Municipal Solid Waste:
A Solution to the Growing Problem

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Purpose

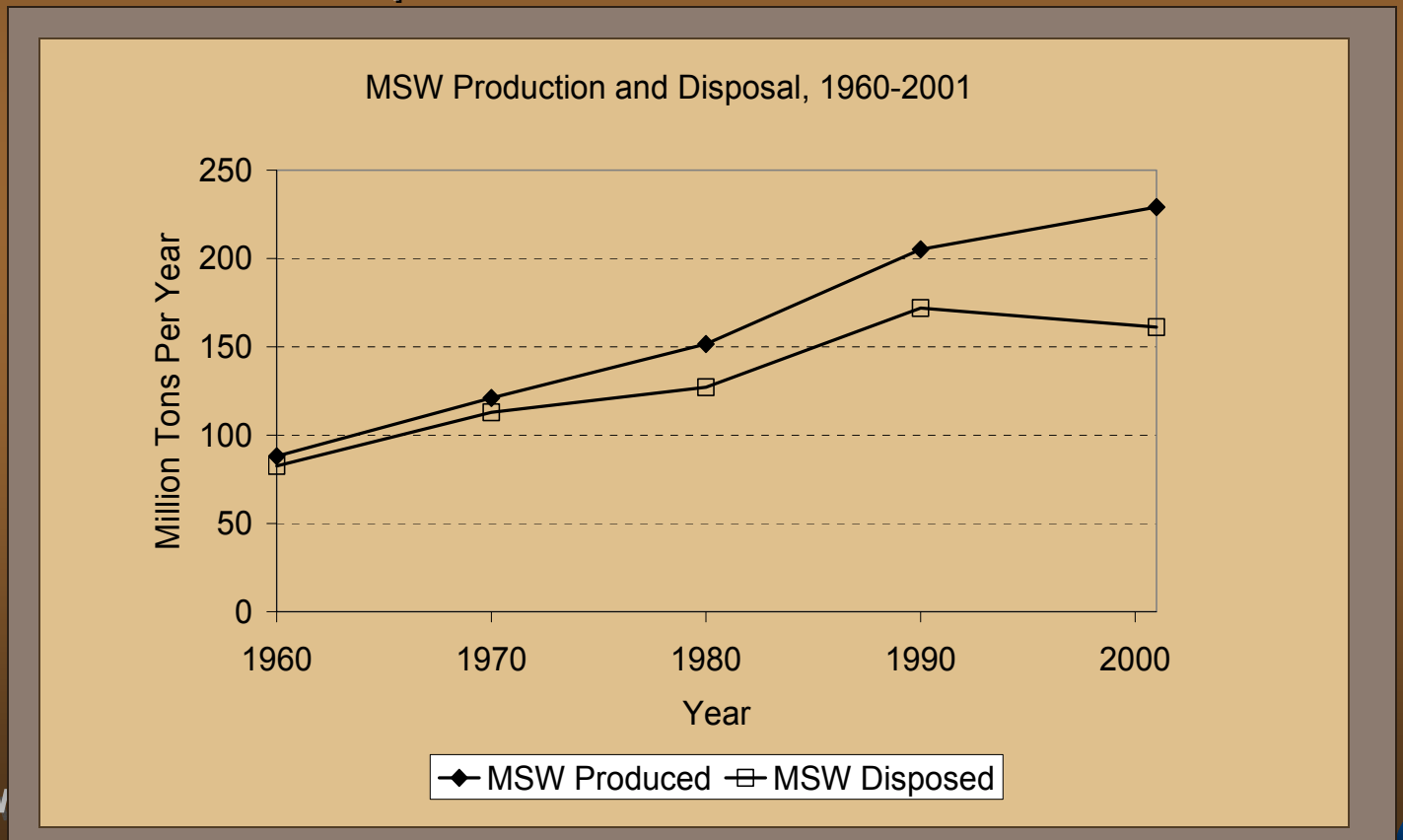
- Investigate and select an alternative method of MSW disposal
- Design a waste processing plant
- Advance the previous deterministic model to optimize a construction and expansion timeline
- Select a feasible investment strategy

Today's Agenda

1. MSW in the United States
   - City selection
   - Waste disposal methods
2. Pyrolysis Processing Plant
3. Producing Hydrogen from Synthetic Gas
   - Other possible end products
4. MSW Processing Plant Capital Costs
5. Deterministic Model
6. Results
7. Ownership

Background

- Municipal Solid Waste in the United States
  - Composition
  - Waste Disposal



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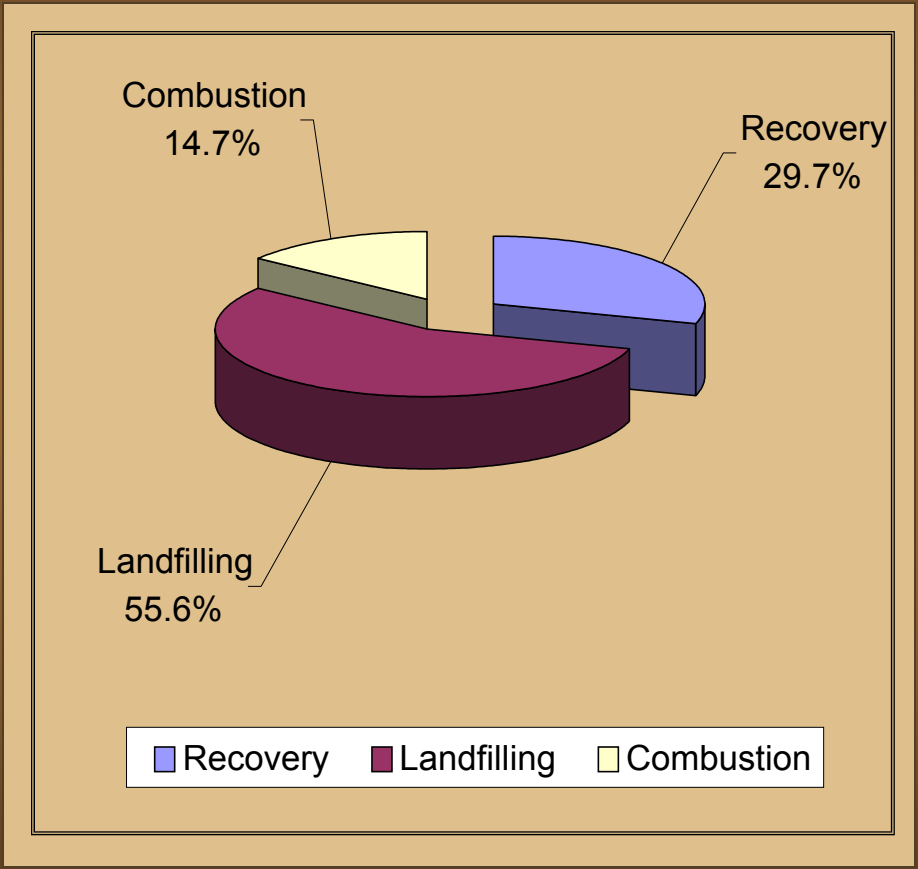
Waste Disposal in the U.S.



- Close to 210 million tons of MSW per year
- Methods
  - Landfilling
  - Incineration
  - Pyrolysis
  - Recycling

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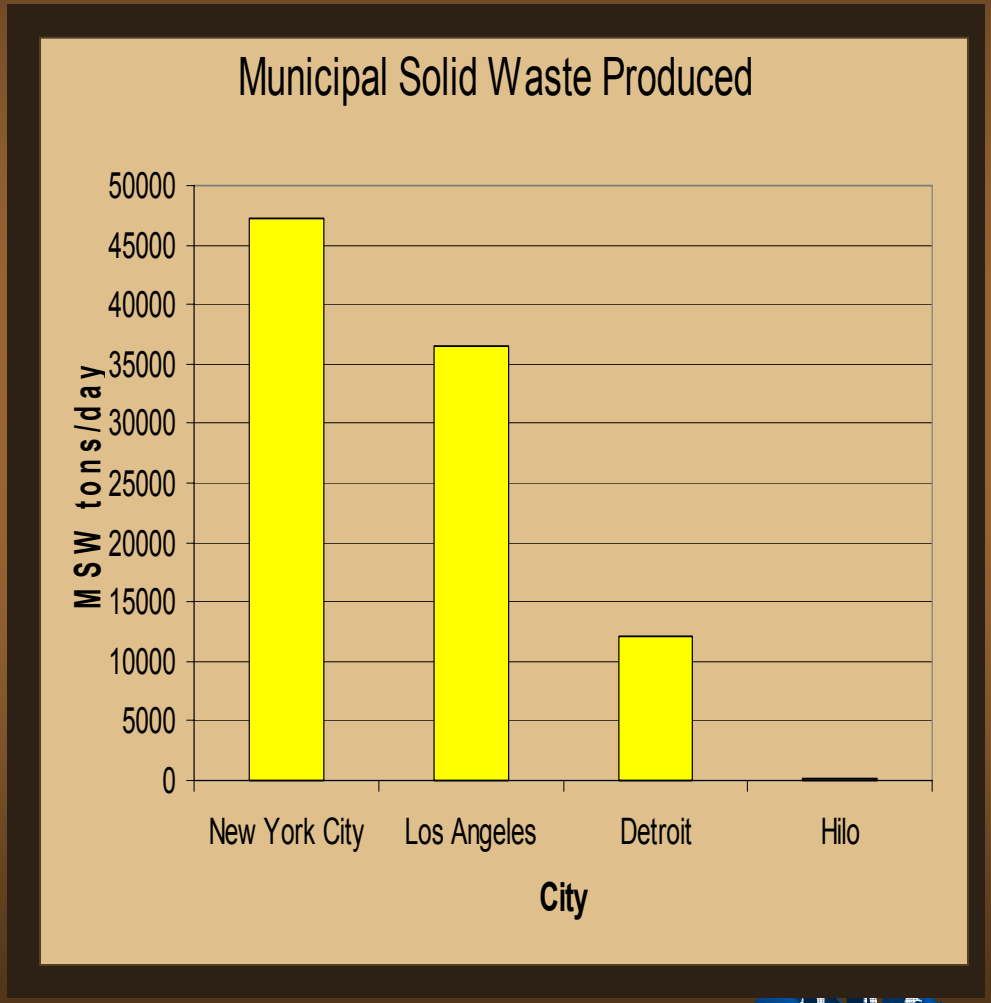
City Selection

- Cities Considered:
  - New York City, New York
  - Los Angeles, California
  - Detroit, Michigan
  - Hilo, Hawaii
- Basis of Analysis
  - Amount of MSW produced
  - Population and Population growth
  - Cost of current disposal method

Municipal Solid Waste Produced

- Total MSW Generation
- Recycling Rates
- Waste Disposal Methods
  - NYC—Transporting MSW
  - Detroit—Incineration and Landfilling
  - Hilo—Transporting MSW and Landfilling
  - Los Angeles—Landfilling



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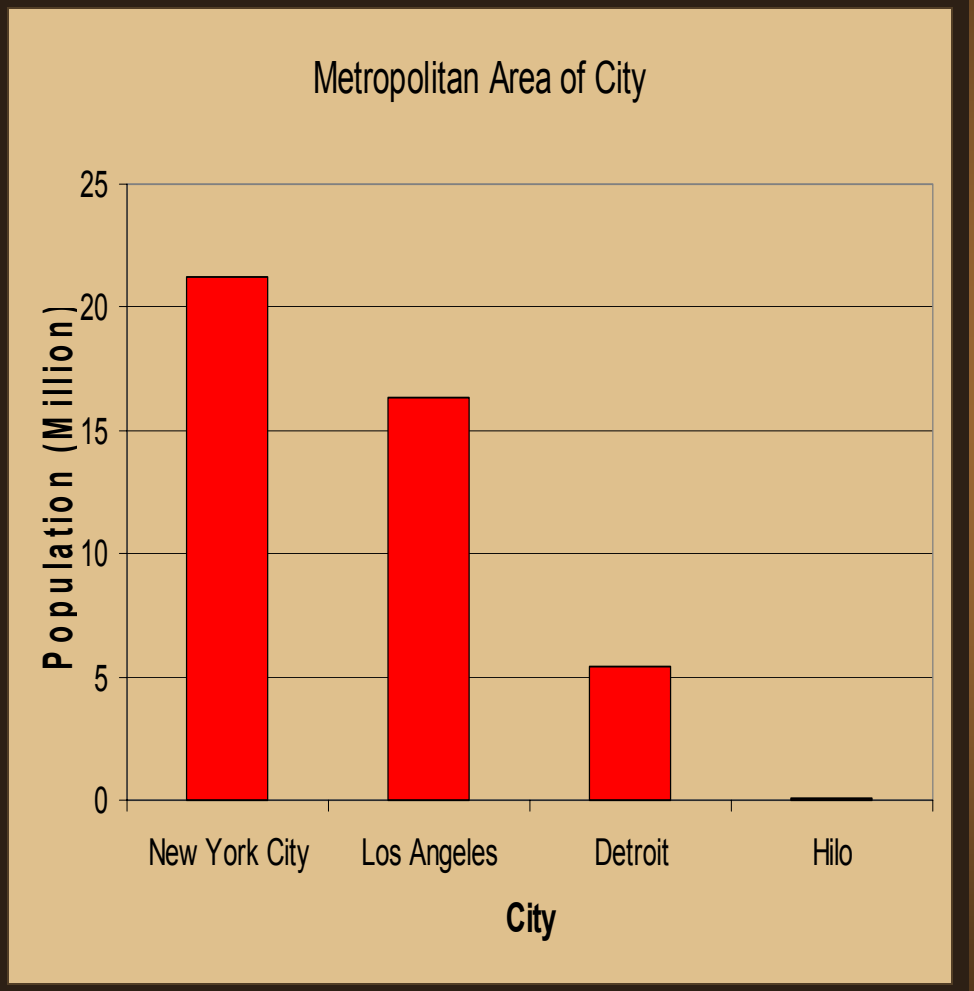
Population



- Metropolitan Area Populations
- NYC has largest metropolitan population
- Hilo has a population under a million

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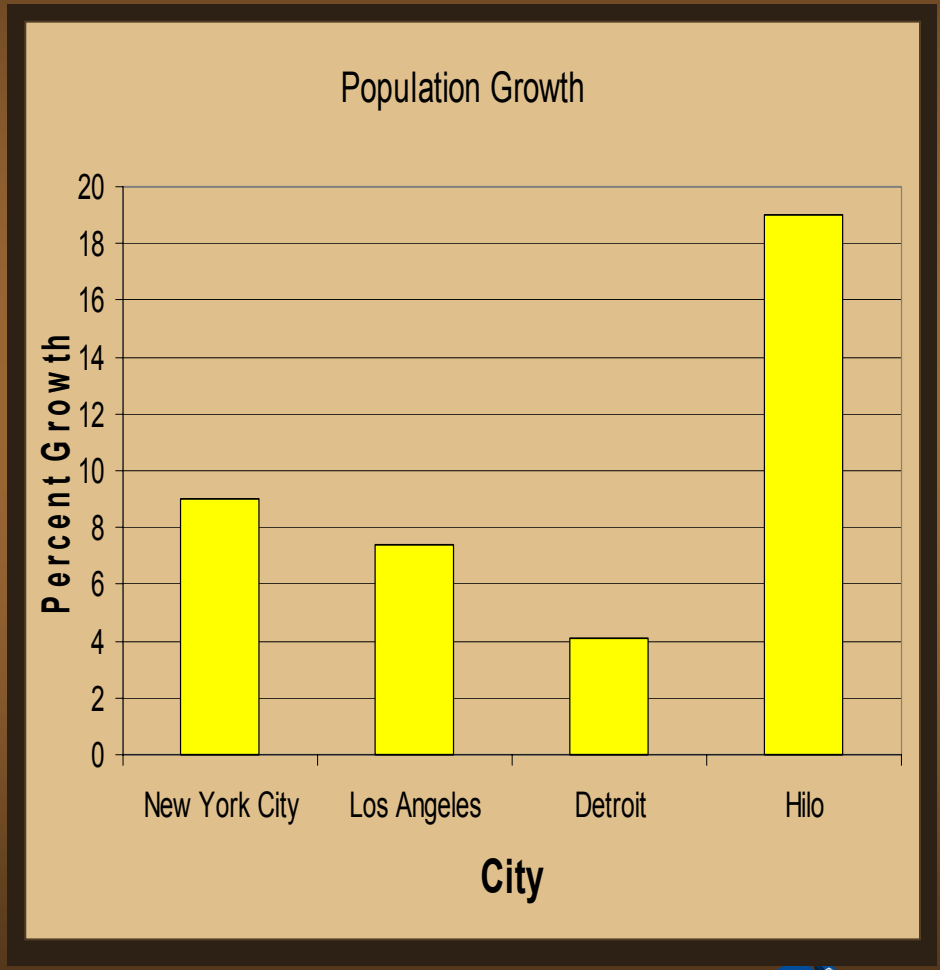
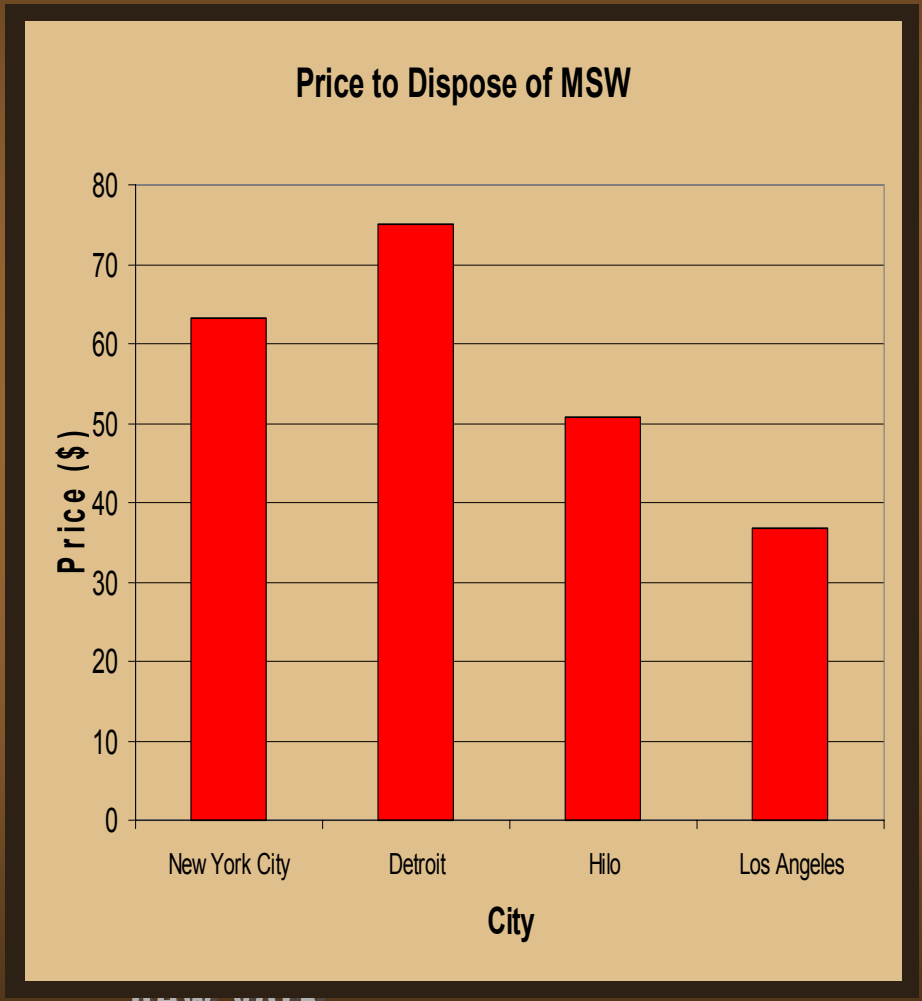
Population Growth

- Hilo has the largest population growth but very small population
- New York also has large population growth
- Detroit has smallest population growth



Price to Dispose of MSW



- Average Prices
- New York Fresh Kills Landfill Closed—Transporting Waste Out of State
- Cost of Incineration High
- Hilo Running Out of Space
- West Coast Has More Space than East Cost

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Location Choice…

- New York City:
  - Price to Dispose of MSW: $63.30
  - Population of Metropolitan Area: 22 million
  - Amount of MSW in Metro: 46,000 tons/day
  - Landfilling in NYC
    - Prevention of landfilling in high density NYC
    - 9 private and 23 public landfills—capacity of 60 million tons
    - 17 companies with three year base contracts and two 1 year extensions

Disposal Methods

- Methods Considered
  - Landfilling
  - Incineration
  - Pyrolysis
- Basis of Analysis
  - Cost to build and operate
  - Environmental Concerns
  - Production of Products

Landfilling

- Advantages
  - Small Capital Investment
  - Little Maintenance
  - Cheaper Disposal Fees
- Disadvantages
  - Environmental Pollution
    - Methane Carbon Dioxide
    - Leachate
  - Property Decrease in Value

Source: http://www.zerowasteamerica.org/Landfills.htm

Incineration

- Advantages
  - Minimizes Landfill Volume
  - Recovery of Energy
- Disadvantages
  - High Building and Operation Costs
  - Air Emissions
  - Toxic Ash

Source: http://www.meniscusclients.com/portfolio/cwa/tech_info.htm

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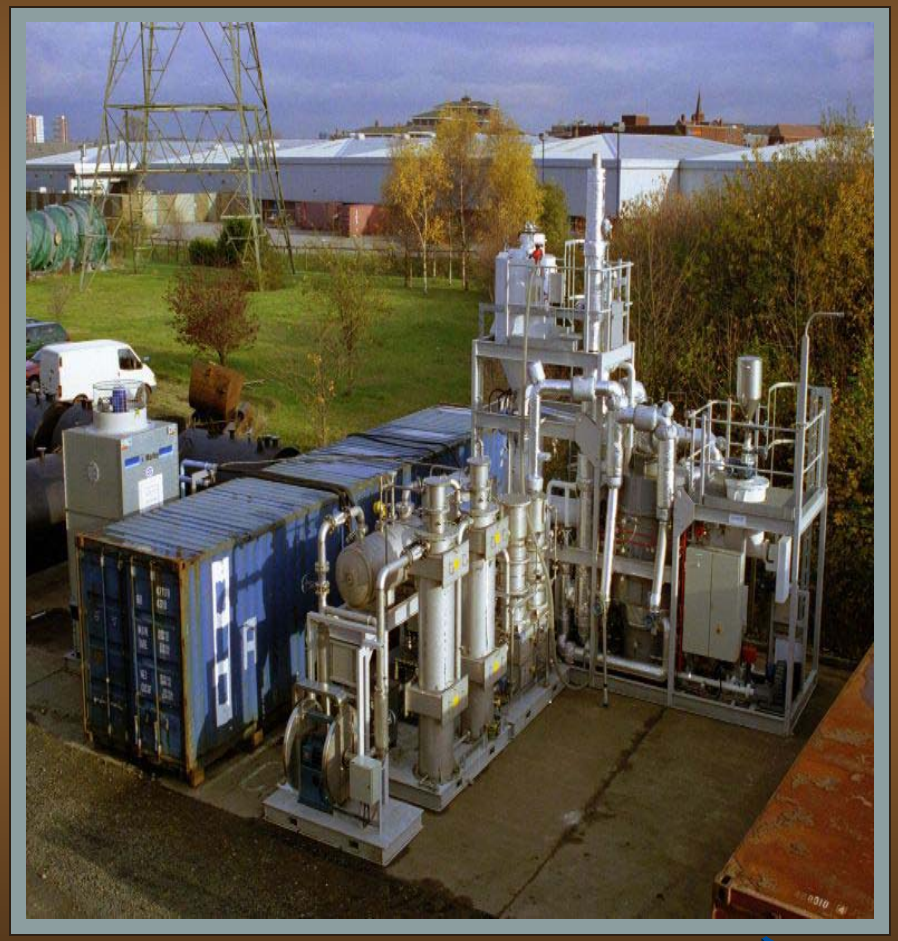
Pyrolysis

- Advantages
  - Minimizes Landfill Volume
  - Recovery of Energy
  - Production of Synthetic Gas
- Disadvantages
  - Air Emissions—
  - Leachate
  - Slag—Landfilled or used in road foundations



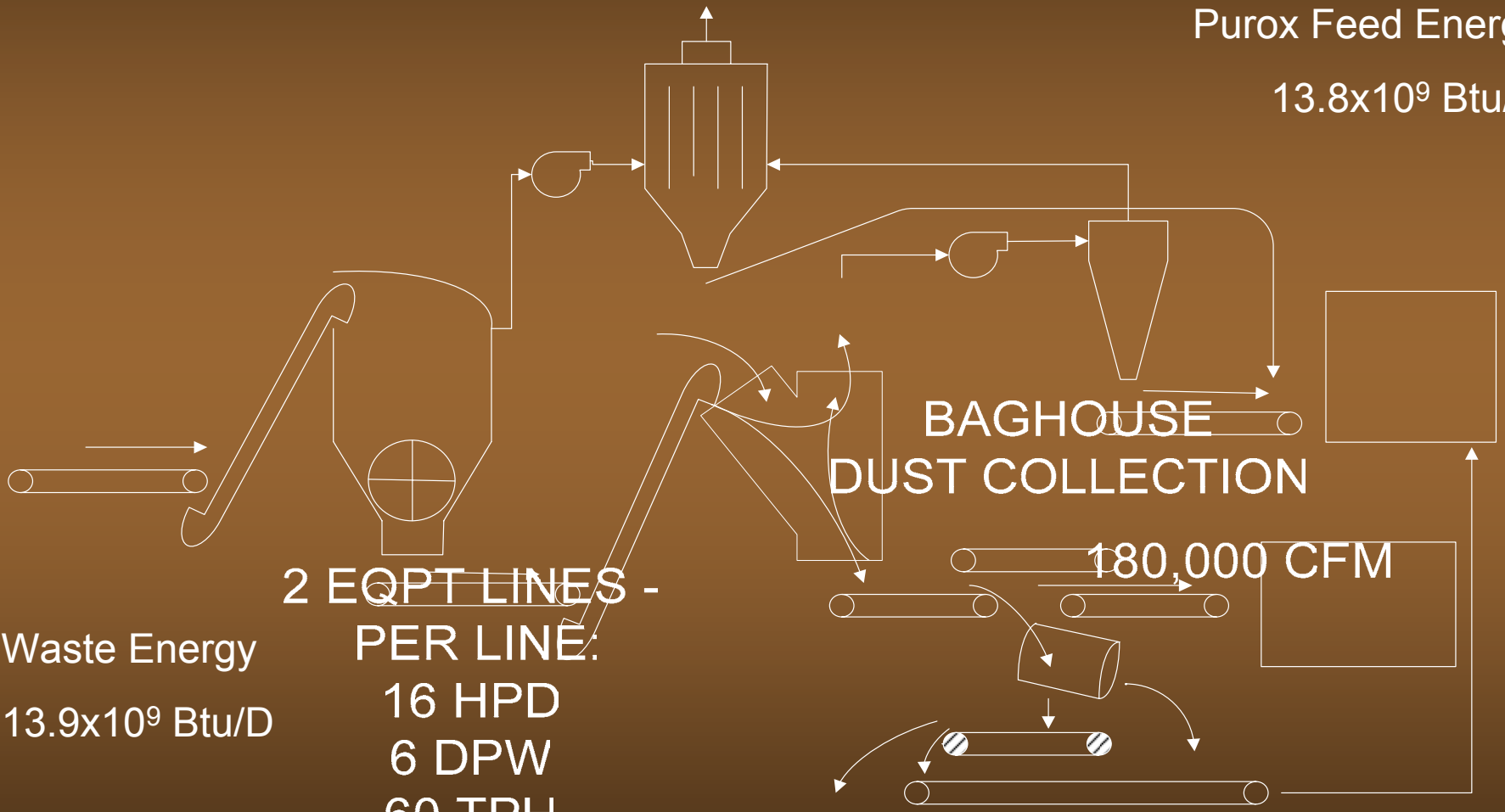
Method Choice…

- Pyrolysis
  - Land Constraints in NYC
  - Production of Syngas
    - Mixture of CO, CO_2 and H_2
    - Can lead to production of synthetic fuels, hydrogen, ammonia, alcohols, aldehydes, carboxylic acids

Pyrolysis Process

- Why Separate Before Pyrolysis?
  - Enhance Profit / Reduce Costs
    - Sell Recyclable Metals; Low Heat Value
    - Reduce Wear and Tear on Equipment
    - Easier Than Separation After Pyrolysis
  - Control Refuse Properties
    - Slag Seals Refuse if Proper Proportions

Front End Separation



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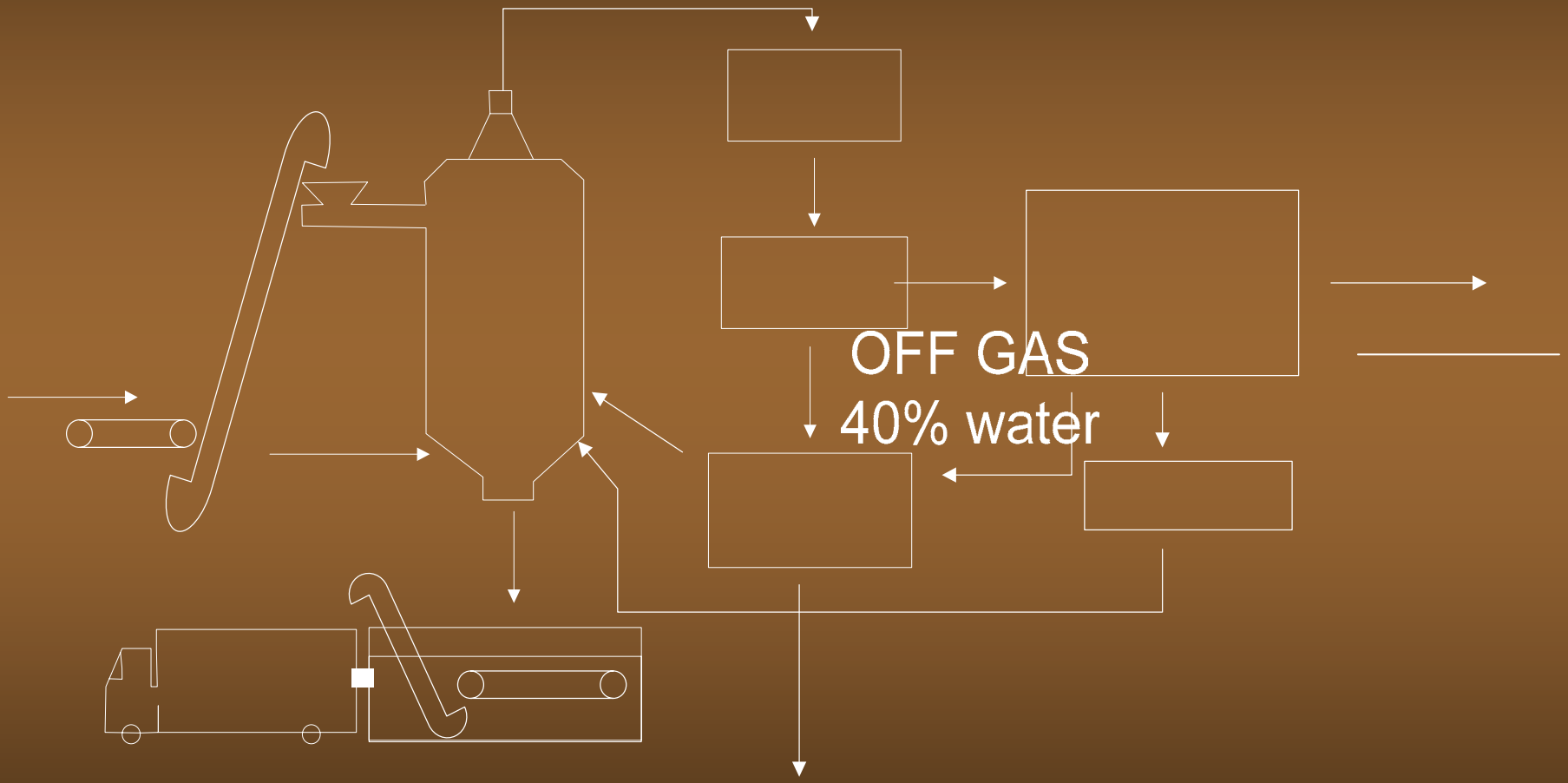
FRONT END

CEMs
AIR

Purox Pyrolysis Facility



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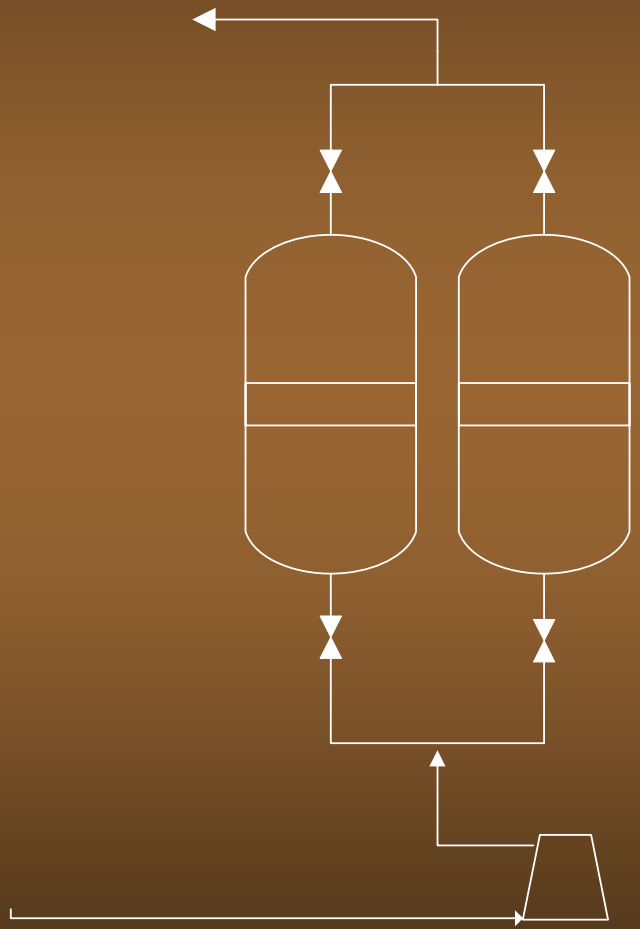
RAM
FEED

PUROX
REACTOR

CEMs

Desulfurization



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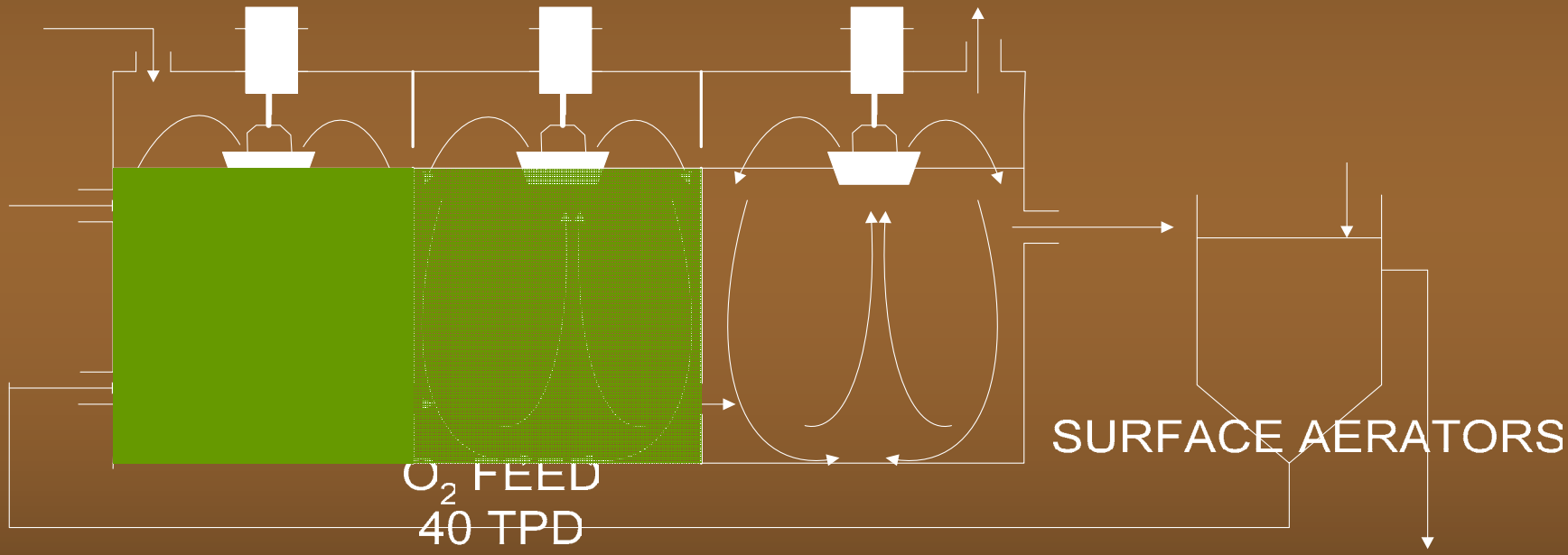
~450°C

Wastewater Plant



WASTE WATER
480 TPD
700 GPM
50,000 mg/L BOD

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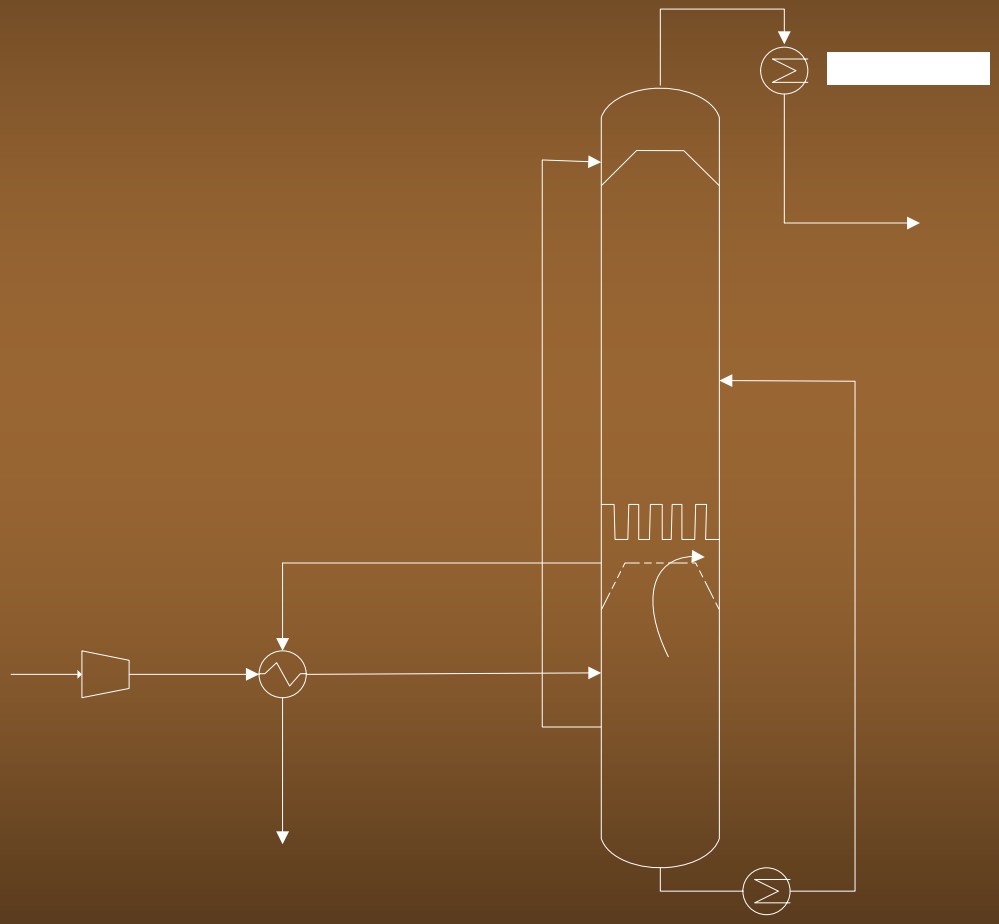
Oxygen Plant



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Oxygen Plant (cont.)

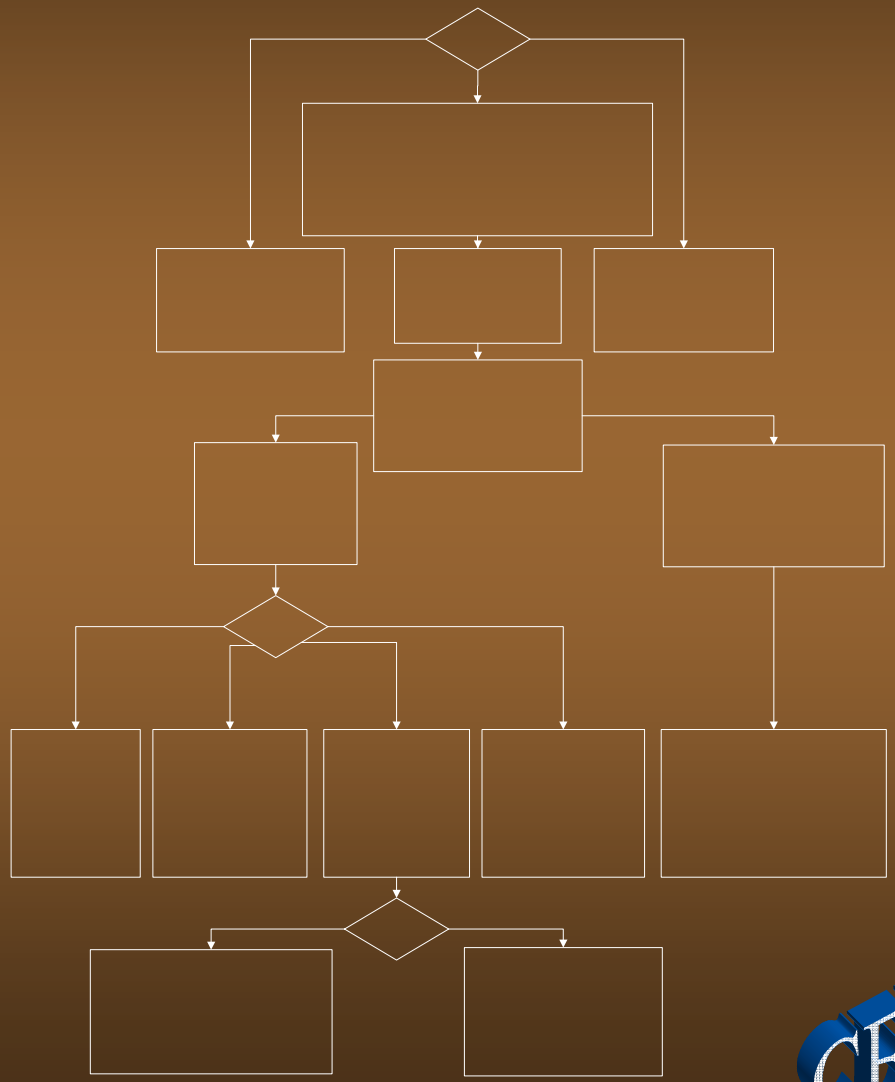
- Air Separation
  - 78.1% N_2, 20.9% O_2, 0.934% Ar, 0.035% CO_2
- 280 TPD O_2 = 1 Purox Reactor
- Equipment: Compressor, Heat Exchanger, Distillation Columns

Oxygen Plant (cont.)

- Purpose:
  - Eliminate Nitrous Oxides
    - Environmental aspects
  - Increases concentration of reactants
  - Raise reactor temperature to effectively destroy toxins

End Product Possibilities

- Hydrogen
- Ammonia
- Polycarbonates
- Synthetic Fuel
- Methanol
- Dimethyl Ether
- Acetic Acid



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End Product Possibilities

- **Hydrogen**

  Uses: fuel cells, alternative fuels, petroleum industry applications

  (1) $CH_4 + 2\ H_2O \leftrightarrow 4\ H_2 + CO_2$

  (2) $CO + H_2O \leftrightarrow CO_2 + H_2$

  Sale Price: $2500/ton

End Product Possibilities

- **Ammonia**

  Uses: fertilizers, refrigeration, processing

  $N_2 + H_2 \rightarrow 2\ NH_3$

  Sale Price: $200/ton

  -using H_2 ($2500/ton) and N_2 ($160/ton)

End Product Possibilities

- **Polycarbonates**

  Uses: drink bottles, CD/DVD substrates, audio/video cassettes

  (1) $CO_2 + H_2 \rightarrow CO + H_2O$

  (2) $2\ NaCl + CO \rightarrow 2\ Na + Phosgene$

  (3) $Phosgene + bisphenyl\text{-}A \rightarrow Polycarbonate + 2\ HCl$

  Sale Price: $66/ton (HCl $72/ton)

  -using H_2 ($2500/ton)

  -using bisphenyl-A ($2000/ton) and NaCl ($46/ton)

End Product Possibilities

- **Synthetic Fuel**

  Uses: diesel fuel, waxes

  $CO + 2\ H_2 \rightarrow CH_2 + H_2O$

  Sale Price: $630/ton

  - using H_2 ($2500/ton)

End Product Possibilities

- **Methanol**

  Potential Uses: MTBE, DME,

  (1) $CO + H_2O \rightarrow CO_2 + H_2$

  (2) $CO + 2H_2 \rightarrow CH_3OH$

  (3) $CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$

  Sale Price: $254/ton

  - using H_2 ($2500/ton)

End Product Possibilities

- **Dimethyl Ether**

  Uses: alternative fuel (developing countries)

  (1) $3\ CO + 3\ H_2 \rightarrow CH_3OCH_3 + CO_2$

  (2) $2\ CO + 4\ H_2 \rightarrow CH_3OCH_3 + H_2O$

  Sale Price: $109/ton

  - using H_2 ($2500/ton)

End Product Possibilities

- **Acetic Acid**

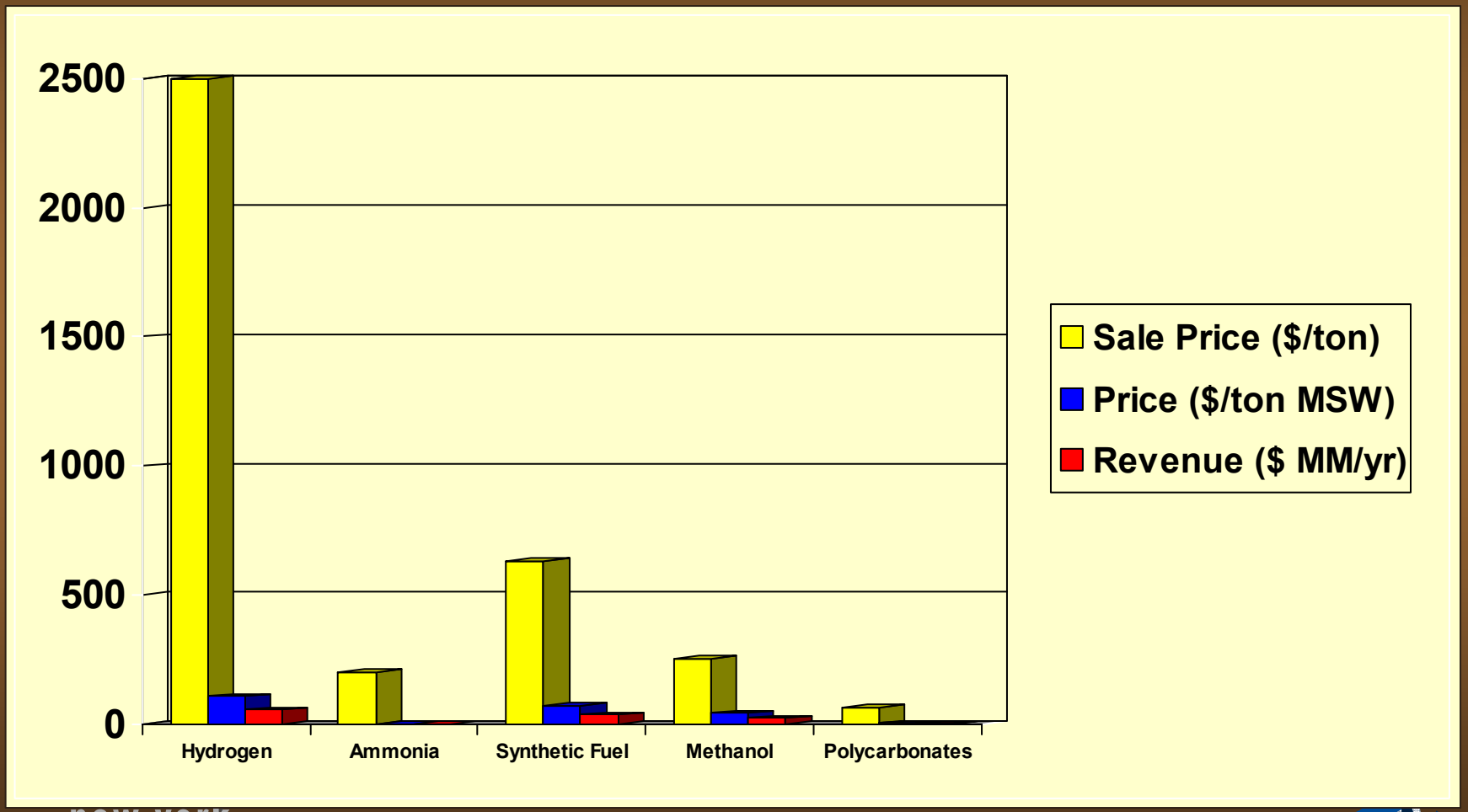
  Uses: photo film, vinyl acetate, vinegar

  $CH_3OH + CO \rightarrow CH_3COOH$

  Sale Price: $800/ton

  - results from CH_3OH that results from H_2 ($2500/ton)

End Product Comparison



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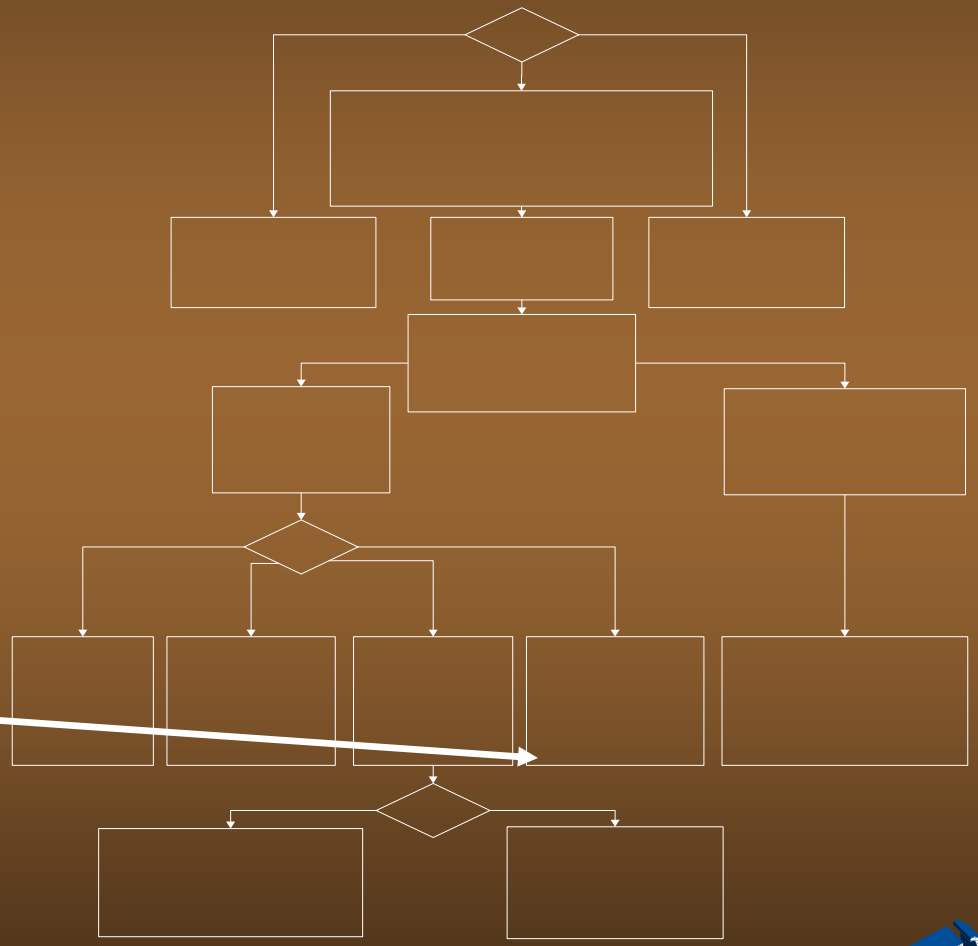
Product Possibilities

- Ammonia
- Polycarbonates
- Synthetic Fuel
- Methanol
- Dimethyl Ether
- Acetic Acid
- Hydrogen



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Synthetic Gas

Component	Composition
H_2	12.5%
CO	20.8%
CH_4	5.7%
H_20	47.9%
CO_2	12.5%
N_2	0.6%

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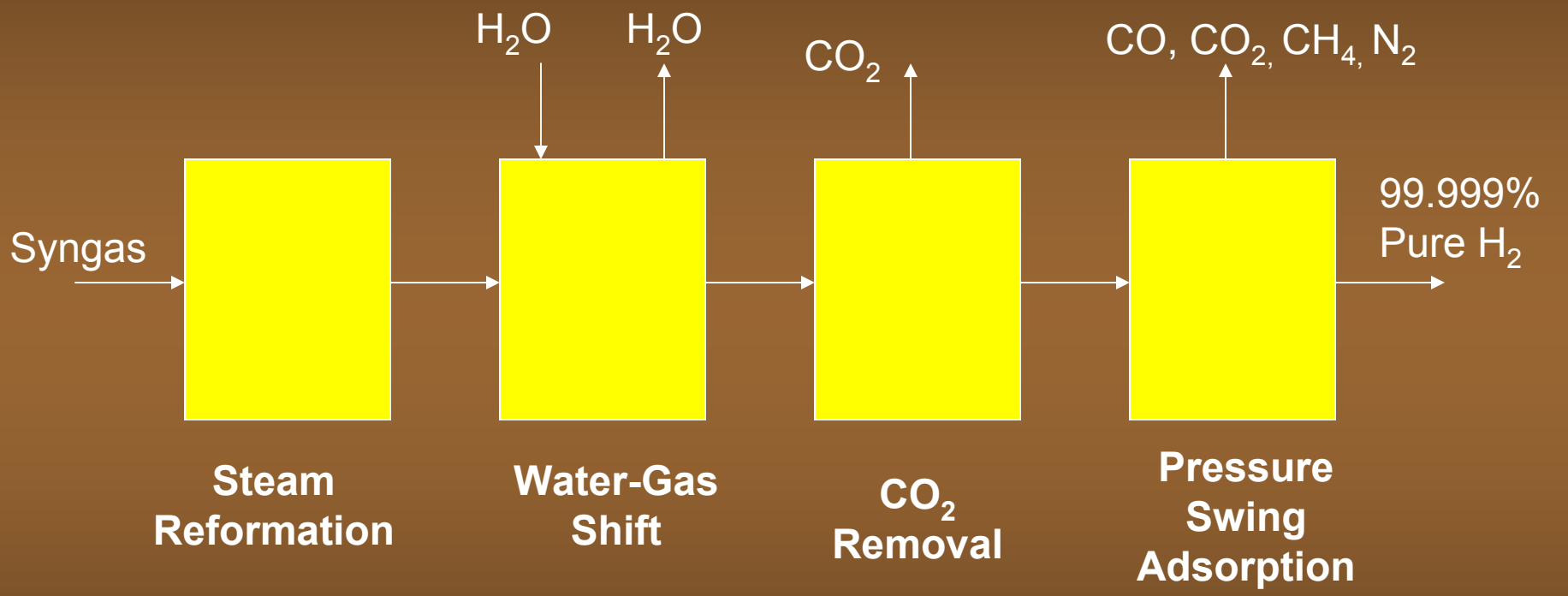
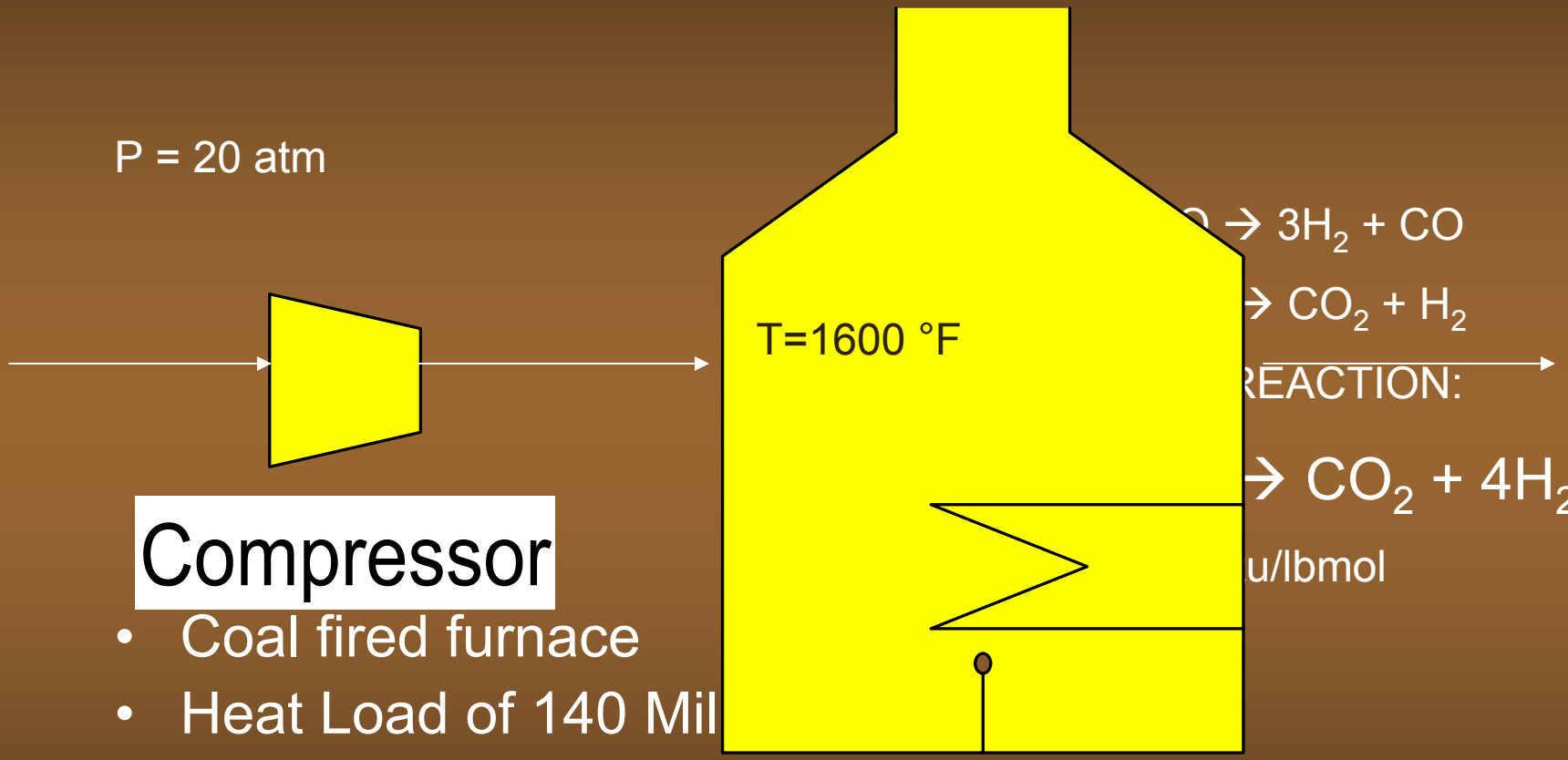
Hydrogen Plant



Steam Reformation

33.8 MM Btu/hr

P = 20 atm



$\rightarrow 3H_2 + CO$

$\rightarrow CO_2 + H_2$

REACTION:

$\rightarrow CO_2 + 4H_2$

u/lbmol

Compressor

- Coal fired furnace
- Heat Load of 140 Mil
- Steam:Methane = 8
- 170 tubes, 5-in ID,

Reformer Furnace

- 380,000 lbs Nickel-Alumina Catalyst

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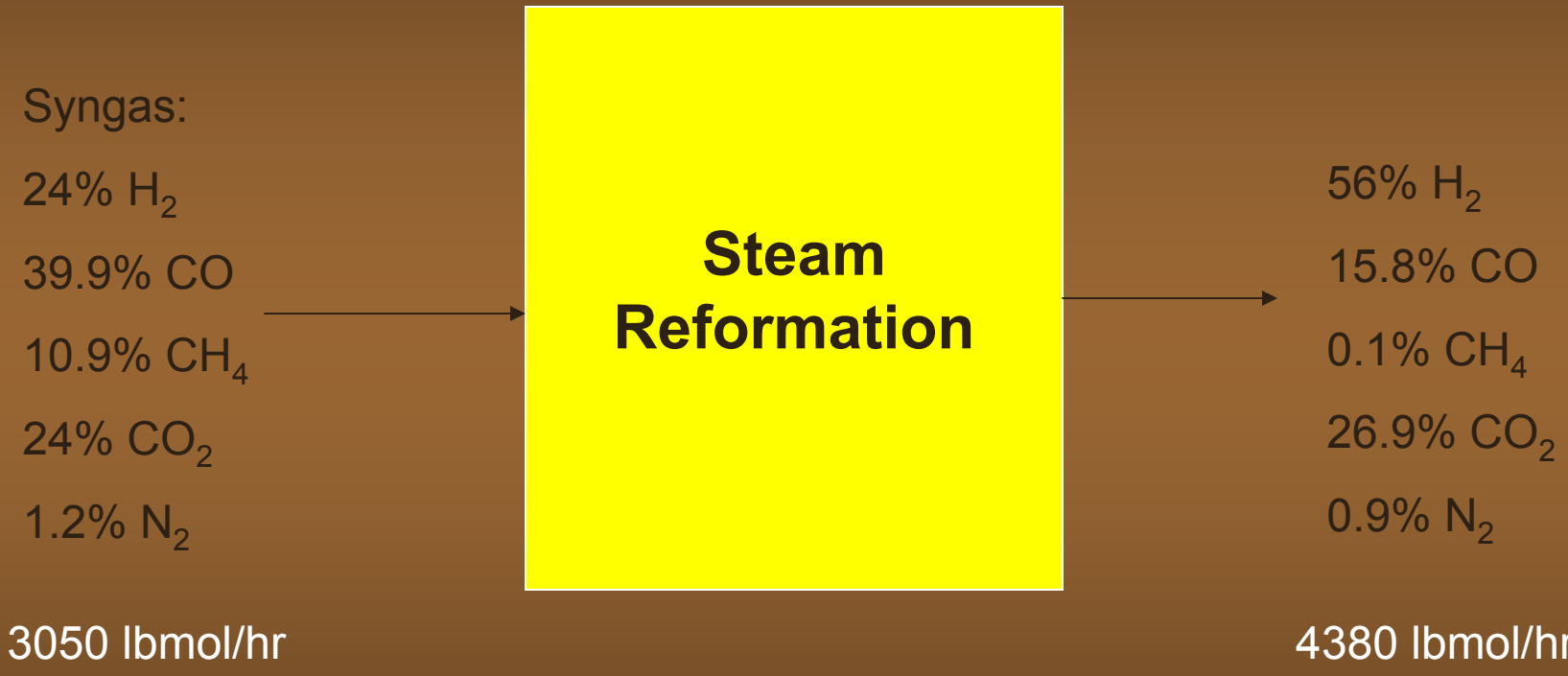
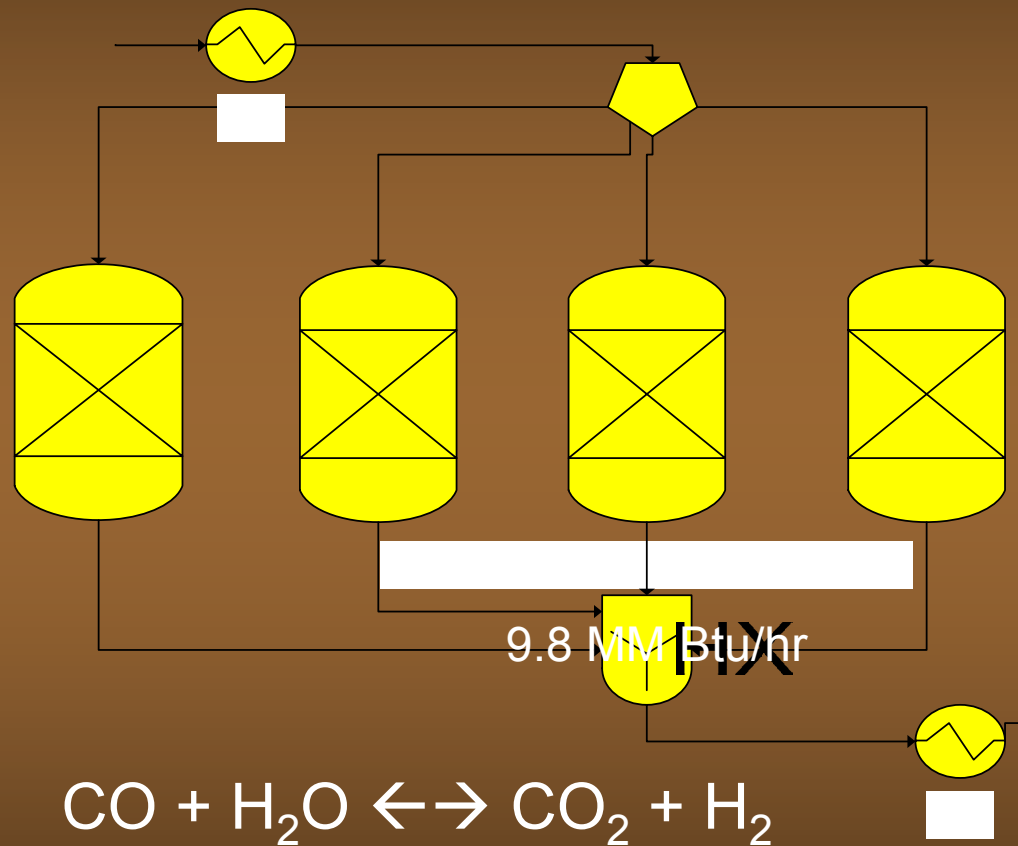
Hydrogen Plant



Water-Gas Shift

36.8 MM Btu/hr



$$CO + H_2O \leftrightarrow CO_2 + H_2$$

- 300,000 [redacted] mia-promote[redacted]talyst
- Steam:CO = 8
- 4 X 36ft reactors
  - 100 tubes
  - 3-in ID
- 2 X Heat Exchangers
- Flash Drum

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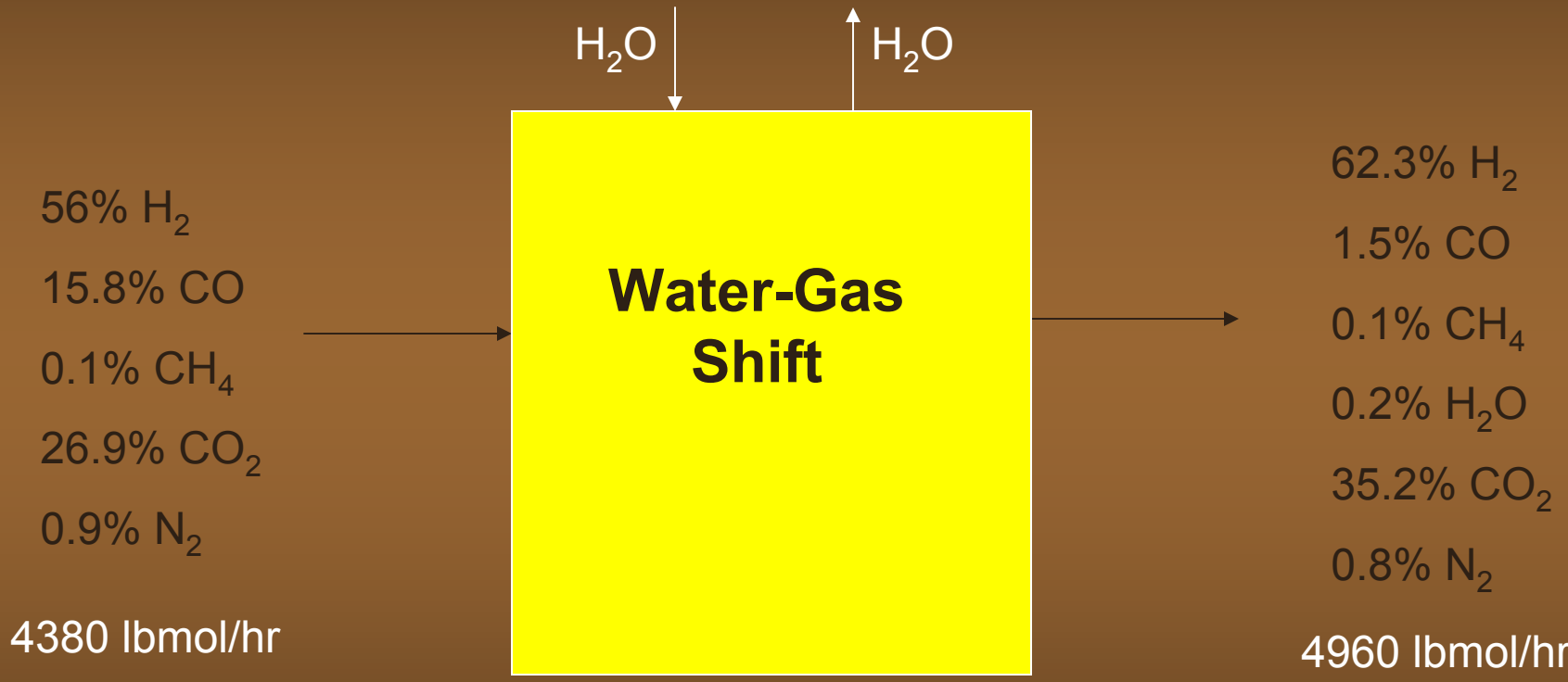
Hydrogen Plant



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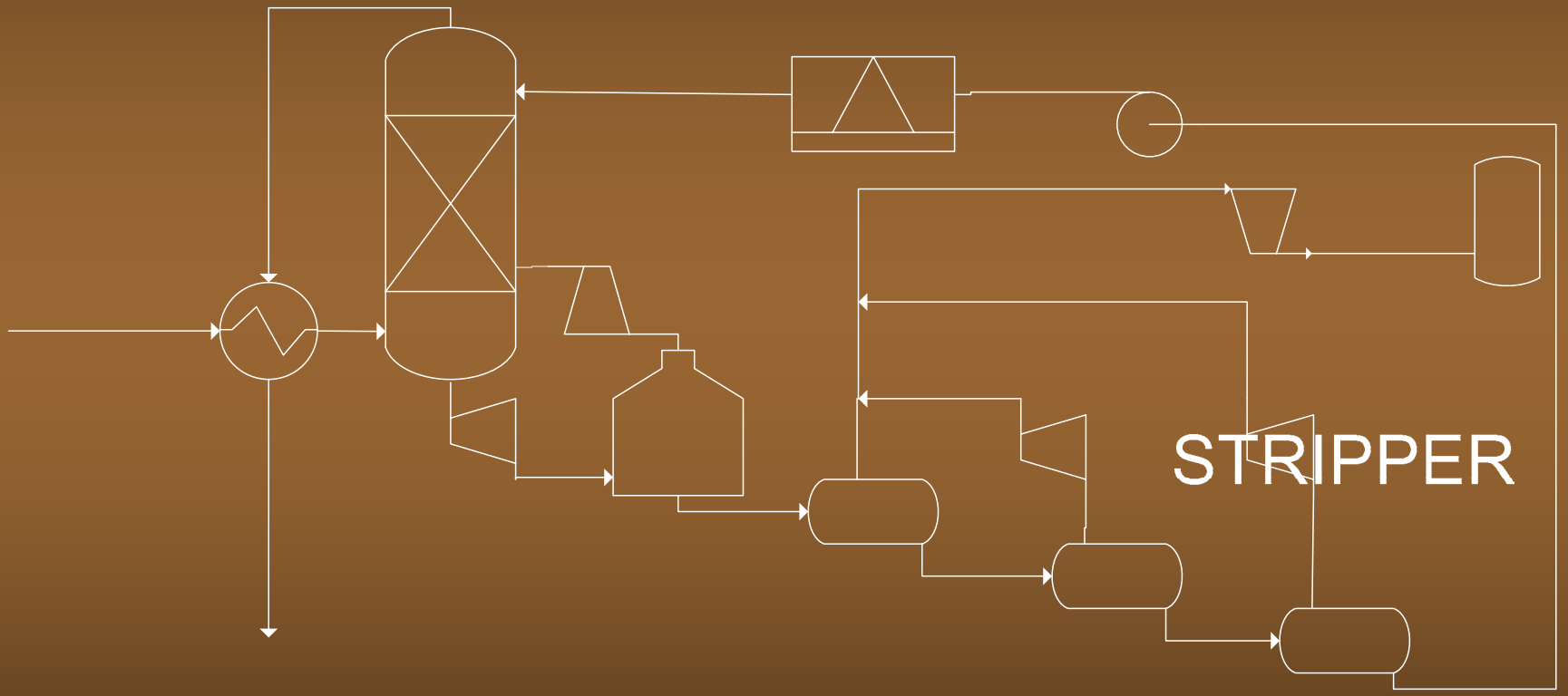
CO_2 Removal



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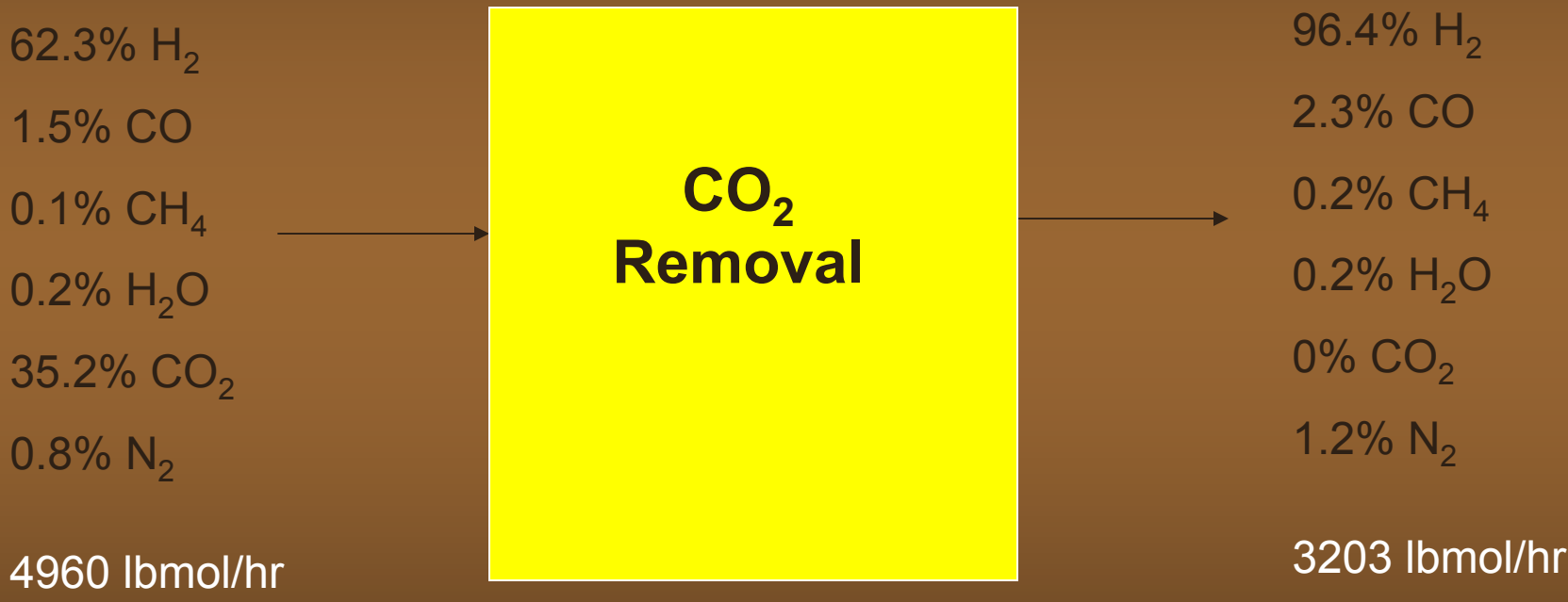
HEAT

Hydrogen Plant



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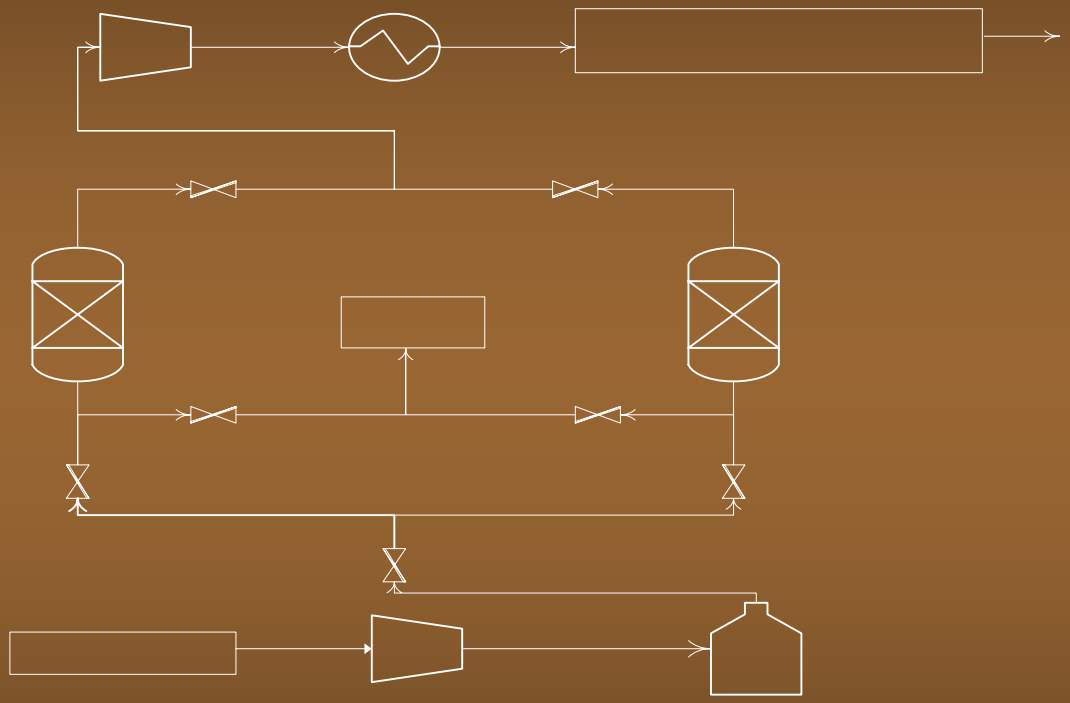
Pressure Swing Adsorption

W=5551.58 HP



Heat Ex

W=1022.2 HP

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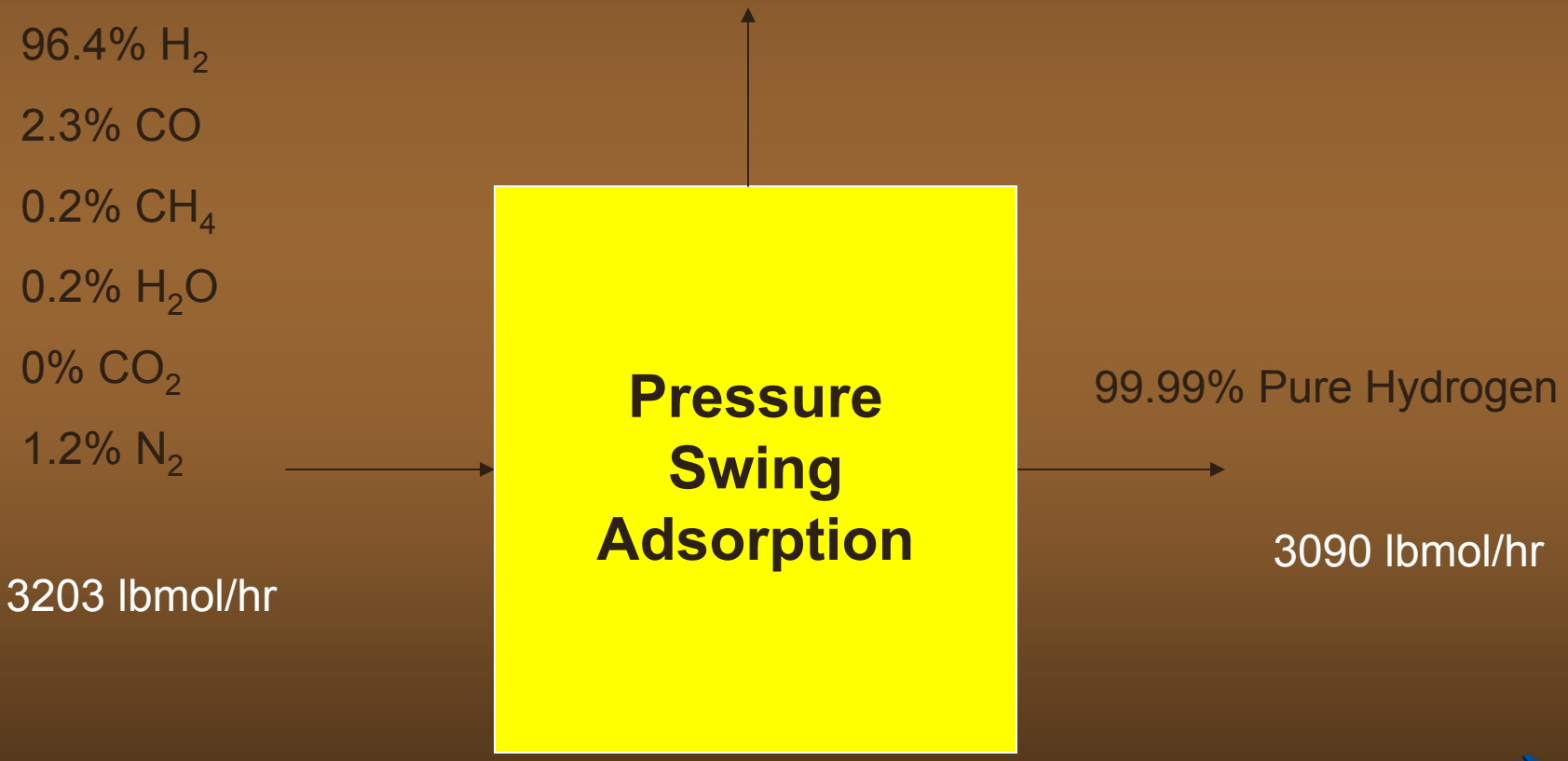
PBR 1

Hydrogen Plant



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MSW Processing Plant Capital Costs

- Based on plant processing 1500 TPD MSW
- Capital Investment
  - Purox Pyrolysis Plant
  - Hydrogen Production Plant
- Production Costs
  - Operating Costs
  - Transportation Costs

Purox Pyrolysis Capital Costs

Item	1975 $ millions	2004 $ millions
Construction	47.1	126.9
Interest during construction	4.30	11.59
Startup Costs	2.56	6.90
Working Capital	1.56	4.21
TOTAL CAPITAL INVESTMENT	55.5	149.6

Hydrogen Capital Costs

Steam Reformation	**Compressor**	**$5,727,400**
	Steam Reformer	**$2,000,000**
Water-Gas Shift	**High Temp. Reactor X 4**	**$1,029,776**
	Heat Exchanger	**$8,000**
	Flash Drum	**$112,000**
CO2 Removal	**Stripper**	**$1,694,000**
	Turbine	**$312,000**
	Slump Tank	**$26,000**
	Compressor X 4	**$964,000**
	Flash Drum X 3	**$126,000**
	CO2 Storage Tank	**$3,400,000**
	Pump	**$114,000**
	Refrigerator	**$485,000**
PSA stuff	**PSA**	**$2,201,000**
Storage/Production	**Compressor**	**$3,000,000**
	Heat Exchanger	**$1,500**
	Storage Tanks X 12	**$3,700,000**
Total Equipment Costs		**$24,900,676**

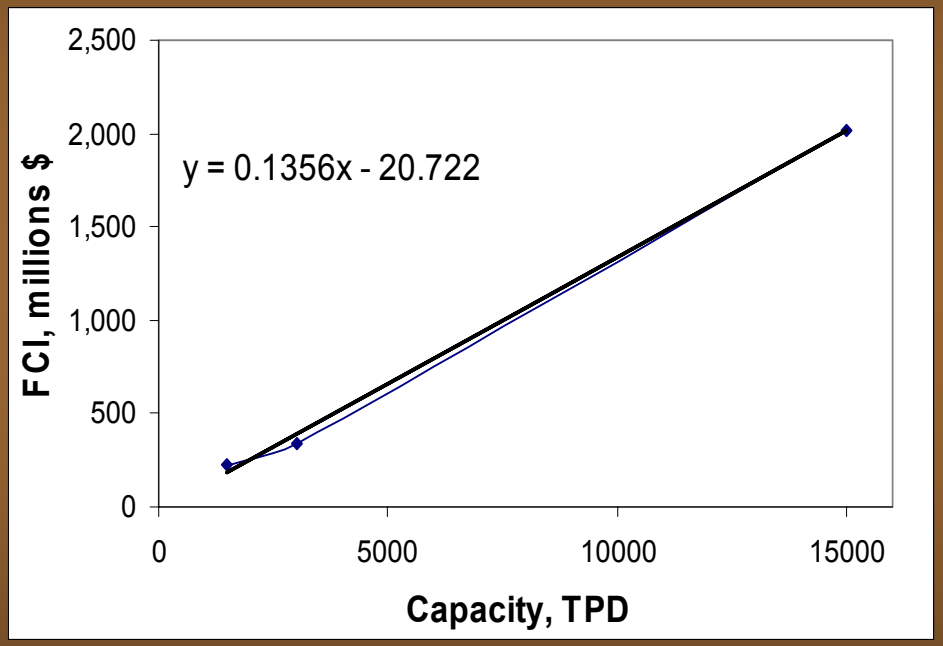
Waste to Hydrogen TCI & Production Costs

- TCI of Plant
  - $300 million
- Production Costs
  - $56 million/year
  - Utilities, Catalysts, Labor
  - Do not account for transportation costs

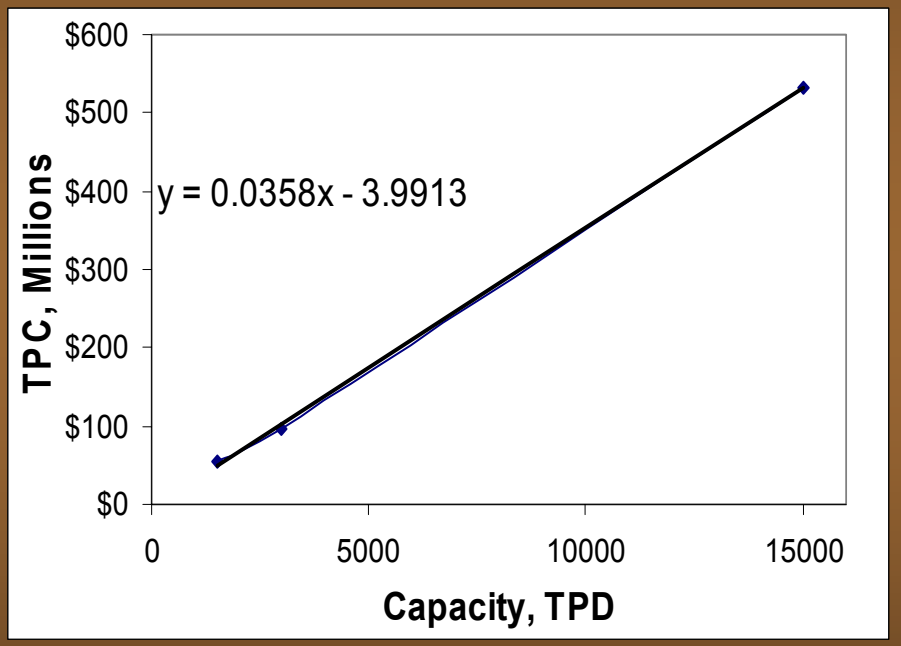
Deterministic Model

- Advance the previous deterministic model
- New additions:
  - Refined Plant Investment & Production Costs
  - Allowed plants to expand by incorporating new capital costs
  - Updated contracts and locations
  - Developed new transportation costs

Refined Plant Investment & Production Costs



Scaled Up TCI



Scaled Up Operating Costs

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Contracts & Locations

- Updated contracts
  - Many contracts recently expired
- Reconfigured mileage
  - Account for highways and driving times
  - More accurate mileage from transfer location to possible facilities

Plant Transportation Costs

- MSW Semi-Dump Trucks
  - Capacity = 15 tons of waste
  - $80,000 each
  - Mileage = 6 miles/gallon
  - Lifetime = 1MM miles +

$$\#trucks_{MSW} = \frac{(waste/day)}{(Capacity_{MSWtrucks} * (\#trips/day))}$$

- H_2 Tanker Trucks
  - Capacity = 4.5 tons hydrogen
  - Tube Trailer = $340,000
  - Truck Cab = $110,000

$$\#trucks_{H_2} = \frac{(H_{2\ produced}/day)}{(Capacity_{H_2trucks} * (\#trips/day))}$$

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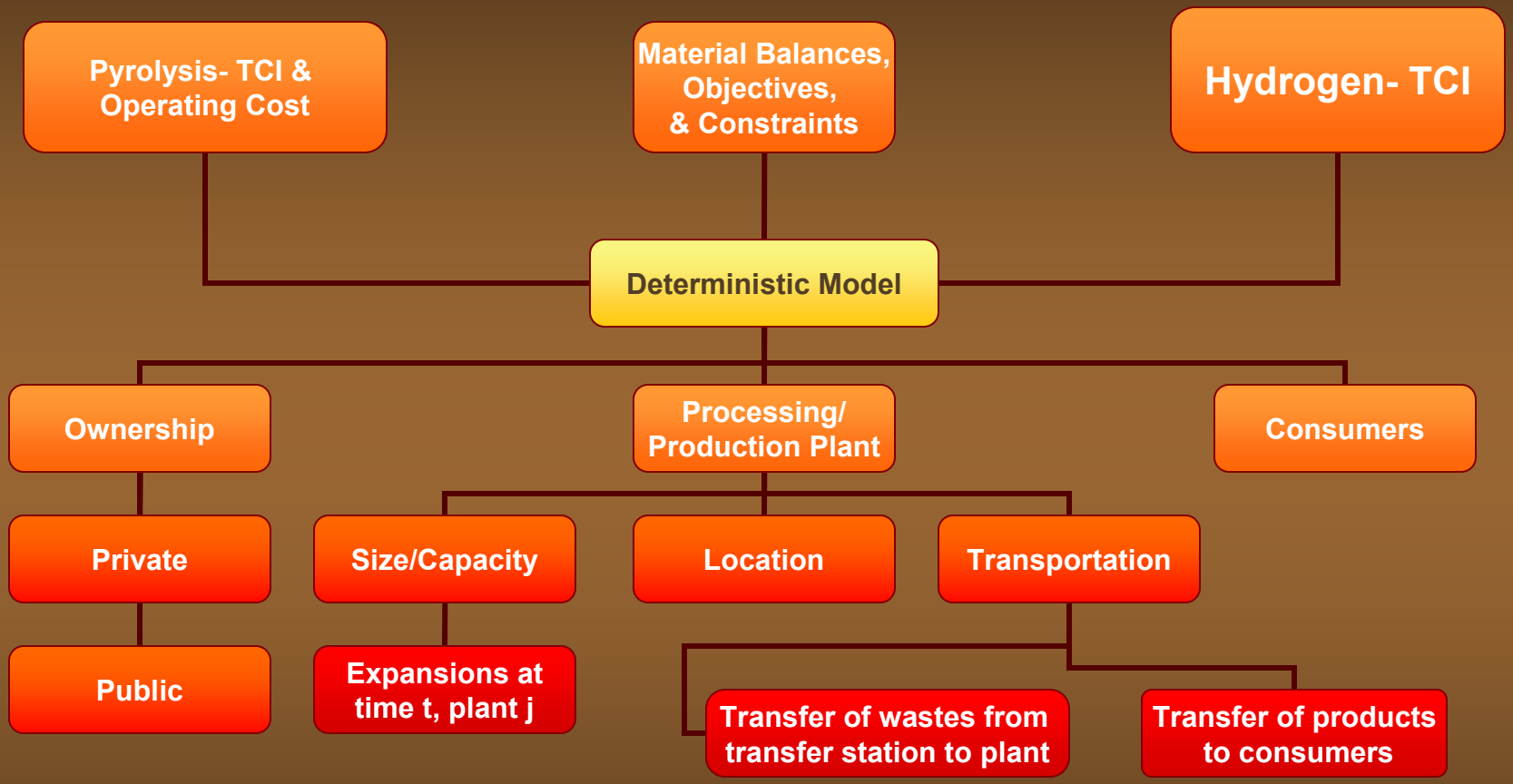
Private Enterprise

- Private
  - Model will determine profitability based on NPW
  - Determine if ROI is greater than 10%
  - Raise money through investors
- Public as an alternative
  - Raise money through municipal bonds
  - Model will determine minimum disposal fee with out process losing money

Mathematical Model

- Pre-determined Factors
  - Process: Pyrolysis
  - Final Product: Hydrogen

- Implement deterministic, stochastic mathematical model for logistic planning



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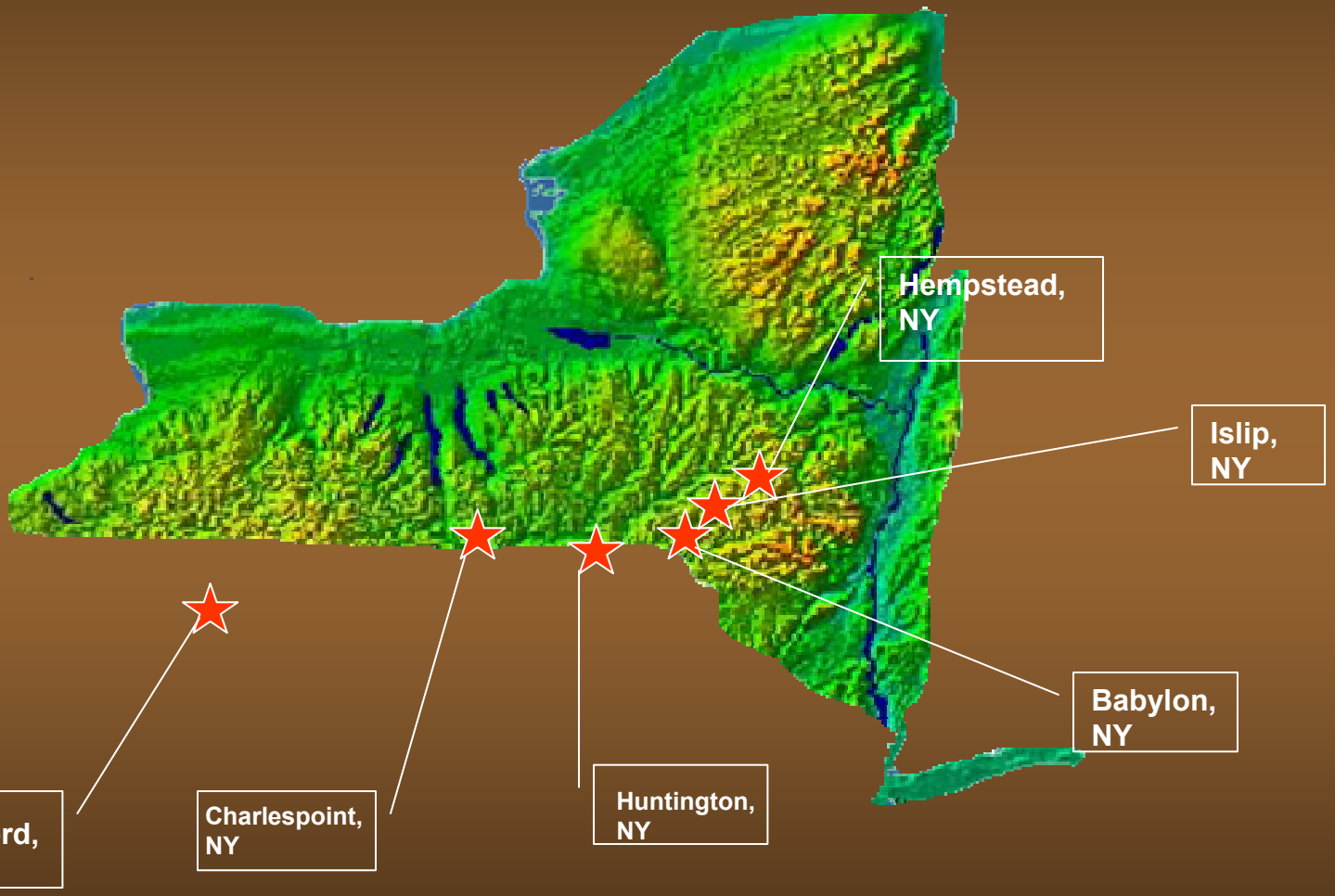
CEMs

Importance of Model

- Aid in planning of process
  - Implement and control the most efficient and cost-effective flow of materials in relation to time
  - Account for current MSW disposal contracts
  - Encompass transport of MSW and final products
  - Execute the right number, location, and capacity of plants
  - Incorporate expansions in relation to time, money, and the amount of trash

Private Plant Locations



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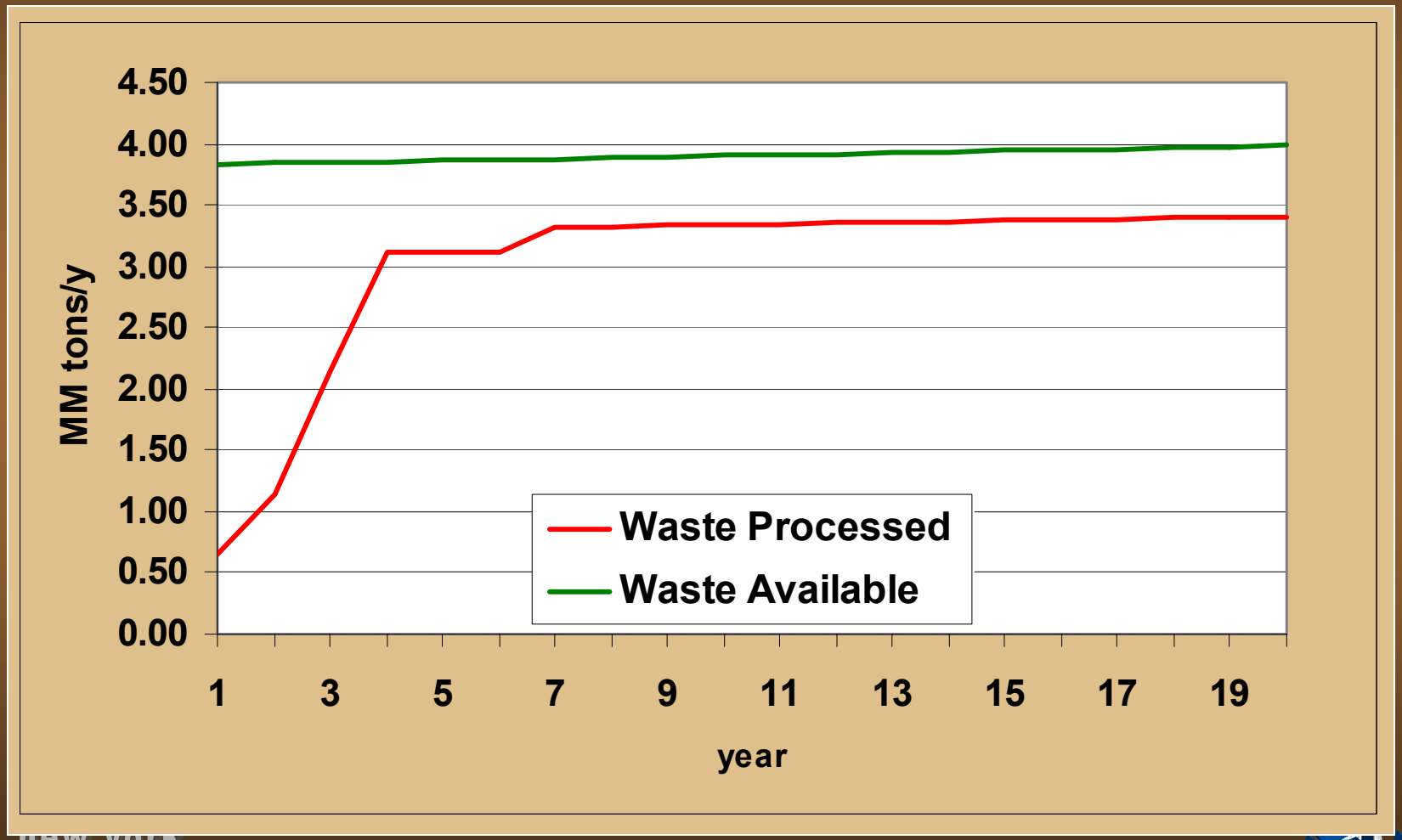
Private: Annual Waste Processed compared to Waste Available



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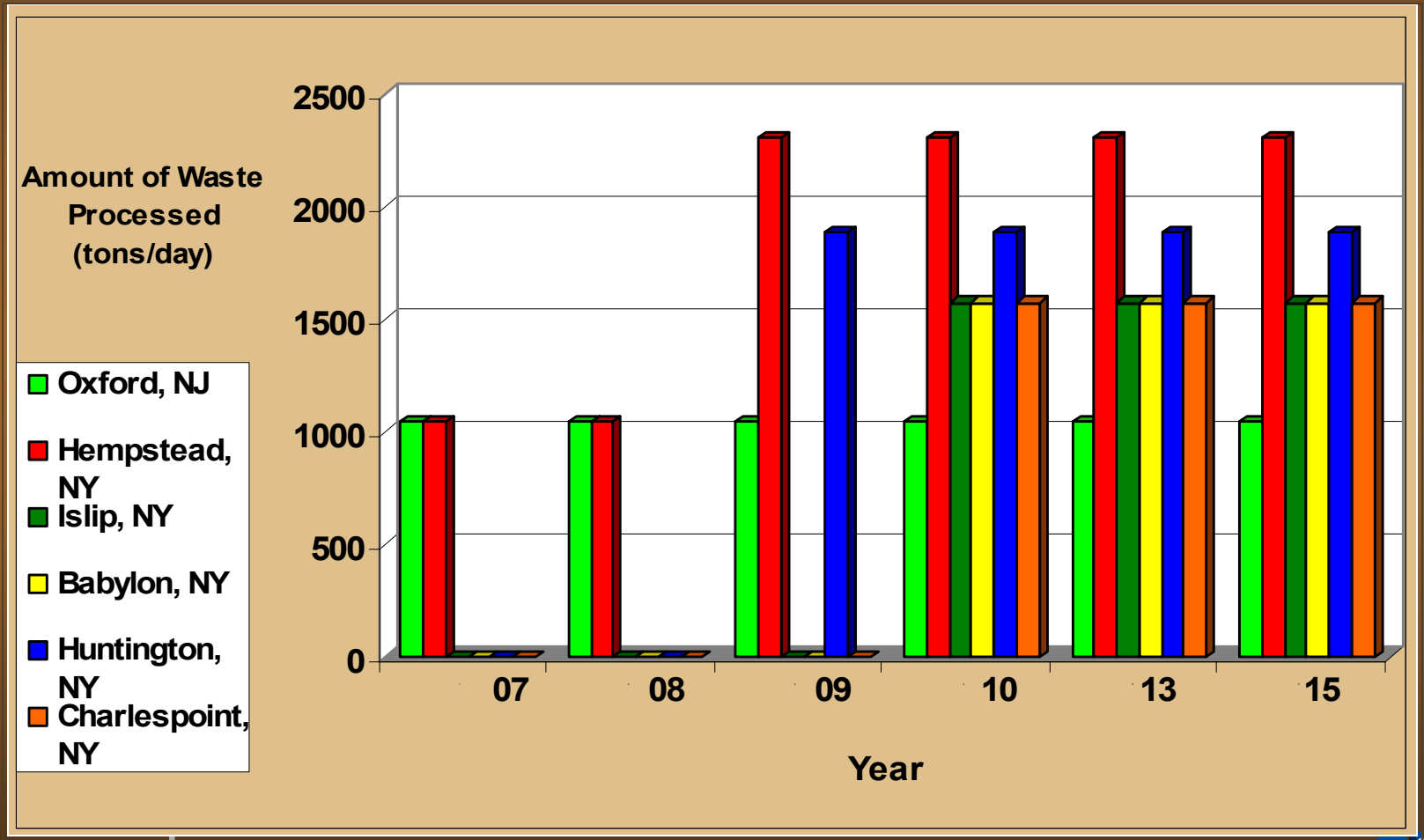
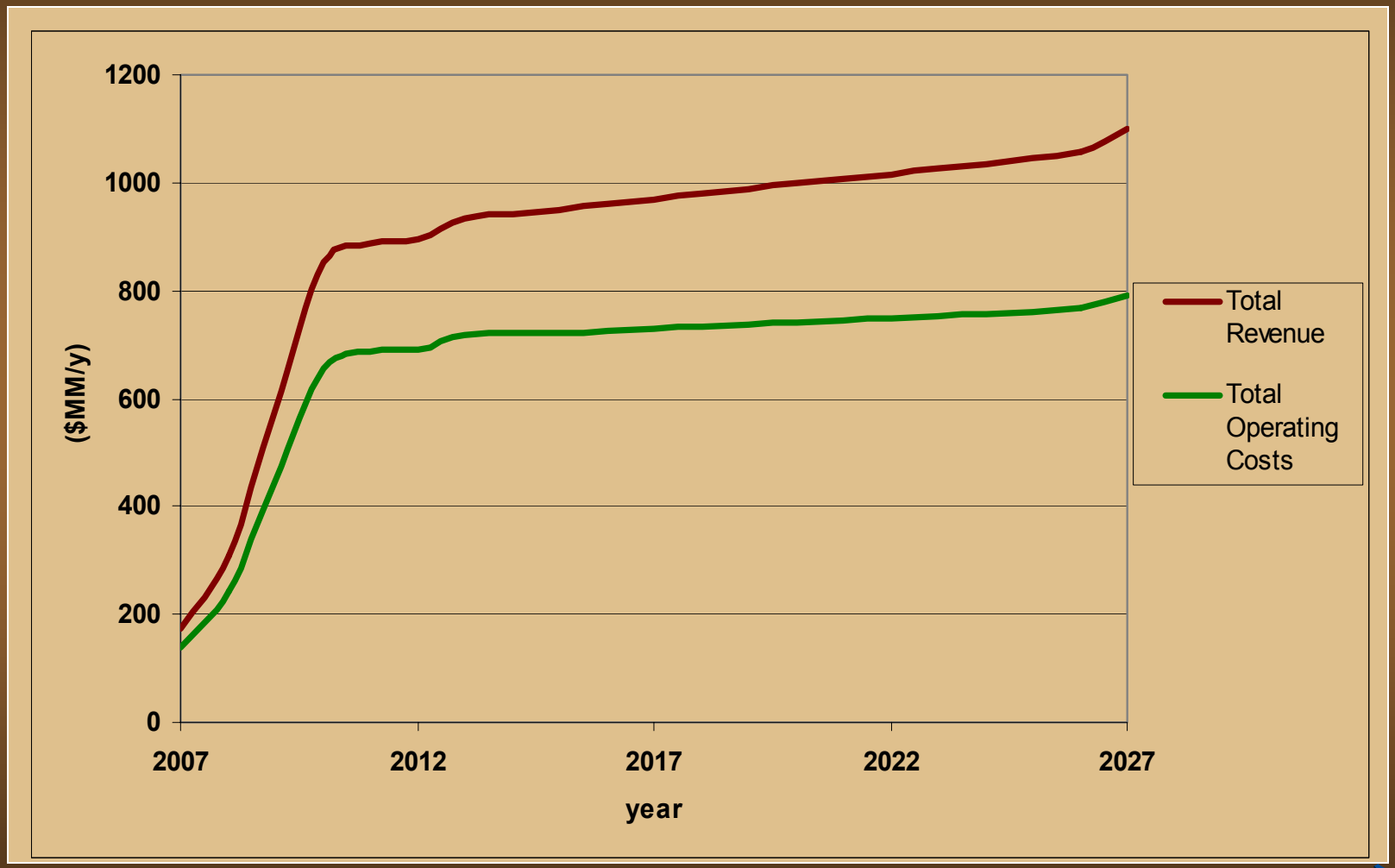
Private: Waste Processed/ Expansions at Each Plant



Private: Revenue and Operating Costs



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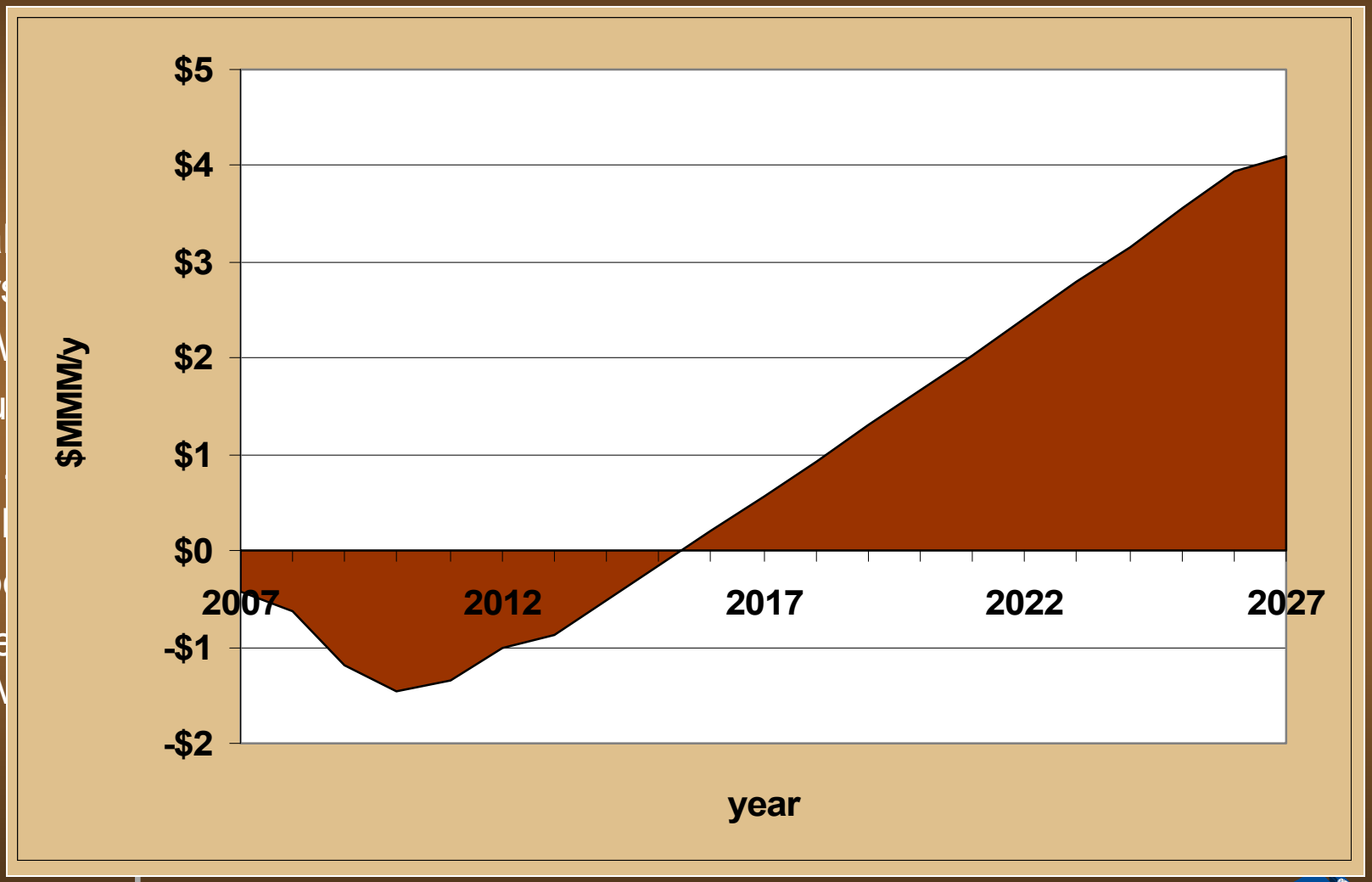
Private: Cumulative Cash

- Total
  years
- NPW
- Retu
  = 12
- 508 I
- Dispo
- Save
  $54M



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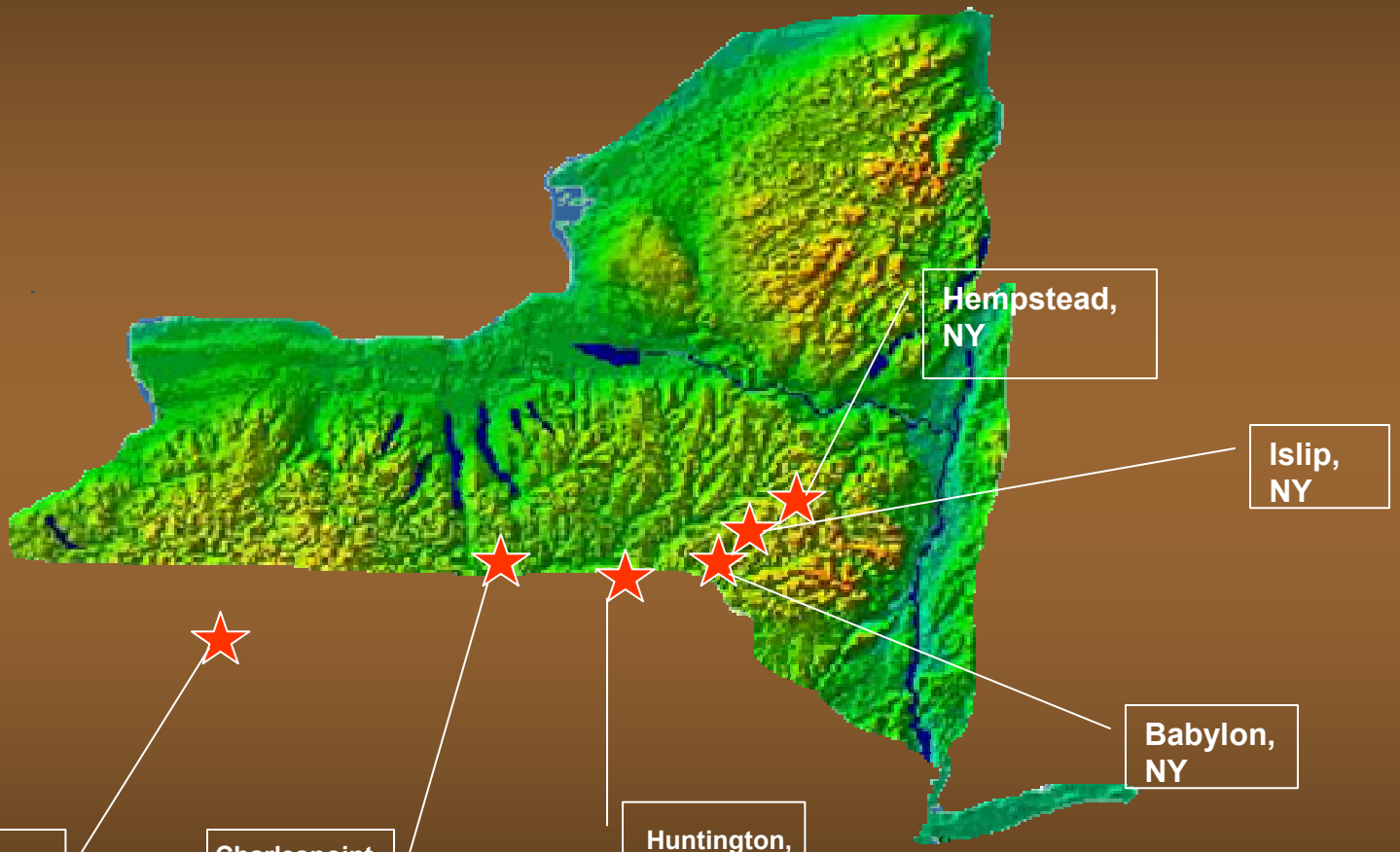
Investment Strategy

- Private Feasible
  - Total Capital Investment (20 years) =$2.0 MMM
  - NPW (20 years) =$198 MM
  - Return on Investment =12.5%

Public as an Alternative

Public Plant Locations



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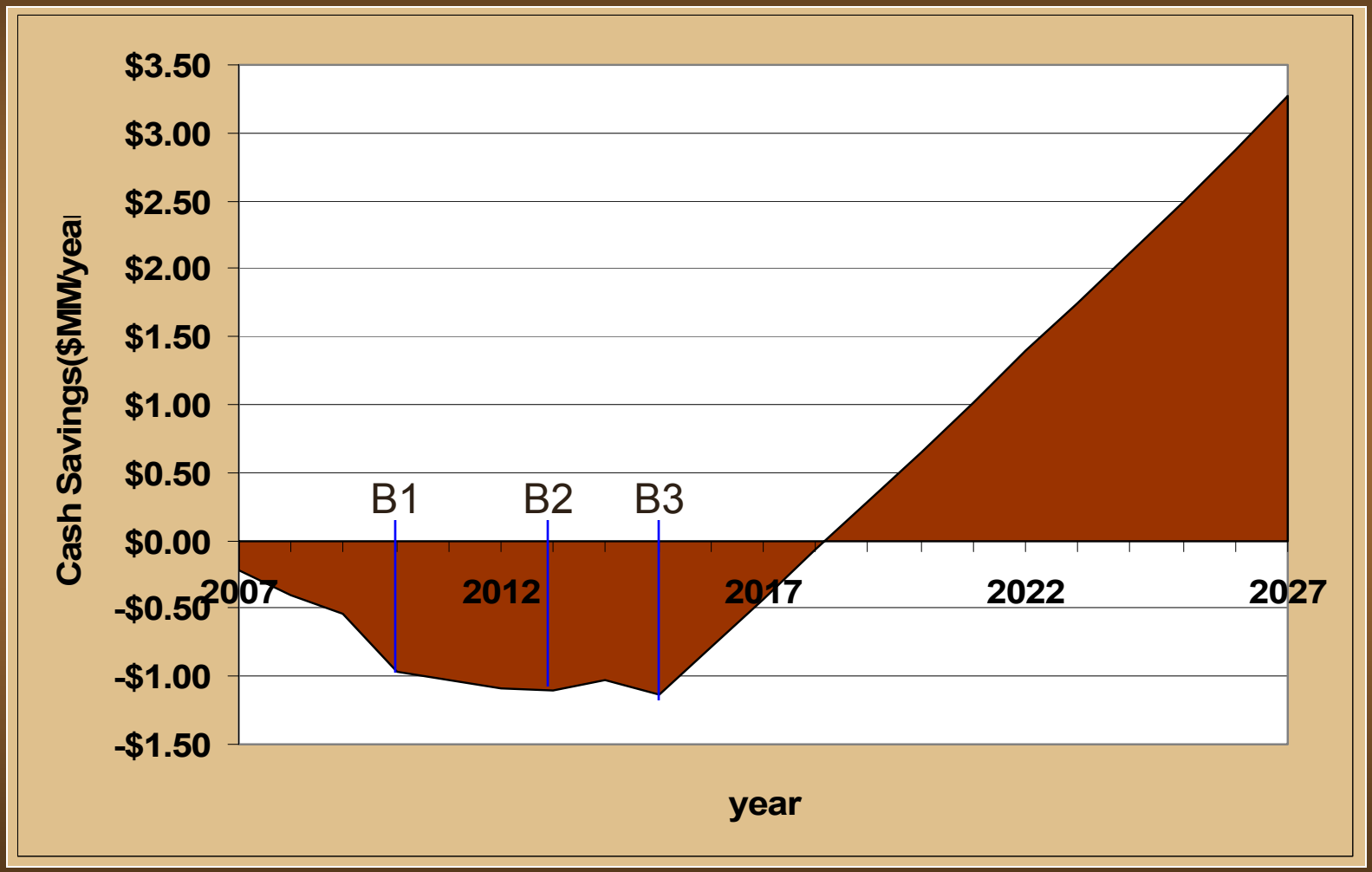
Public: Cumulative Cash



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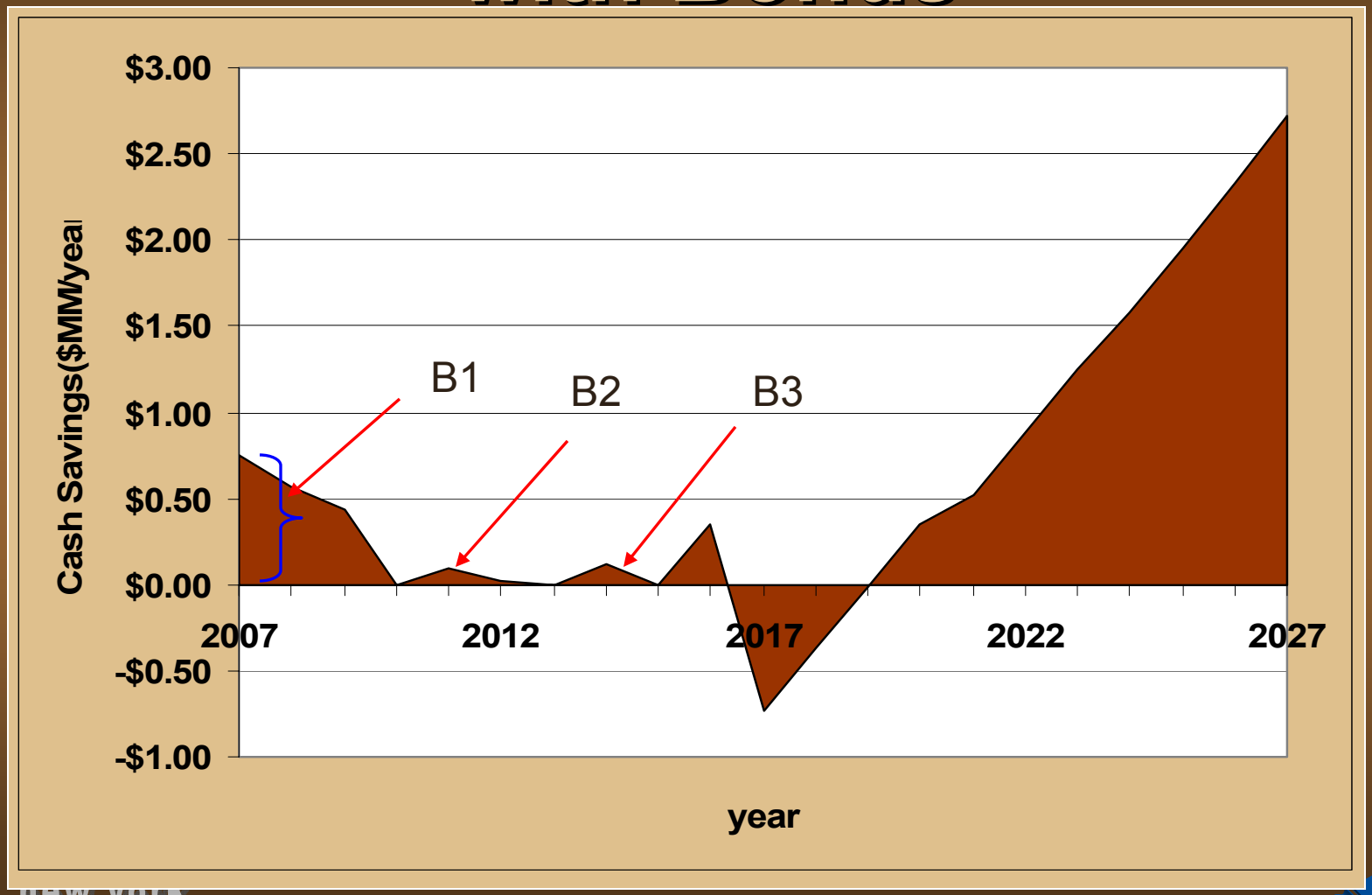
Public: Cumulative Cash with Bonds



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Public: Bonds

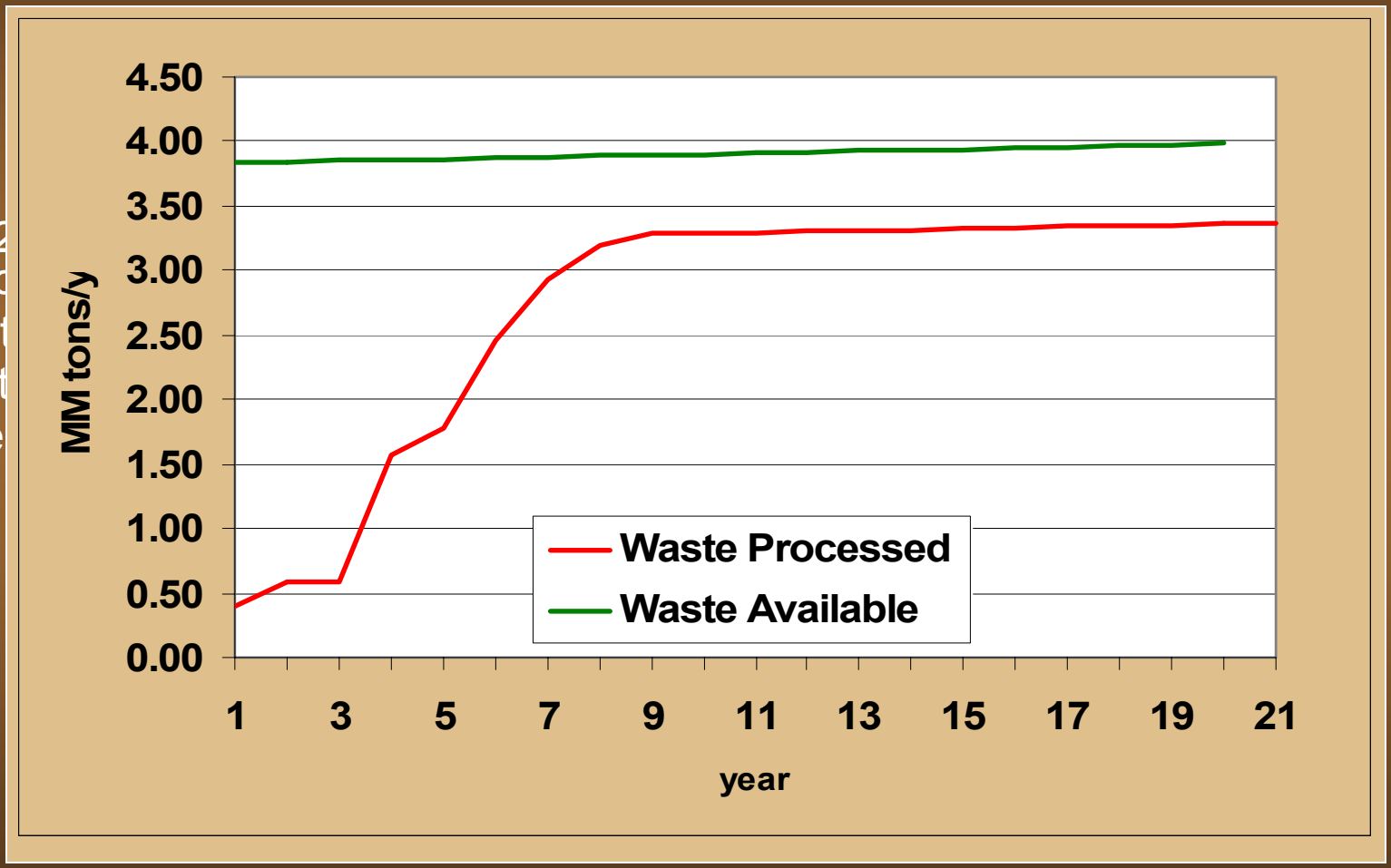
All bonds are 10 year bonds at 4% interest

- Bond 1
  - Amount issued in 2007 = $974 MM
  - Pay off amount (w/interest) = $1.44 MMM
- Bond 2
  - Amount issued in 2011 = $136 MM
  - Pay off amount (w/interest) = $201 MM
- Bond 3
  - Amount issued in 2014 = $30 MM
  - Pay off amount (w/interest) = $44 MM

- Total Amount in Bonds = $1.14 MMM
- Total Interest Paid = $5.5MM

Public: Annual Waste Processed compared to Waste Available

- By 2
  proc
- Lifet
- No t
- Fee
  city
- TCI



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Questions