Natural Gas Industry In Peru

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Camisea Natural Gas Reservoir

- The Camisea natural gas reserve located in Peru
- Discovered in 1980 by Shell Oil
- Approximately 11 trillion ft^3, estimated 600 million bbl reserve

Project Description

<u>Objective:</u> Present business plan based on varying initial investments

GOALS:

- Research Peruvian market
- Research petrochemical products produced using natural gas
- Find imported petrochemical products
- Use business model to compare different options

Project Scope

- Investigate entire natural gas market
- Eliminate processes
- Determine fixed capital investment and operating costs for processes
- Product prices
- Product demands
- Deterministic Model
- Stochastic Model

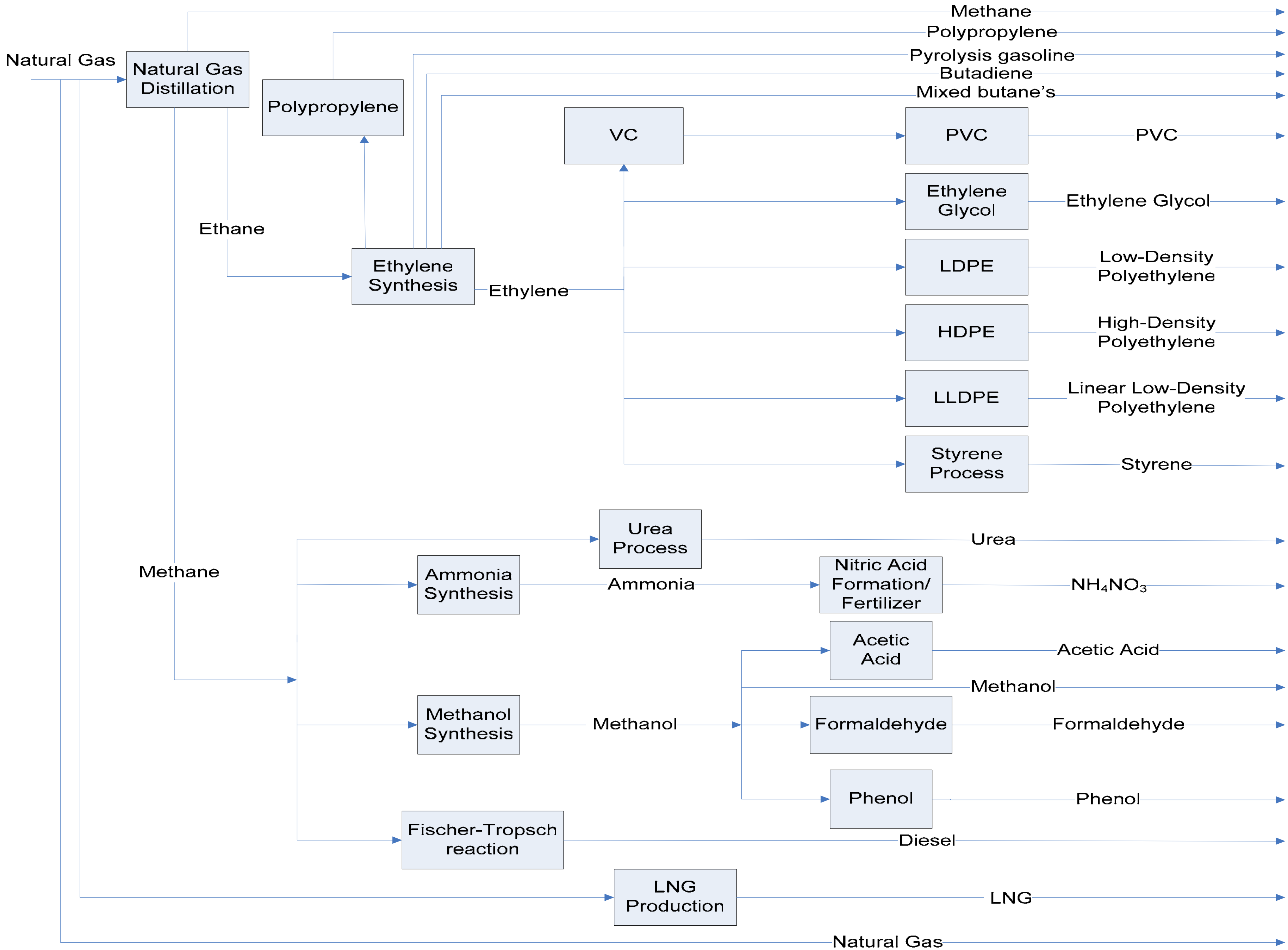
Camisea Pipeline Project

- Route: Camisea Reservoir to Pisco
- Current rate: 400 million cubic feet per day
- Two pipelines
  - NGL (natural gas liquids)
  - Natural Gas

Pipeline Economics

- Length of pipeline 155 miles ~ 250 km
- Total cost: $2.7 billion US dollars
- Cost per mile $17.4 million

Plant Design



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Mixed butane's
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Methanol
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Methanol
Formaldehyde
Formaldehyde
Phenol
Phenol
Fischer-Tropsch reaction
Diesel
LNG Production
LNG
Natural Gas

Deterministic Model

- Optimization software
  - GAMS
- Function
  - Calculates net present worth
  - Selects if and when a process is to be constructed
  - Selects process capacities
  - Regulates expansions

Deterministic Model

- Data required
  - Pipe cost from Camisea to Pisco
  - Fixed capital investment
  - Operating cost
  - Chemical prices
  - Demand

Process Selection

Eliminated Processes

- Acetic Acid
- Formaldehyde
- Urea
- Phenol
- Styrene

Acetic Acid/Formaldehyde

- Acetic Acid
  - Products not in high demand for market

- Formaldehyde
  - Market in region dominated by Brazil
  - Demand satisfied

*Vines, Tonya. Industry Week. *Borden Responds to Consumer Trends;* Apr 2005; pg. 66.

**Chemical Week;* June 30-Jul 7, 2004. pg 40

Urea Process

- Decreasing demand for product
- More economical products can be made by natural gas

*Van Savage, Eleanor. Chemical Market Reporter. *Urea Prices on Depleting Inventories and Raising Natural Gas Prices.* July 15, 2002.

Phenol/Styrene

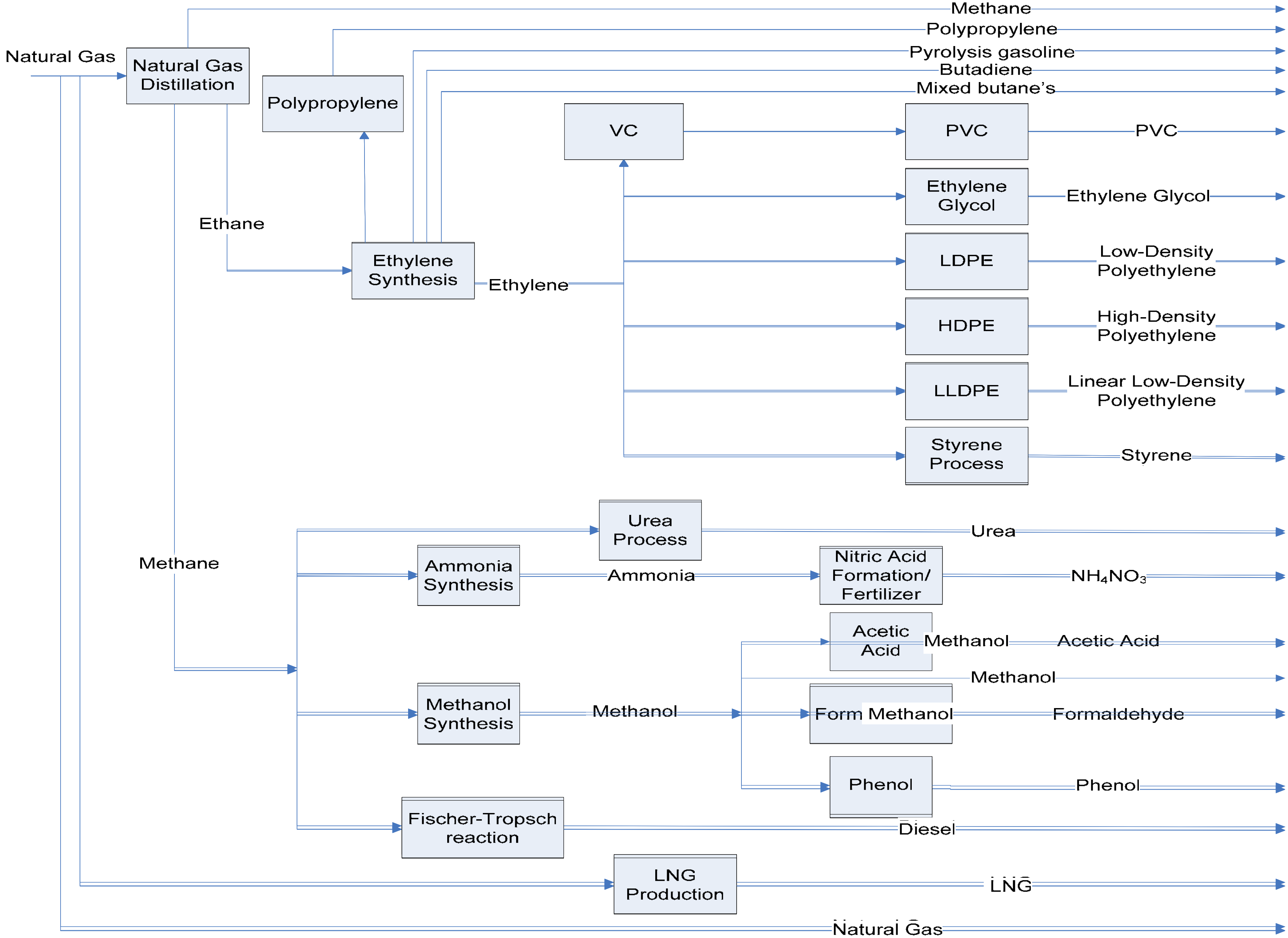
- Phenol
  - Increasing prices, low margins
  - Market is saturated
- Styrene
  - Market for phenol currently satisfied by local companies

*Viswanathan, Prema. *Chemical News;* Feb 28-Mar 6, 2005. pg. 24

Product Evaluation

- Not selling individual gases
  - Ethane
  - Pentane

- These products used in other processes to yield higher profit products



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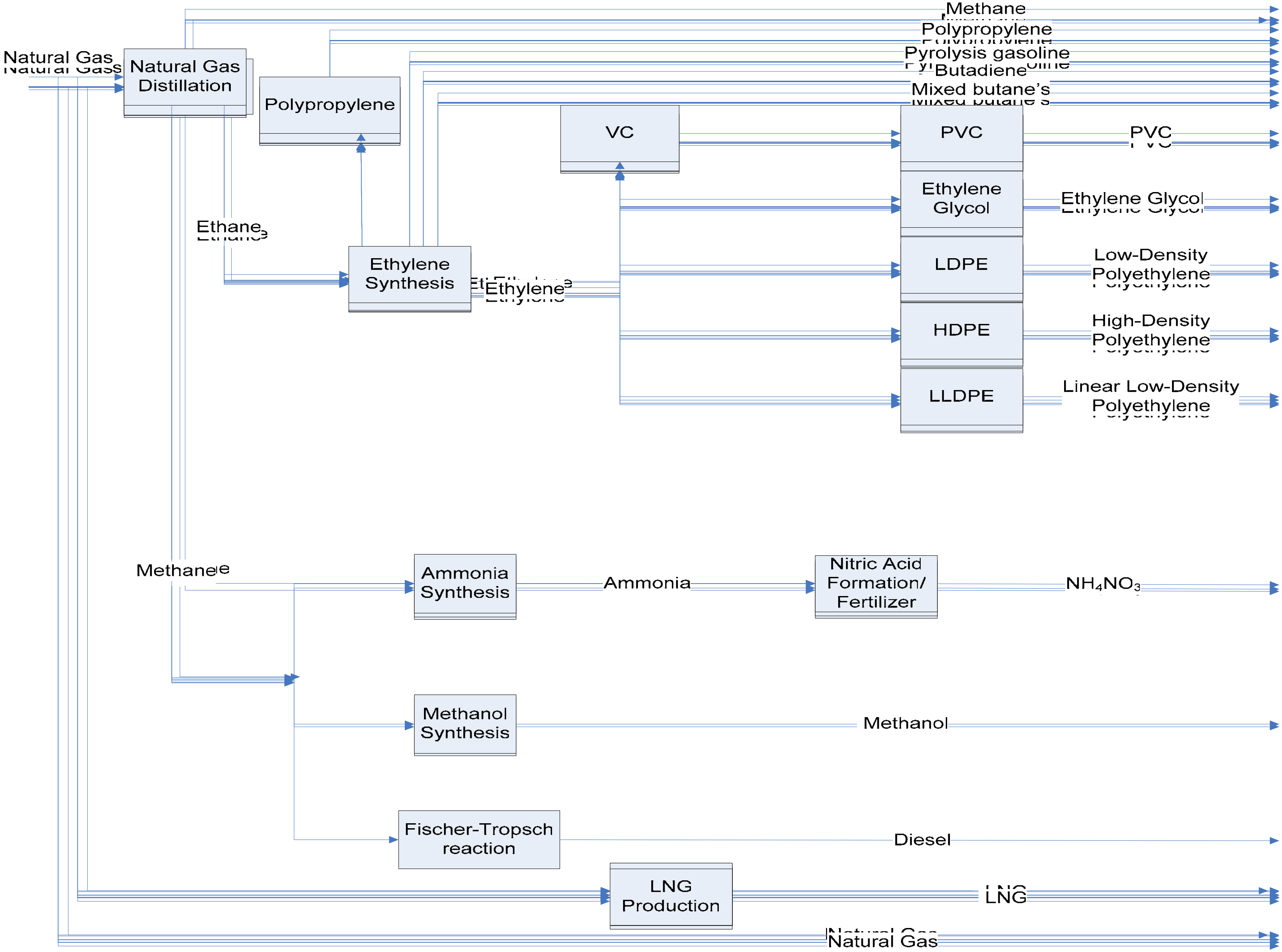
Different Investment Options

- Need to determine
  - What processes to build
  - Capacities
  - Expansions
  - Reinvestment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Methods To Calculate Fixed Capital Investment

- Equipment cost breakdown
  - Process flow diagrams
    - Pressure drop
    - Change in temperature
    - Duties
    - Residence time
    - Conversion
    - Heat transfer coefficients
  - Direct Costs/Indirect Costs
- Research provided by other companies

Ethylene Synthesis

- Initiation

  $C_nH_{2n+2} \rightarrow C_mH_{2m+1}\cdot + C_{(n-m)}H_{2(n-m)+1}\cdot$
- Propagation

  $C_nH_{2n+2} + C_mH_{2m+1}\cdot \rightarrow C_nH_{2n+1}\cdot + C_mH_{2m+2}$

  $C_nH_{2n+1}\cdot \rightarrow C_mH_{2m} + C_{(n-m)}H_{2(n-m)+1}\cdot$
- Termination

  $C_nH_{2n+1}\cdot + C_mH_{2m+1}\cdot \rightarrow C_nH_{2n} + C_mH_{2m+2}$

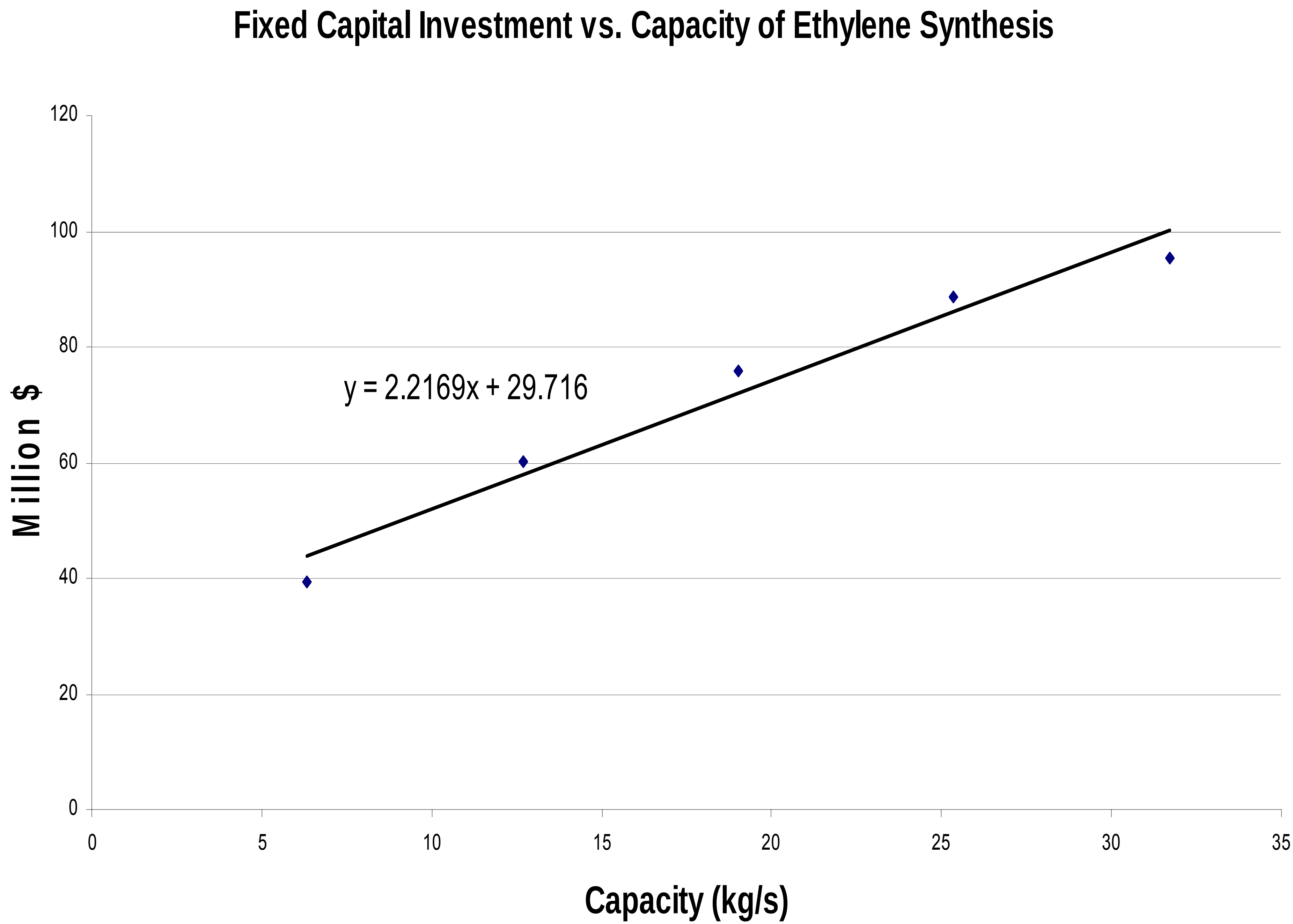
  $C_nH_{2n+1}\cdot + C_mH_{2m+1}\cdot \rightarrow C_nH_{2n+2} + C_mH_{2m}$

  $C_nH_{2n+1}\cdot + C_mH_{2m+1}\cdot \rightarrow C_{n+m}H_{2(n+m)+2}$

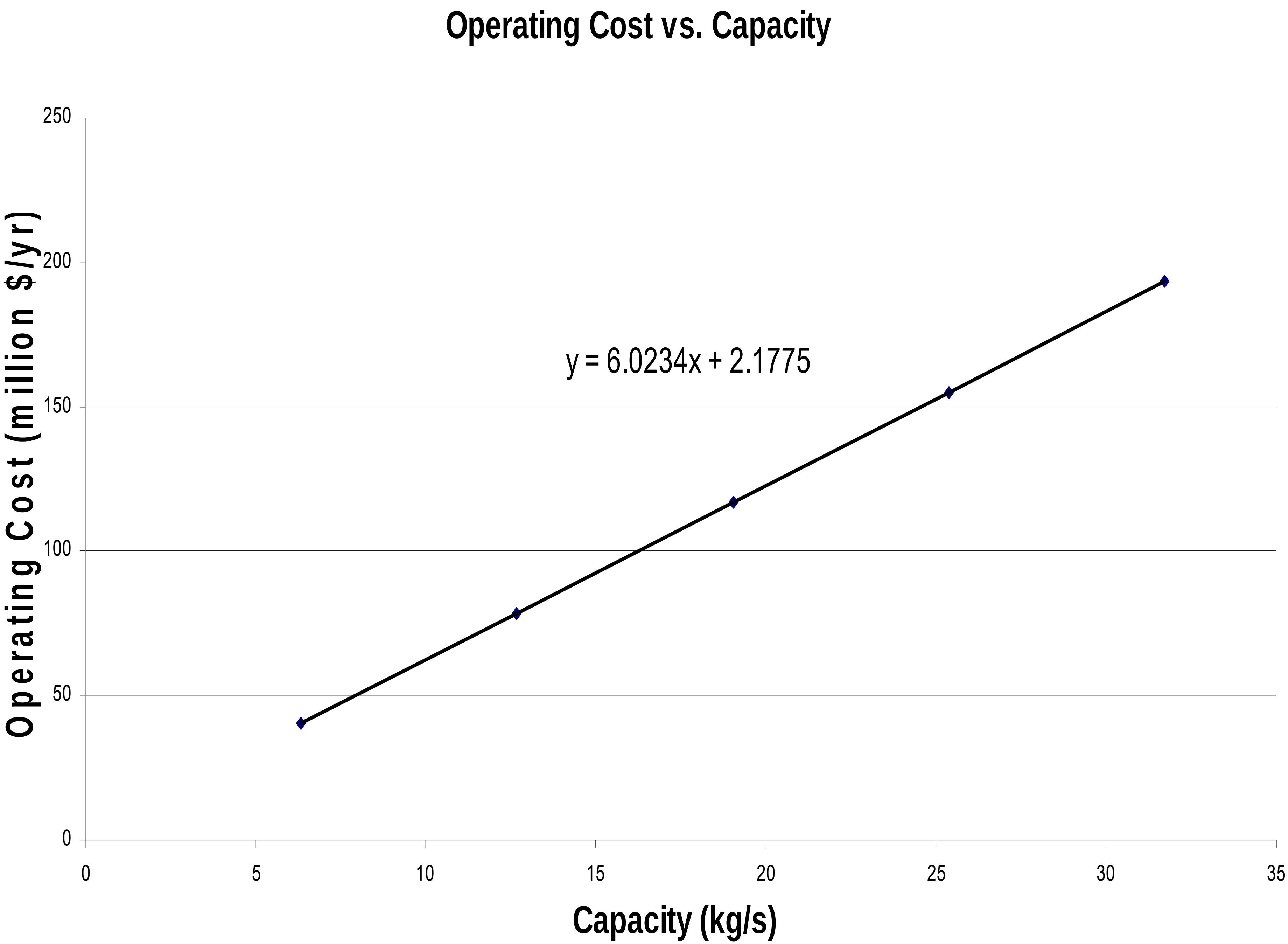
Ethylene Synthesis Technology

ABB Lummus Global SRT Cracking Technology

- 1.5 MMTA
- Residence time of <1s
- Good environmental performance



Fixed Capital Investment vs. Capacity of Ethylene Synthesis
y = 2.2169x + 29.716
Million $
Capacity (kg/s)
0
20
40
60
80
100
120
0
5
10
15
20
25
30
35



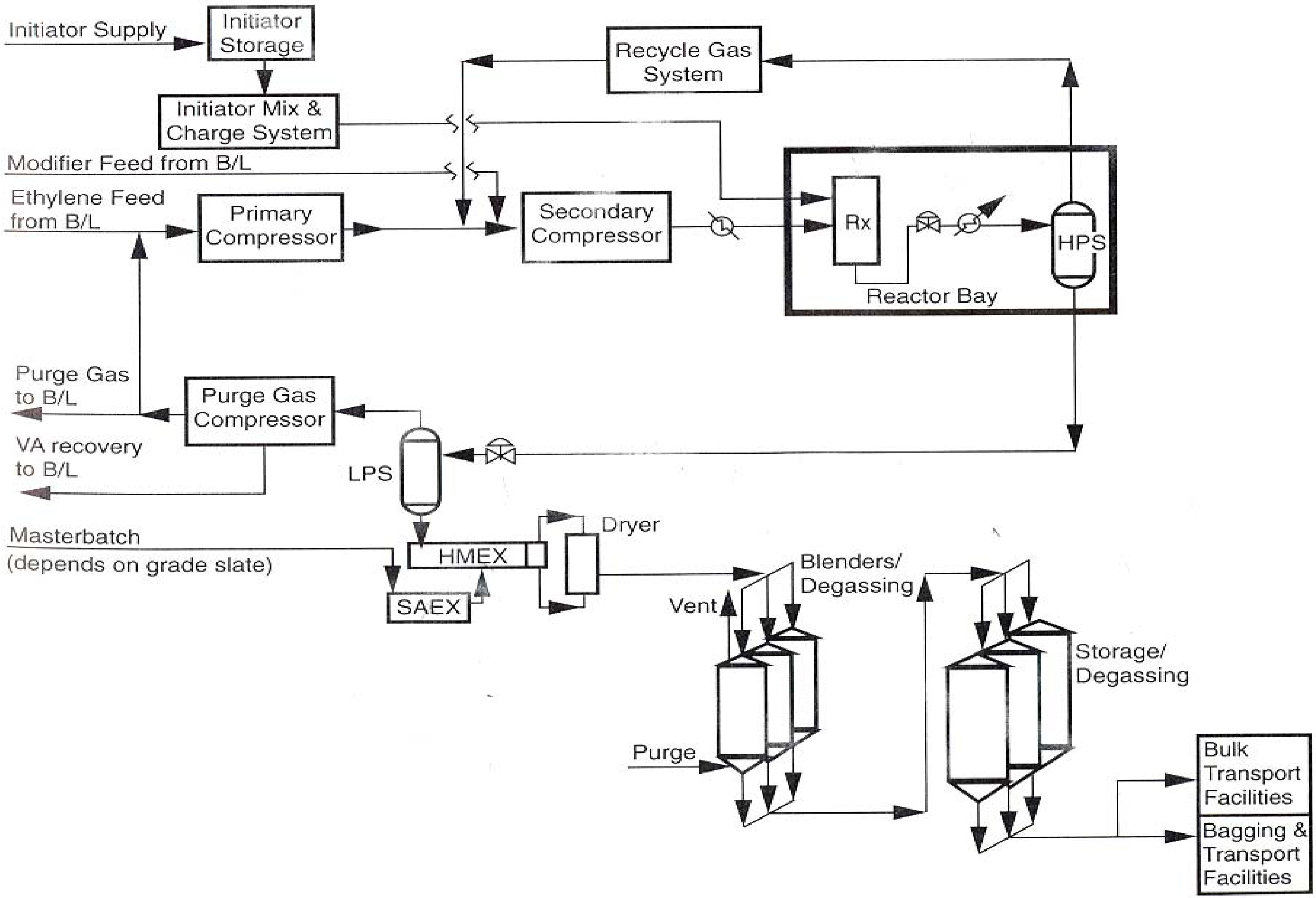
Operating Cost vs. Capacity
y = 6.0234x + 2.1775
Operating Cost (million $/yr)
Capacity (kg/s)
0
50
100
150
200
250
0
5
10
15
20
25
30
35

Low Density Polyethylene

- Overall polymerization reaction

  $n(CH_2{=}CH_2) \rightarrow (\text{-}CH_2\text{-}CH_2\text{-})_n$

- Peroxides provide the source of free radicals
- Catalyst is a Ziegler-Natta



ExxonMobil High-Pressure Process for Low Density Polyethylene

Low Density Polyethylene Technologies

Polimeri Europa High-Pressure Process

- Benefits
  - Ziegler-Natta catalyst allows for flexibility of products
  - 400,000 MTA
  - Conversions up to 30%

Low Density Polyethylene Technologies

ExxonMobil High-Pressure Process

- Benefits
  - Predominant polyethylene process
  - 400,000 MTA
  - Control of product properties and quality
  - Conversion up to 40%

Phillips Polypropylene Process

- Ziegler-Natta catalyst

- Overall Reaction

  $Ti\text{-}Et + n(CH_3CH_2{=}CH) \rightarrow Ti(CH_3CH_2CH)_n\text{-}Et$

Phillips Polypropylene Process Description

Mixture fed to pipe loop reactor

- High-purity propylene
- Ethylene comonomer
- Catalyst
- Modifiers

Separator

- Catalyst residues
- Soluble polymer slurry

Flash drum

- Soluble polymer slurry

Dryer

- Soluble polymer

Extruder

- Polymer pelletized

Polypropylene Technologies

BASF Novolen

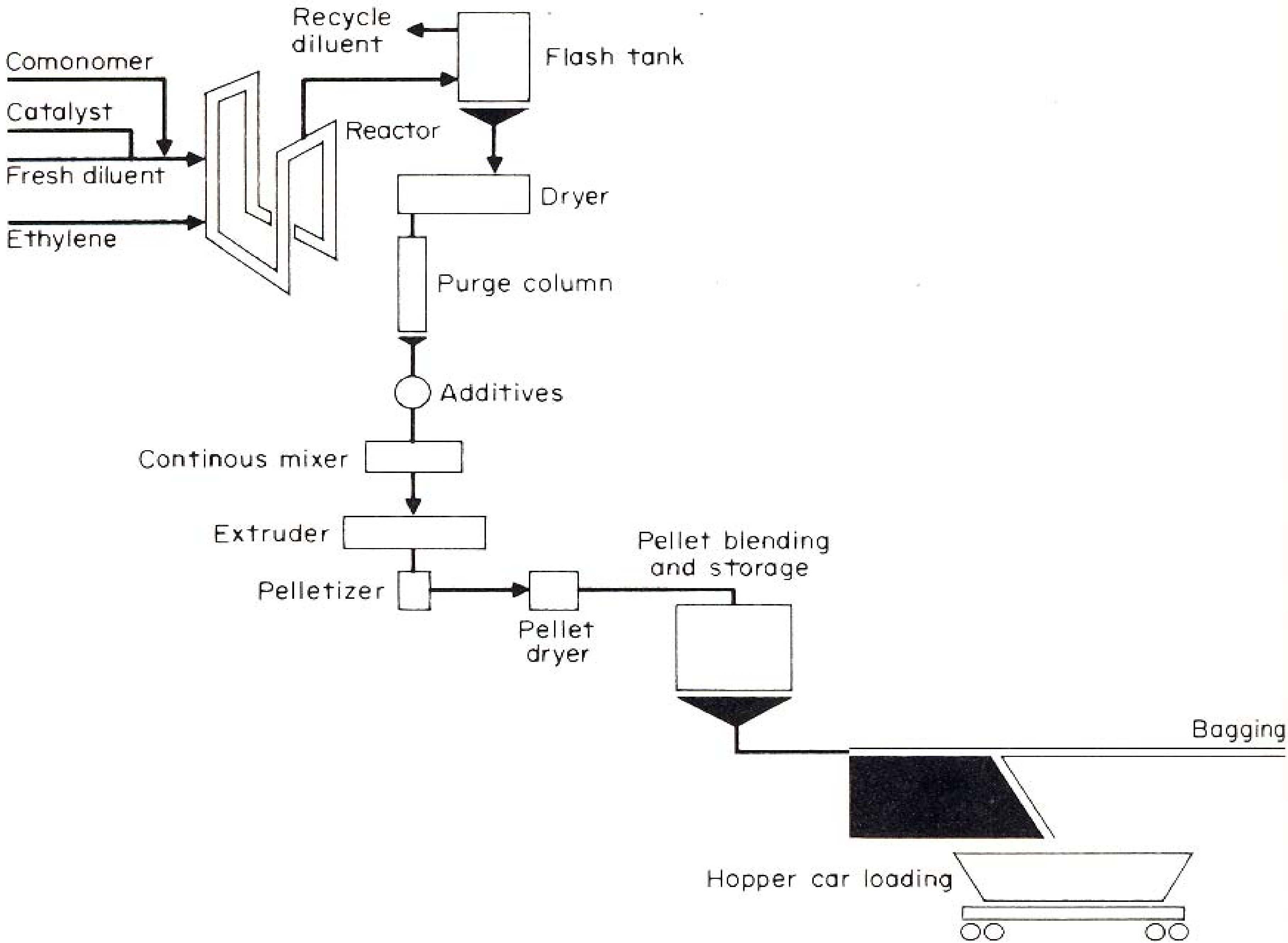
- Benefits
  - Excellent homogeneity
  - Flexible
  - Emission result only from leaks
  - Low utility costs

Phillips

- Benefits
  - Simplest, most efficient process
  - Flexible
  - Operate on a wide variety of catalysts
  - Low waste

High Density Polyethylene

- Manufactured using 3 process technologies at low pressure
  - Slurry
  - Solution
  - Gas Phase
- Ziegler-Natta catalyst or chromium oxide
- Highest crystallinity



*Phillips High Density Polyethylene Process

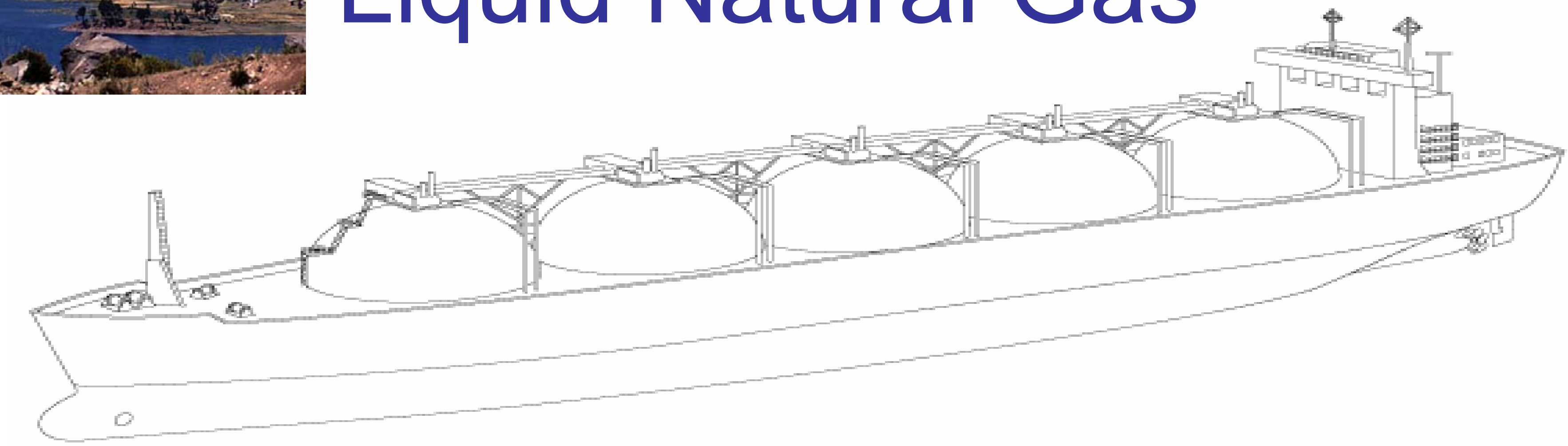
High Density Polyethylene Technologies

- Hoechst
  - Control of molecular weight
  - Optimal steady state behavior
  - Low investment costs
- Phillips
  - Predominant technology
  - Simple
  - Low investment costs

Linear-Low Density Polyethylene

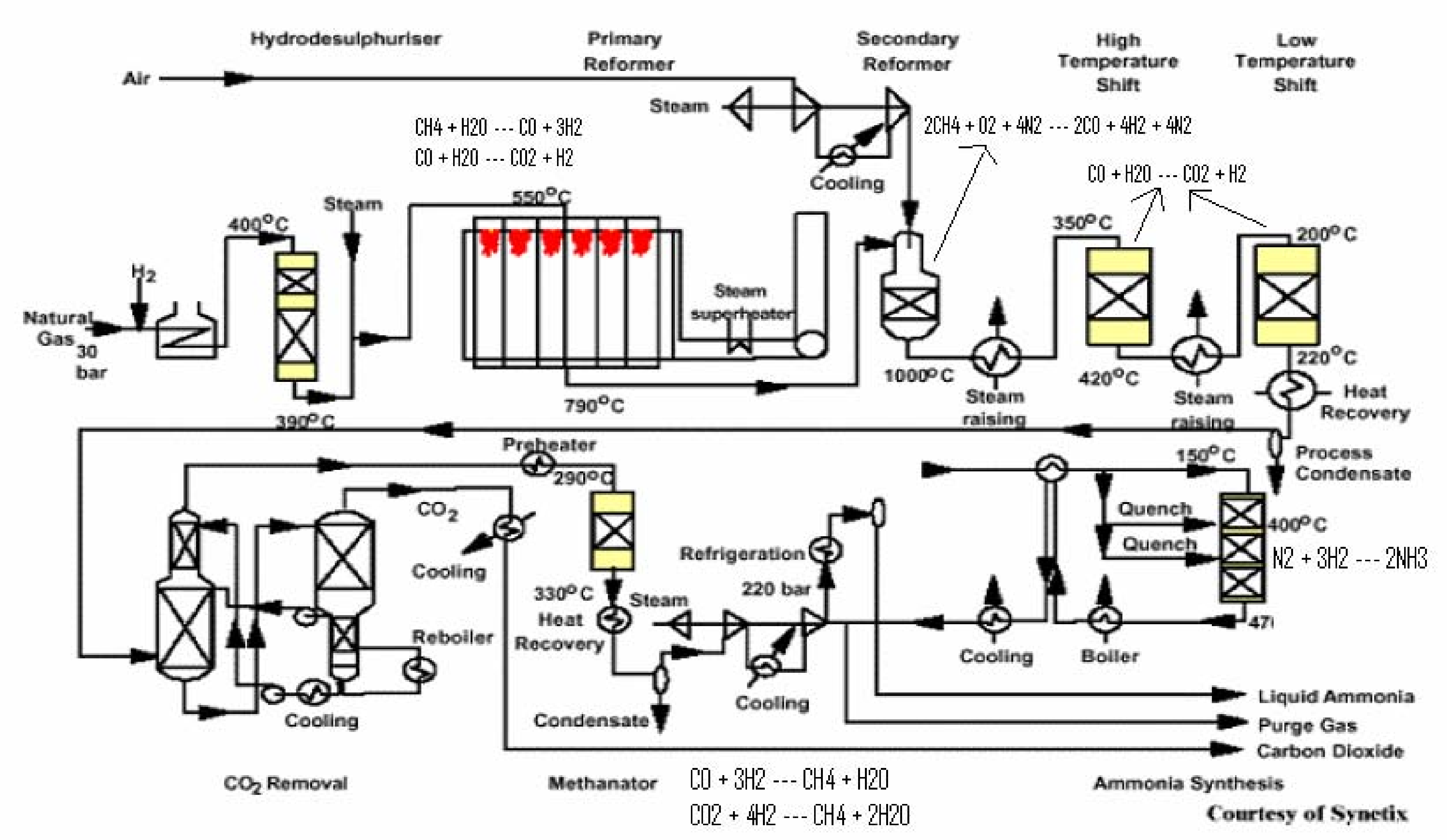
- Processes
  - Gas Phase
  - Solution
- Catalysts
  - Ziegler (titanium)
  - Phillips (chromium)

Liquid Natural Gas



- Fixed Capital Investment
  - Tanker cost
- Operating costs
  - Crew cost
  - Lubes & Stores
  - Maintenance & Repair
  - Insurance
  - Administration
  - Fuel

Ammonia Synthesis



Ammonia Synthesis

- Five technologies
  - ICI process
  - Haldor – Topsoe process
  - Uhde Ammonia process
  - Kellogg Brown & Roots Advanced Ammonia plus process (KAAPplus^{TM})

Ammonia Synthesis

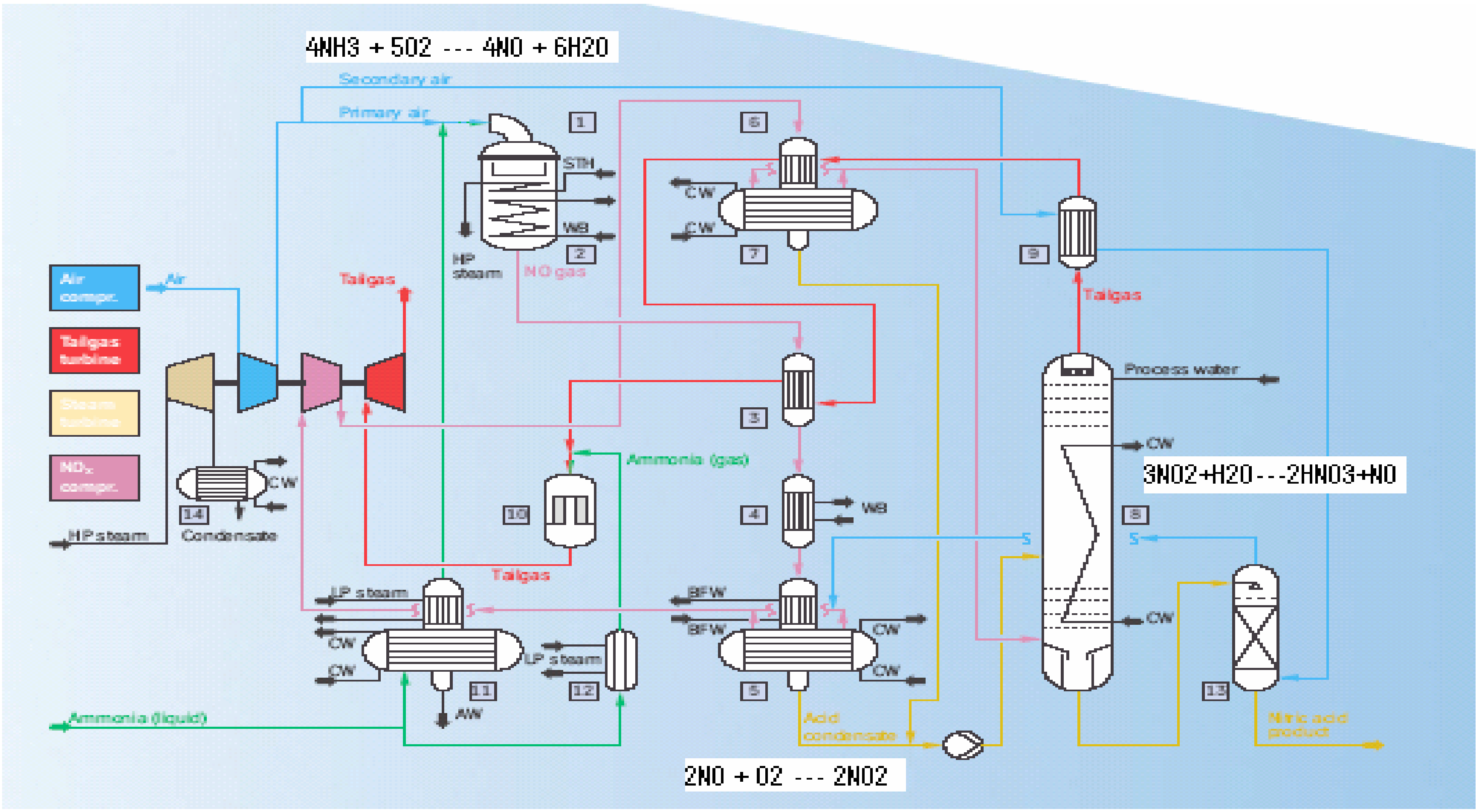
KAAP plus™ :

- Lower capital cost
- Improved reliability
- Reduced operating cost
- Lower energy consumption

Fertilizer - Ammonium Nitrate

- Ammonium Nitrate from Ammonia
  - Nitric acid formation:
    - NH_3 (g) + $2O_2$ (g) ↔ HNO_3 (aq) +H_2O (l)
  - Ammonium nitrate fertilizer:
    - HNO_3 (aq) + NH_3(g) ↔ NH_4NO_3 (aq)

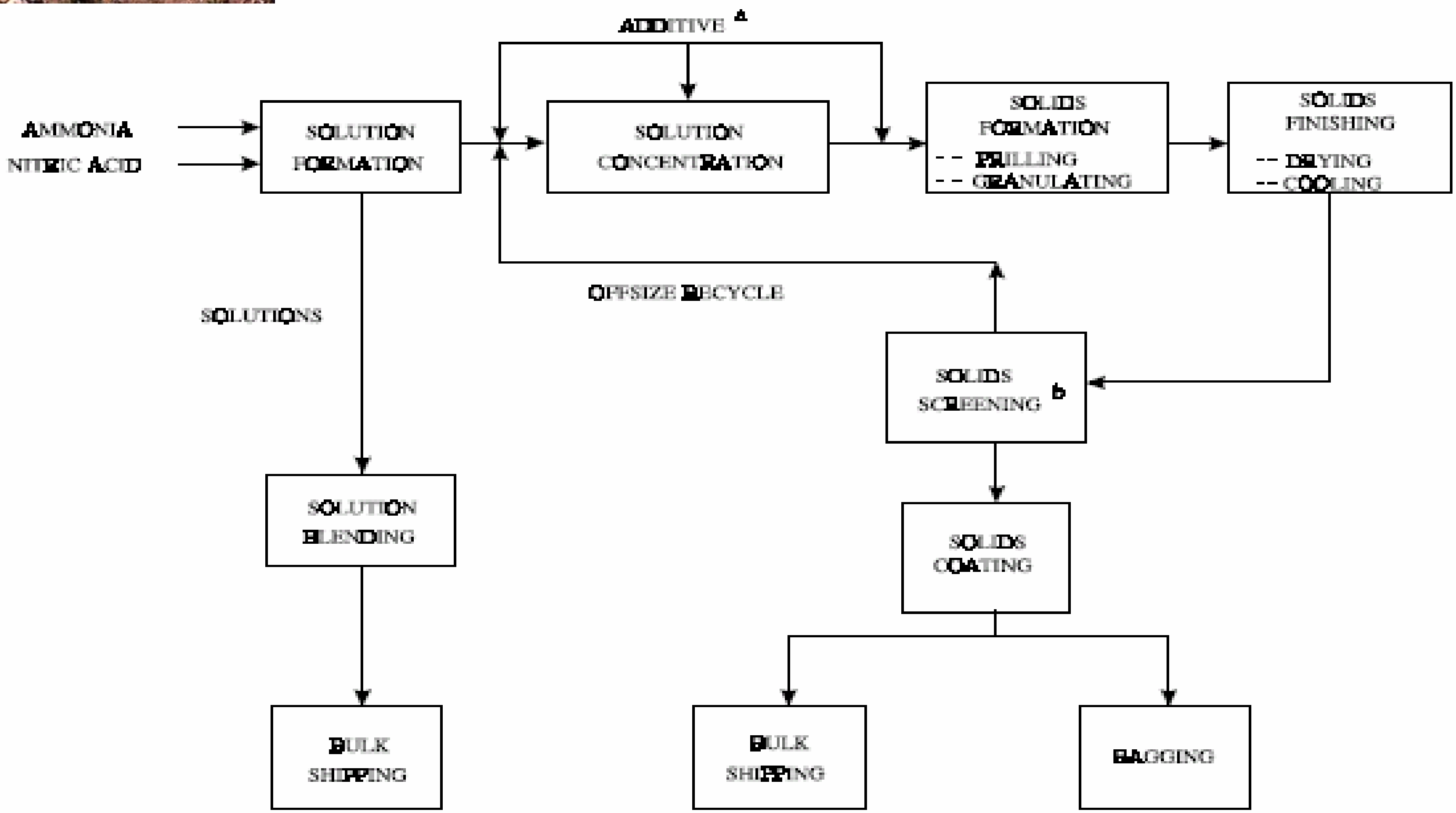
Nitric Acid


4NH3 + 5O2 --- 4NO + 6H2O
Secondary air
Primary air
1
6
STH
CW
CW
WB
7
2
9
HP steam
NO gas
Air
Tailgas
Tailgas
Air compr.
Tailgas turbine
Steam turbine
NOx compr.
Process water
3
CW
Ammonia (gas)
3NO2+H2O---2HNO3+NO
CW
14
10
4
WB
8
HP steam
Condensate
Tailgas
LP steam
BFW
BFW
CW
CW
CW
CW
LP steam
CW
11
12
5
13
AW
Ammonia (liquid)
Acid condensate
Nitric acid product
2NO + O2 --- 2NO2

Nitric Acid

- Uhde Nitric acid
  - High pressure
  - Medium pressure
  - Dual pressure
- Dual pressure
  - Lower operating pressure
  - Lower electricity cost
  - Lower catalyst lost (platinum)

Ammonium Nitrate



a ADDITIVE MAY BE ADDED BEFORE, DURING, OR AFTER CONCENTRATION

b SCREENING MAY BE PERFORMED BEFORE OR AFTER SOLIDS FINISHING

Vinyl Chloride

- Vinnolit vinyl chloride process

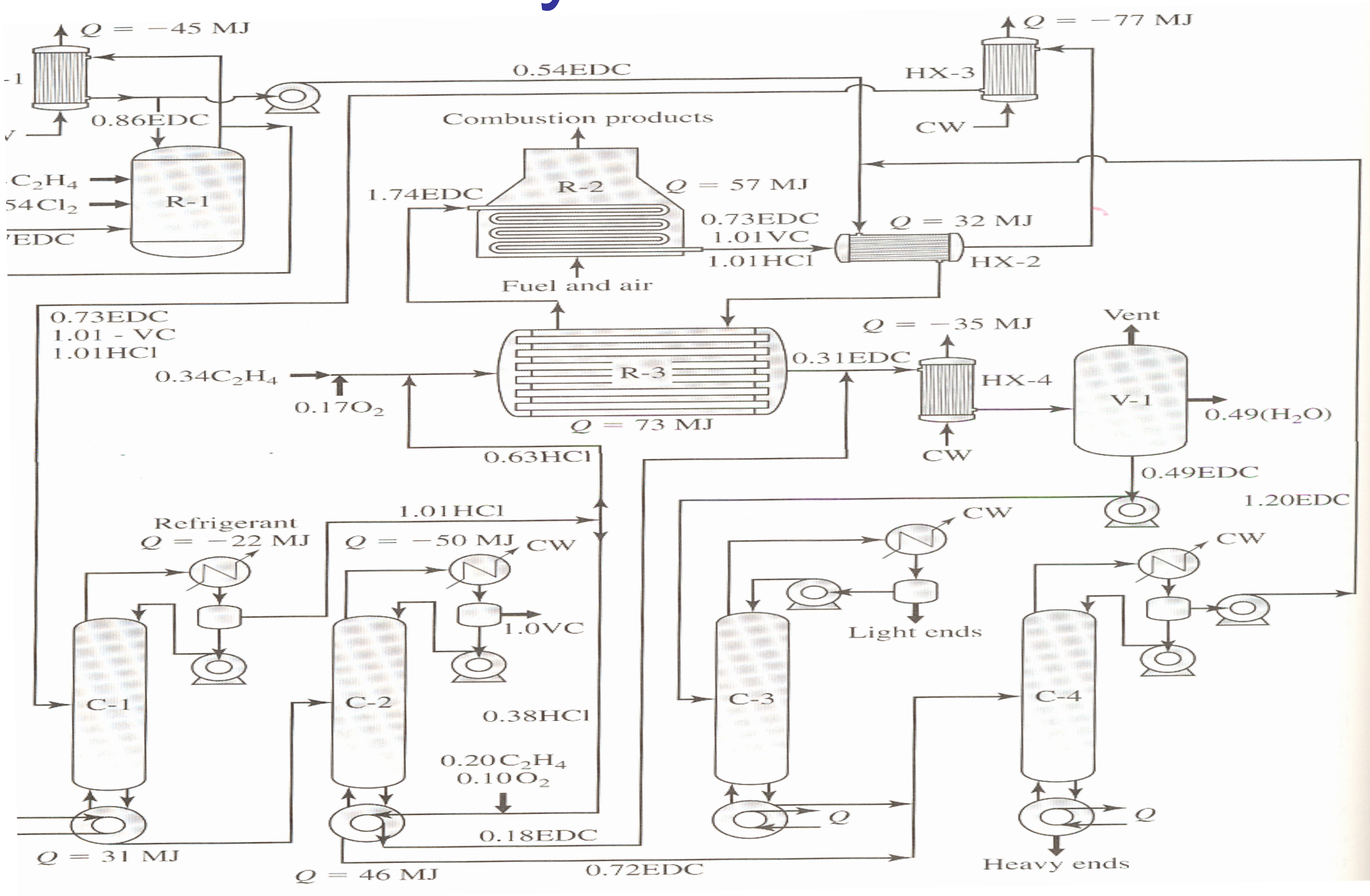
$$C_2H_4 + Cl_2 \rightarrow C_2H_4Cl_2$$

$$C_2H_4 + 2HCl + \frac{1}{2}O_2 \rightarrow C_2H_4Cl_2 + H_2O$$

$$2C_2H_4Cl_2 \rightarrow 2C_2H_3Cl + 2HCl$$

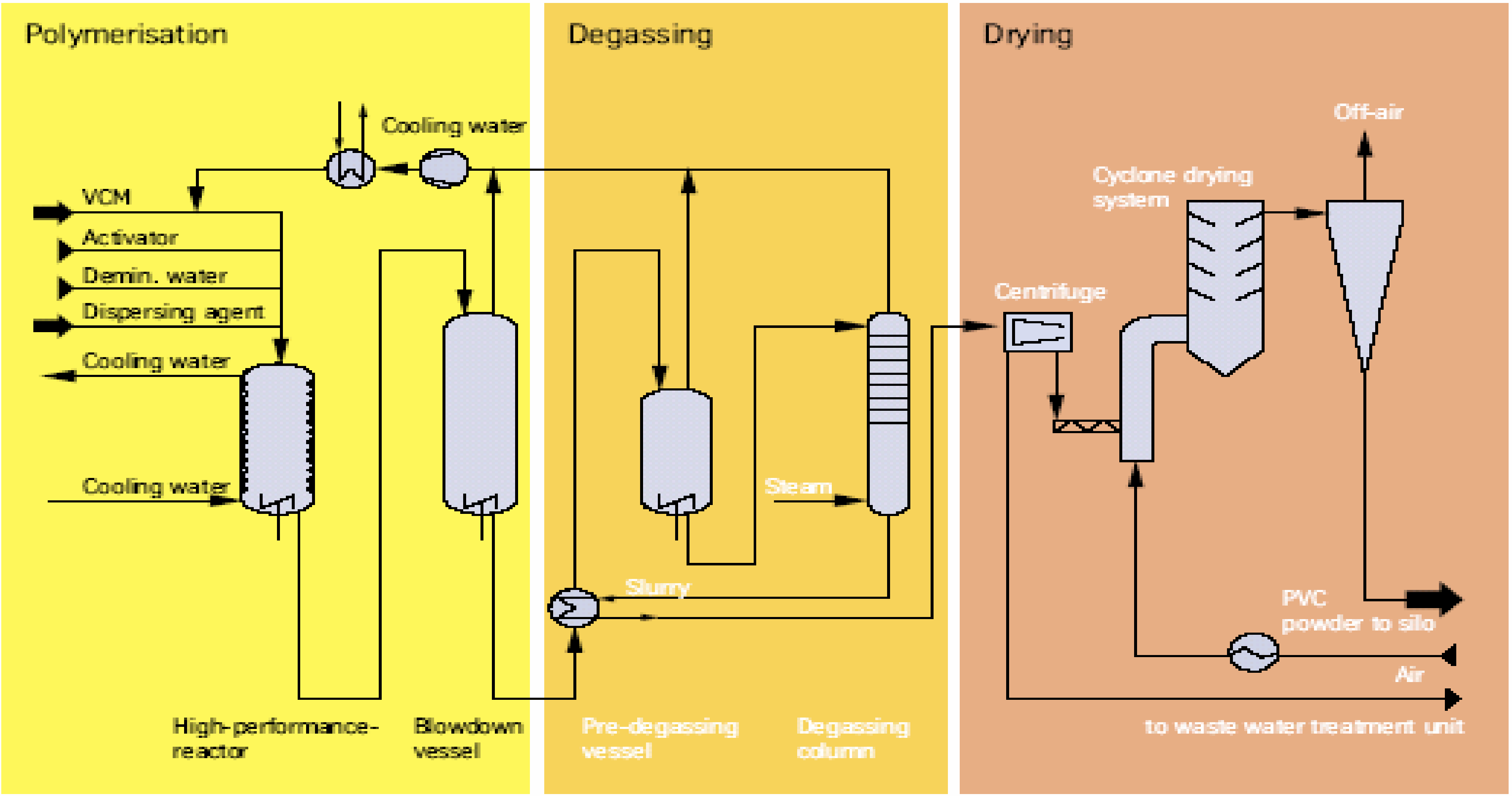
$$2C_2H_4 + Cl_2 + \frac{1}{2}O_2 \rightarrow 2C_2H_3Cl + H_2O(overall)$$

Vinyl Chloride



Polyvinyl Chloride

$$nCH_2 = CHCl \rightarrow [-CH_2 - CHCl -]_n$$



Polyvinyl Chloride (PVC)

Suspension-PVC (S-PVC)

- pipes
- constructions
- bottles
- cable
- bags

Emulsion/Paste-PVC (E/P-PVC)

- flooring
- coated fabrics
- wall coverings

Fischer Tropsch

- Converts natural gas into long chain hydrocarbons and oxygenates

- Alternative Production Route
  - Transportation fuels
  - Petrochemical feedstock

- Large capital investment

- Increased interest
  - High crude oil price

Process Steps

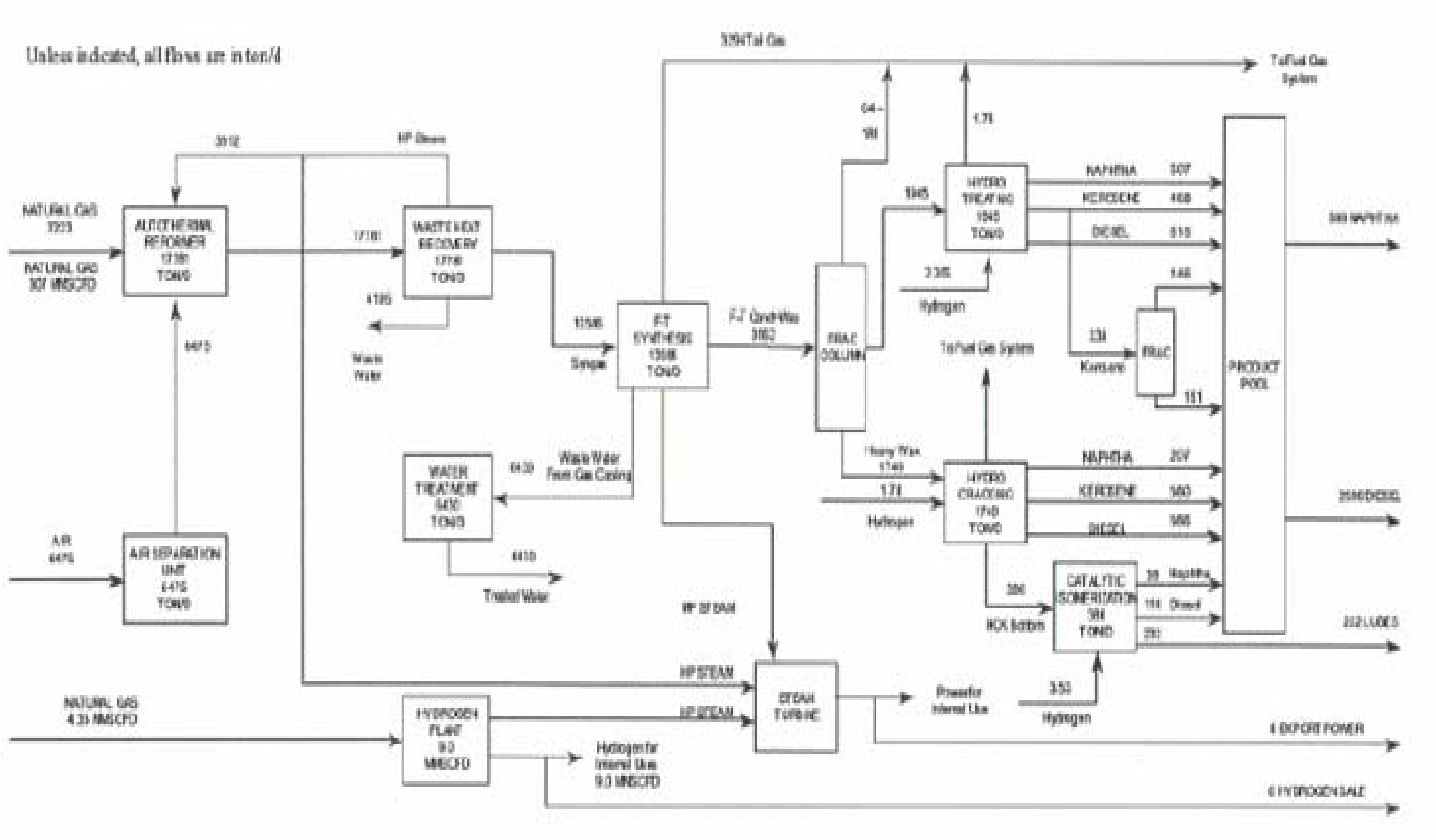
- Synthesis gas manufacturing: produces a mixture of CO and H_2 from natural gas

  $$CH_4 + H_2O \rightarrow CO + 3H_2 \quad \text{(steam reforming)}$$

- Fischer-Tropsch synthesis: converts syngas into a large range of linear hydrocarbons (synthetic crude oil)

  $$nCO + 2nH_2 \rightarrow -(CH_2)_n- + nH_2O$$

- Product upgrading: classic crude oil refinery technique



Sasol Technology Fisher Tropsch Process

Technologies

Sasol Technology

- Uses coal-derived gas as feedstock
- Autothermal reformer
- Cobalt catalyst FT slurry reactor

Advanced Gas Conversion (AGC-21)

- Circulating fluidized bed reactor for syngas
- Slurry cobalt catalyst FT reactor
- Developed by ExxonMobil

Shell Middle Distillate Synthesis (SMDS)

- Non-catalytic combined reforming process for syngas generation
- Fixed-bed Arge-type FT reactor

Methanol Production

1. **Feed Gas Preparation**

   produce mixture of CH_4 and steam from Natural Gas

2. **Synthesis Gas Generation**

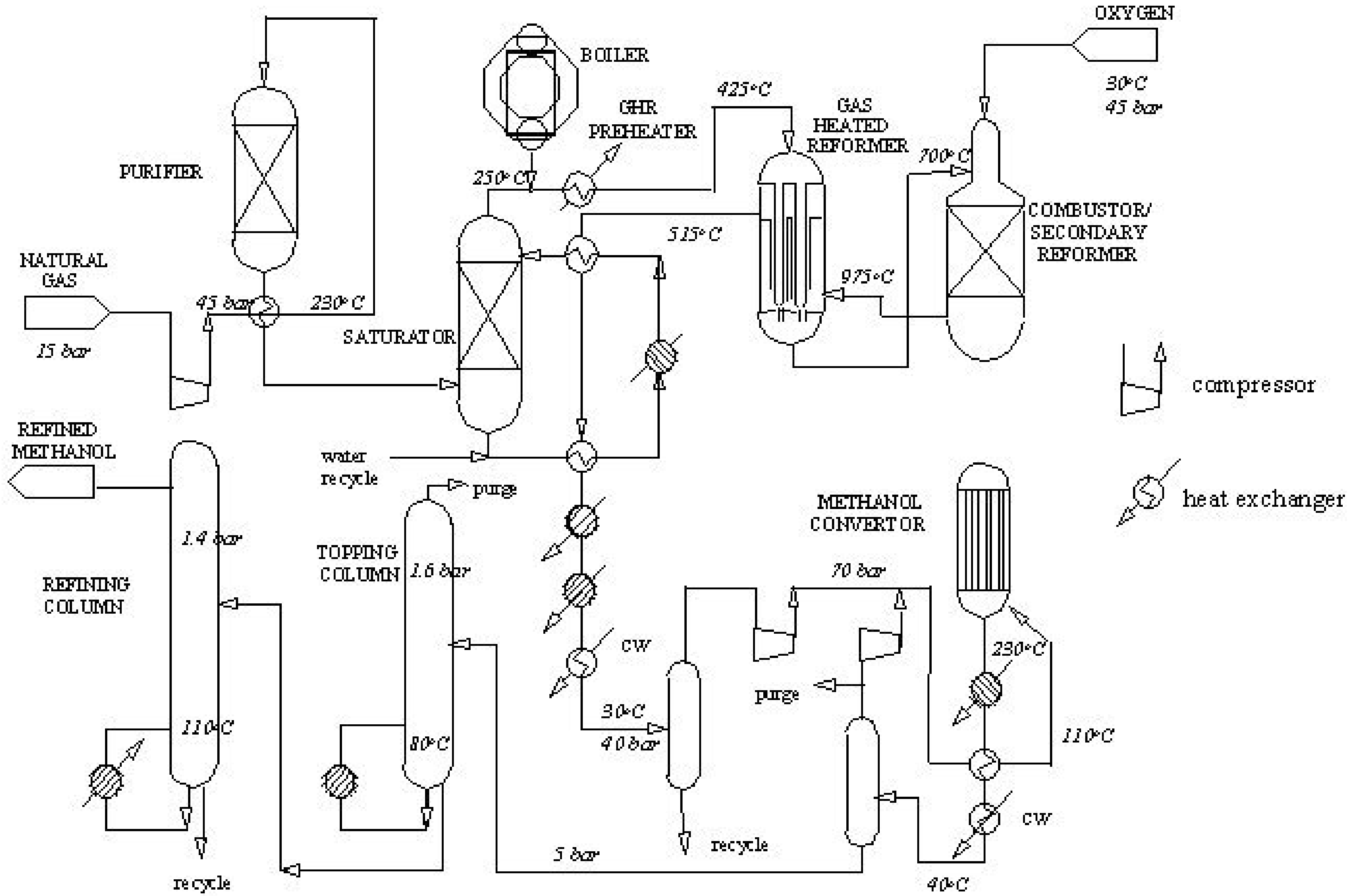
   Steam reforming $CH_4 + H_2O = CO + 3H_2$

   Shift reaction $CO + H_2O = CO_2 + H_2$

3. **Methanol Synthesis**

   $CO + 2H_2 = CH_3OH$

   $CO_2 + 3H_2 = CH_3OH + H_2O$



Flow diagram of a Leading Concept Methanol Plant

Technologies

Low Pressure Methanol (LPM)

- LPM uses low pressure reformer
- Produces 60% of the methanol in the world

Gas Heated Reformer (GHR)

- Enables manufacture of greater volumes of methanol
- Reduces the cost of production

Leading Concept Methanol (LCM)

- LCM brings together GHR with the LPM
- More compact
- More economical

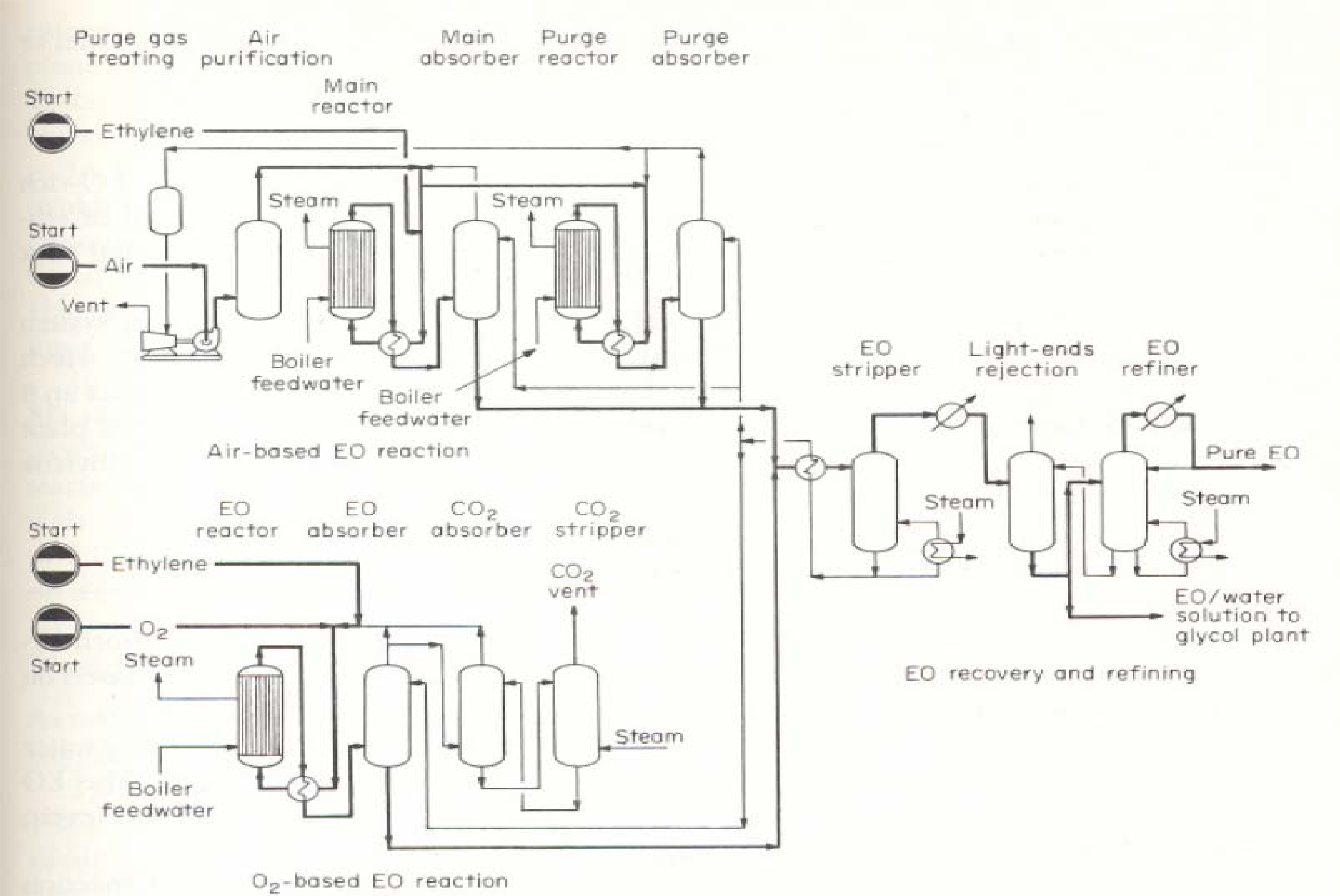
Ethylene Glycol

- Most ethylene glycol plants use hydration of ethylene oxide
- Consisted of two processes
  - Production of ethylene oxide from ethylene

    $$CH_2{=}CH_2 + \tfrac{1}{2}\,O_2 \rightarrow (CH_2)_2O$$

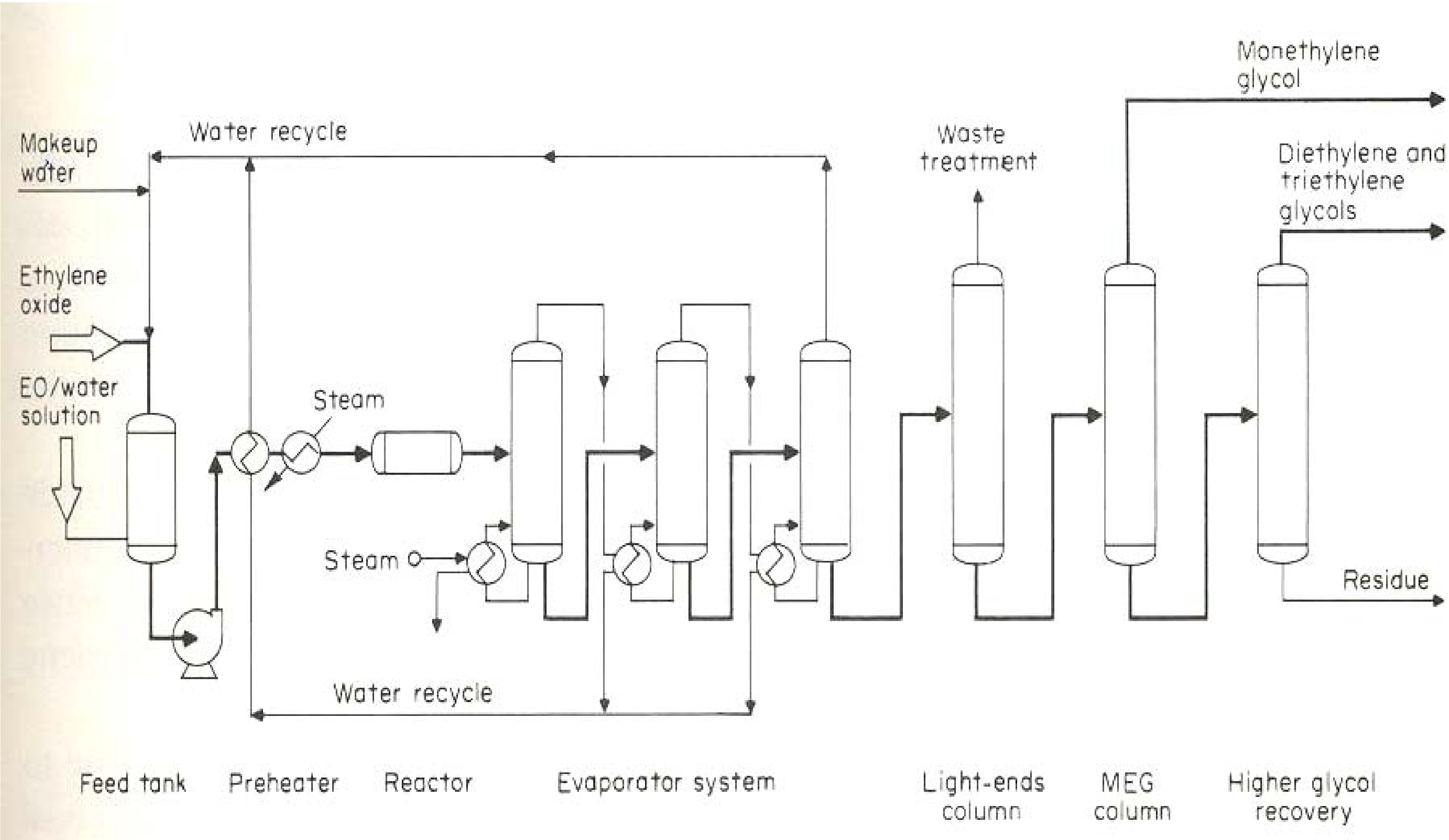
  - Production of ethylene glycol from ethylene oxide

    $$(CH_2)_2O + H_2O \rightarrow \underset{\displaystyle OH}{\underset{|}{CH_2}}\text{—}\underset{\displaystyle OH}{\underset{|}{CH_2}}$$



Halcon SD Group Ethylene Oxide Process

Ethylene Glycol Process



Schematic flow diagram of Halcon SD ethylene glycol plant

Deterministic Model

Planning Model Input

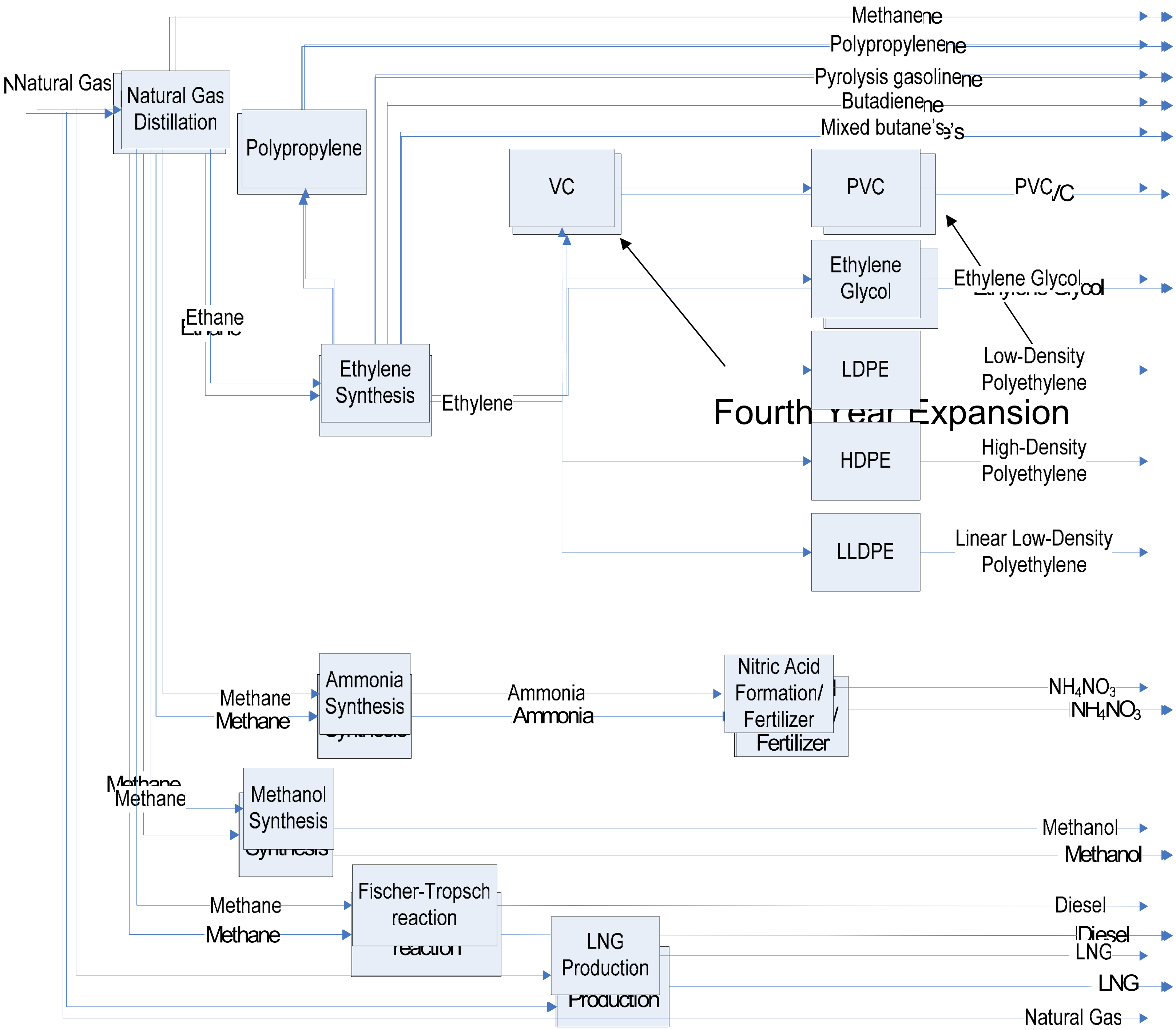
Process	Fixed Capital Investment	Operating Cost
Ethylene Synthesis	$FCI = 2.22Q + 29.72$	$OC = 6.02Q + 2.18$
Low Density Polyethylene	$FCI = 4.46Q + 9.88$	$OC = 1.30Q + 2.49$
High Density Polyethylene	$FCI = 9.76Q + 12.83$	$OC = 2.10Q + 2.18$
Linear-Low Density Polyethylene	$FCI = 9.76Q + 12.83$	$OC = 21.87Q + 2.18$
Polypropylene	$FCI = 12.92Q + 26.30$	$OC = 1.74Q + 2.18$
Vinyl Chloride	$FCI = 0.58Q + 6.70$	$OC = 2.92Q + 5.10$
Polyvinyl Chloride	$FCI = 1.26Q + 16.26$	$OC = 1.85Q + 0.16$
Ammonia Synthesis	$FCI = 28.45Q + 30.59$	$OC = 6.97Q + 6.75$
Fertilizer	$FCI = 1.66Q + 10.58$	$OC = 2.04Q + 11.86$
Methanol	$FCI = 6.46Q + 16.11$	$OC = 1.68Q + 22.83$
Ethylene Glycol	$FCI = 2.05Q + 9.38$	$OC = 2.16Q + 39.22$
Fischer Tropsch	$FCI = 6.23Q + 156.31$	$OC = 1.33Q + 50.23$
Liquid Natural Gas	$FCI = 4.47Q + 620.69$	$OC = 0.0027Q + 35.4$

Deterministic Parameters

- Natural Gas Flow Rate
  - Maximum: 10,000,000 ft^3/day
  - Minimum: 50,000 ft^3/day
- Maximum Initial Investment - $7 Billion
- Taxes – 10%
- Interest Rate – 5%
- Reinvestment – 20%

Initial Model Design Results

- NPW - $40.5 Billion
- FCI - $6.50 Billion
- Expansion Costs - $2.56 Billion
- Natural gas flow rate – 3.5 Million ft^3/day



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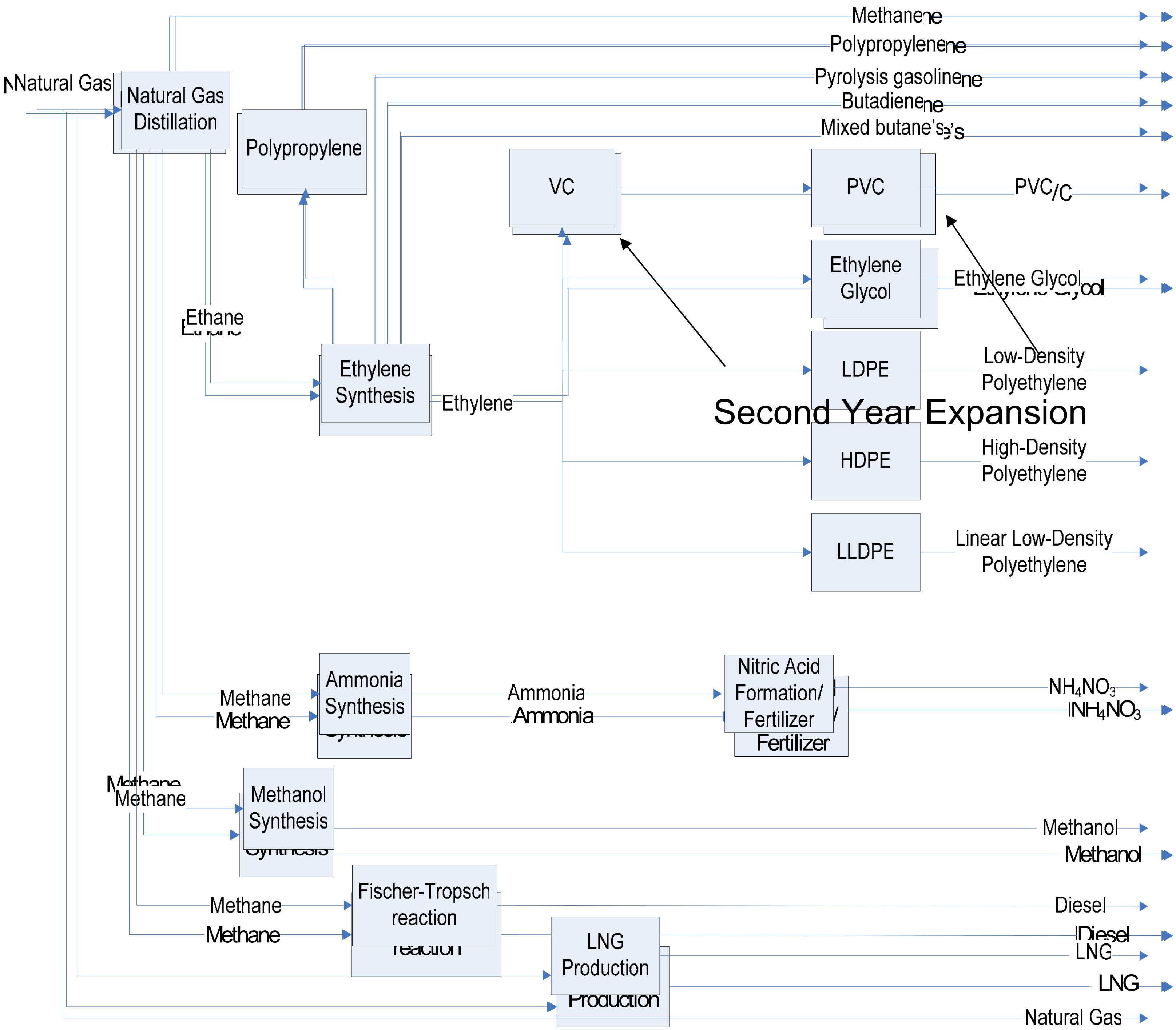
Reinvestment

- Reinvestment initially set to 20%
  - Inefficient
- Reinvestment allowed to vary
  - Maximum Value: 100%
  - Minimum Value: 0%
  - Increased NPW $12 Billion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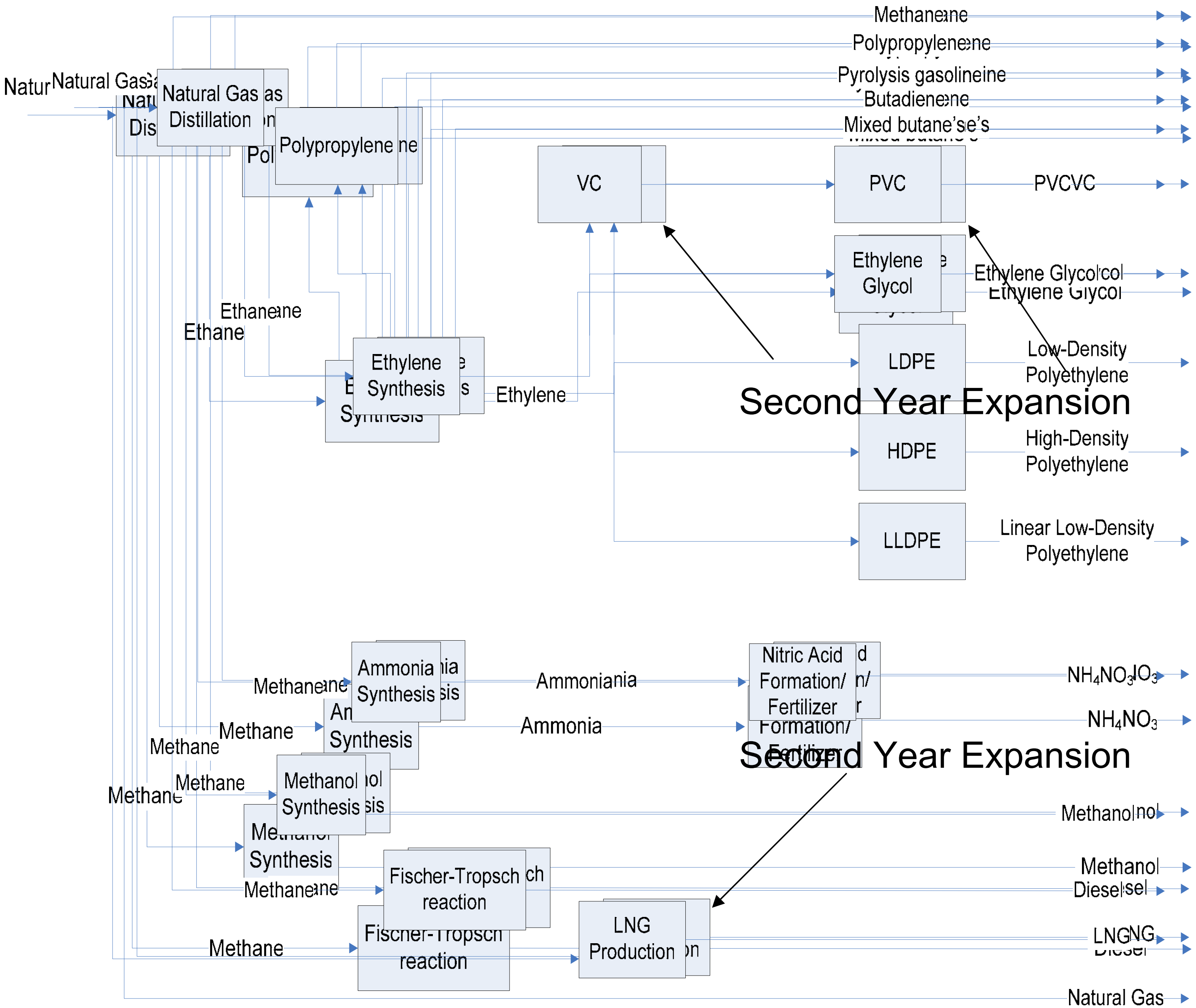
Deterministic Model Results

Maximum Initial Investment (Billions)	NPW (Billions)	Actual Initial Investment (Millions)	Reinvestment (Millions)	Capital (Millions)	ROI
$6	$50.9	$6,000.0	$2,838.83	$8,838.8	57.6%
$7	$52.5	$6,504.7	$2,558.40	$9,063.1	57.9%
$8	$53.3	$6,504.7	$2,558.40	$9,063.1	58.8%
$9	$55.0	$8,963.4	$0.00	$8,963.4	61.4%



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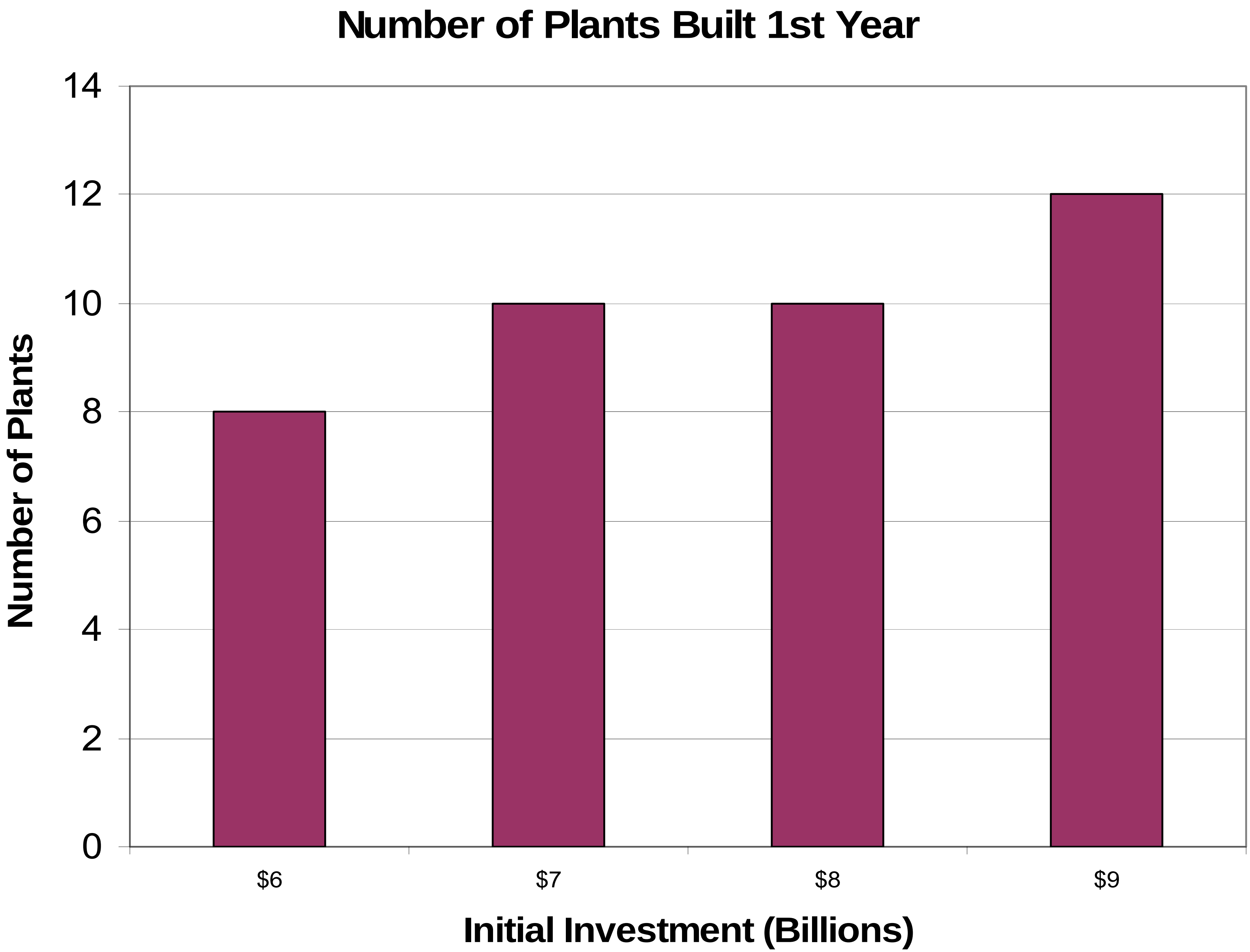
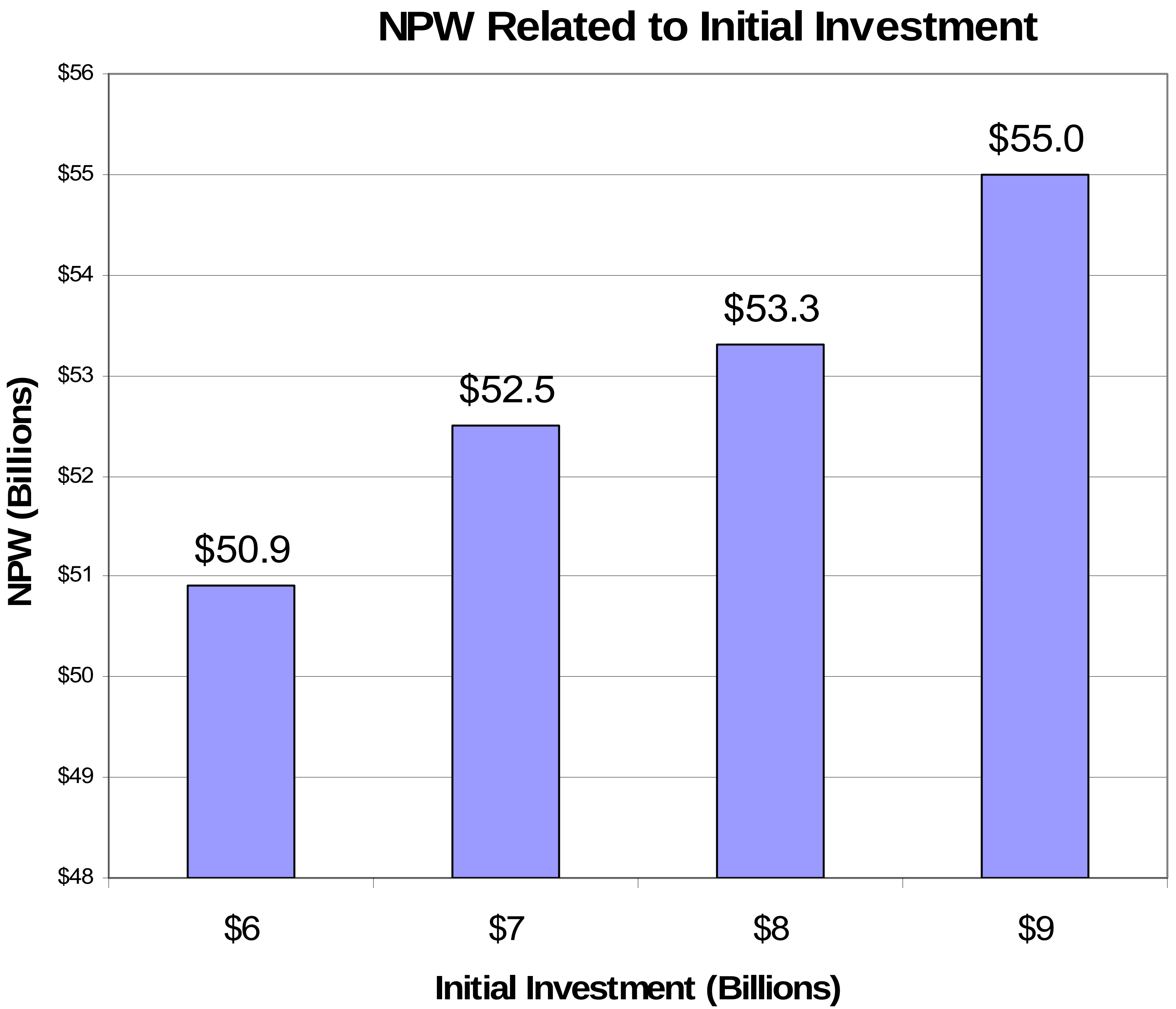


Number of Plants Built 1st Year
Number of Plants
14
12
10
8
6
4
2
0
$6
$7
$8
$9
Initial Investment (Billions)


NPW Related to Initial Investment
$56
$55
$54
$53
$52
$51
$50
$49
$48
NPW (Billions)
$50.9
$52.5
$53.3
$55.0
$6
$7
$8
$9
Initial Investment (Billions)

Sensitivity Analysis

- Vary product prices
  - Determine the effect of price on process flow rate
  - Range of prices that does not affect overall results

Cost Analysis

	Initial Price ($/kg)	Profitable Price ($/kg)	NPW (Billions)
Low Density Polyethylene	$1.65	$3.50	$54.1
High Density Polyethylene	$1.59	$3.00	$54.2

Cost Analysis

- Polyvinyl Chloride, Initial Price - $1.26/kg
  - New Price - $1.10/kg
    - Built 1st year, not 2nd
    - Smaller process flow rate
  - New Price - $1.00/kg
    - Polyvinyl Chloride not sold

PVC Price	NPW (Billions)
$1.26/kg	$52.5
$1.10/kg	$48.7
$1.00/kg	$45.8

Cost Analysis

- Methanol, Initial Price - $0.316/kg
  - New Price - $0.27/kg
    - NPW - $48.9 Billion
  - New Price - $0.10/kg
    - Process still built
    - NPW - $38.4 Billion

Methanol Price	NPW (Billons)
$0.316/kg	$52.5
$0.25/kg	$48.9
$0.10/kg	$38.4

Stochastic Model

Stochastic Model

- Stochastic model
  - Uncertainties
    - Price, demand
  - First Stage Variables
    - “Here and Now Decision”
    - Plants built in first five years
  - Second Stage Variables
    - “Wait and See Decision”
    - Capacities, feed flow rate, plants built after fifth years

Stochastic Model

- What is scenarios?
  - A set of prices and demands of each product in each year
- How to generate scenarios?
  - Sampling distribution probability

El Final

Questions?