 gallons of water

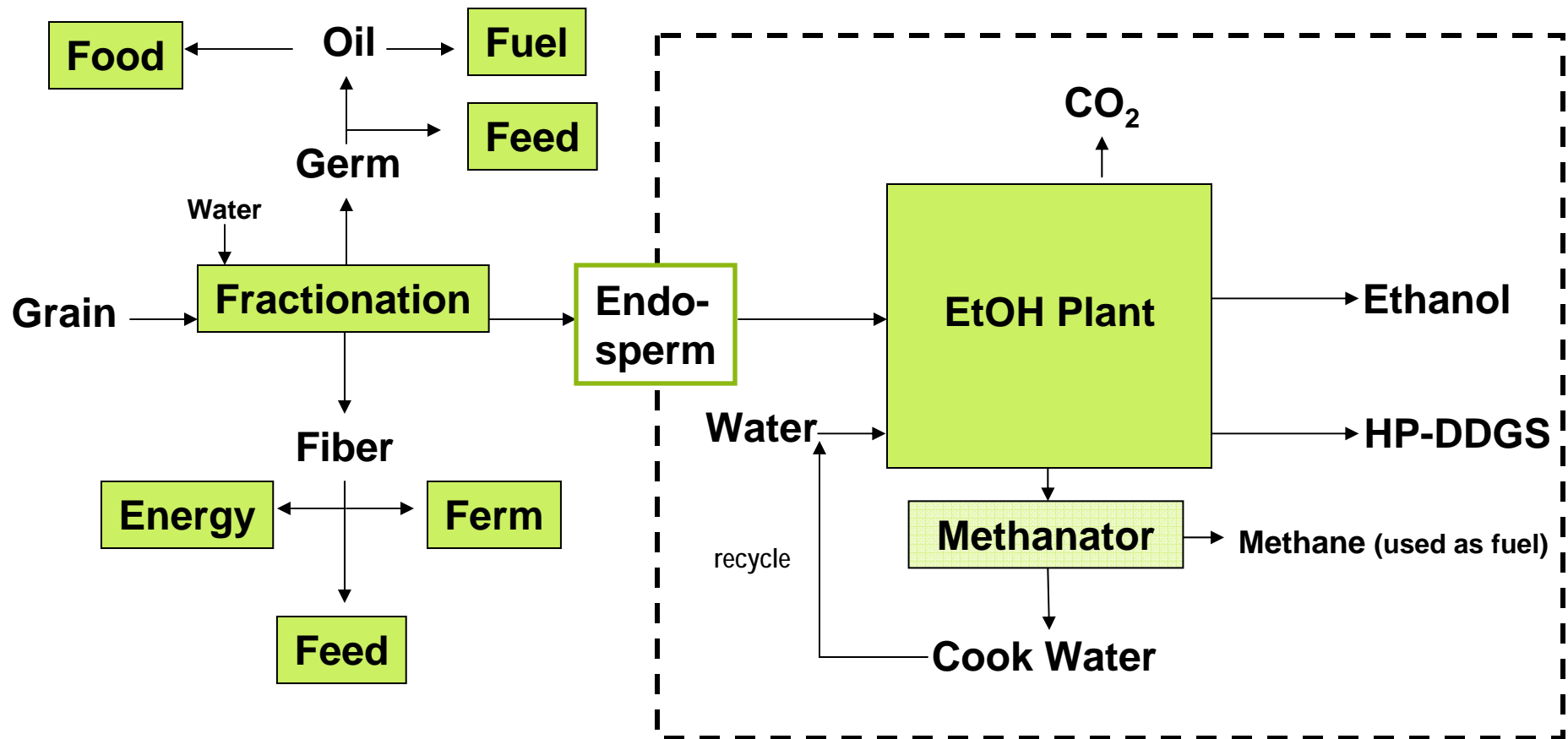


Water use trends

- Zero discharge plants
 - No process water discharge
 - Current industry standard
- Poorer quality water at new construction sites
- High efficiency RO systems
 - Produce more clean water per gallon processed
- Grey water
 - Water previously used
- Zero liquid discharge systems
 - Significant capital expenditure
 - Crystallizers
- New technology for recovering water during drying



Near-Term Ethanol Plant





Questions