LNG Group

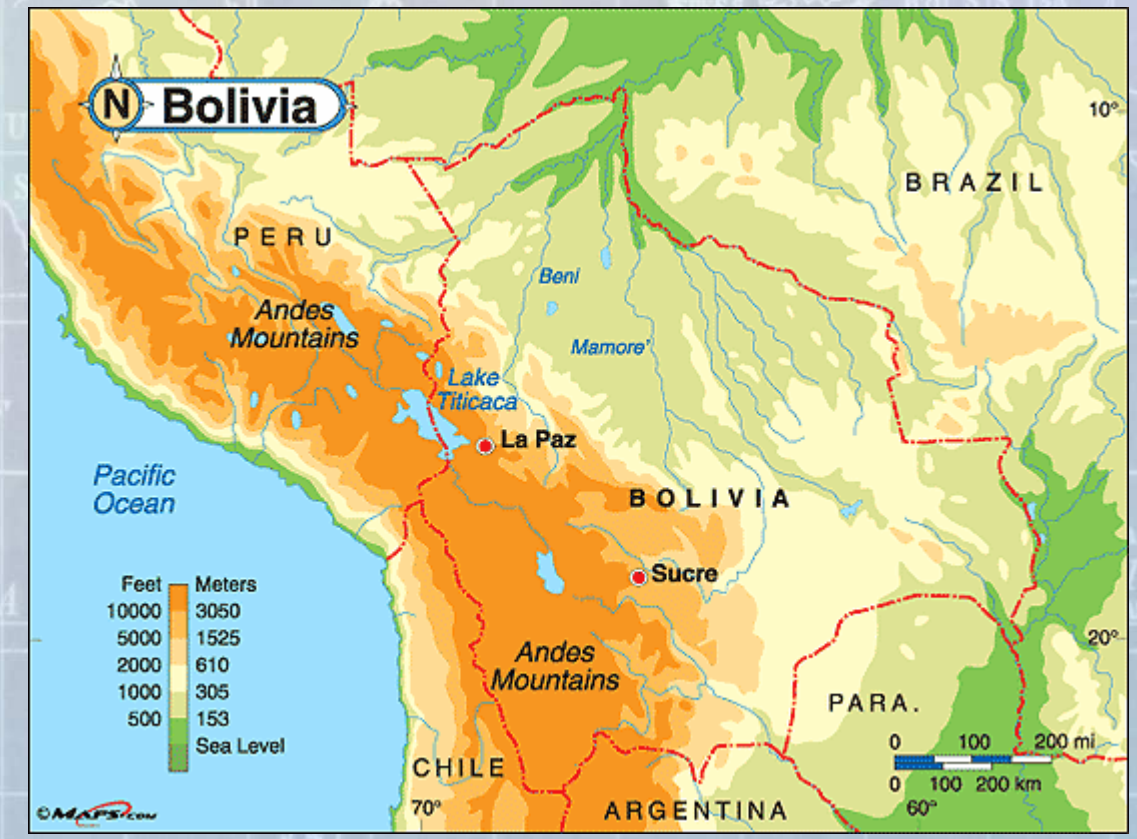
Muhannad Rabeh
Travis Spain
Keith Orendorff

Outline

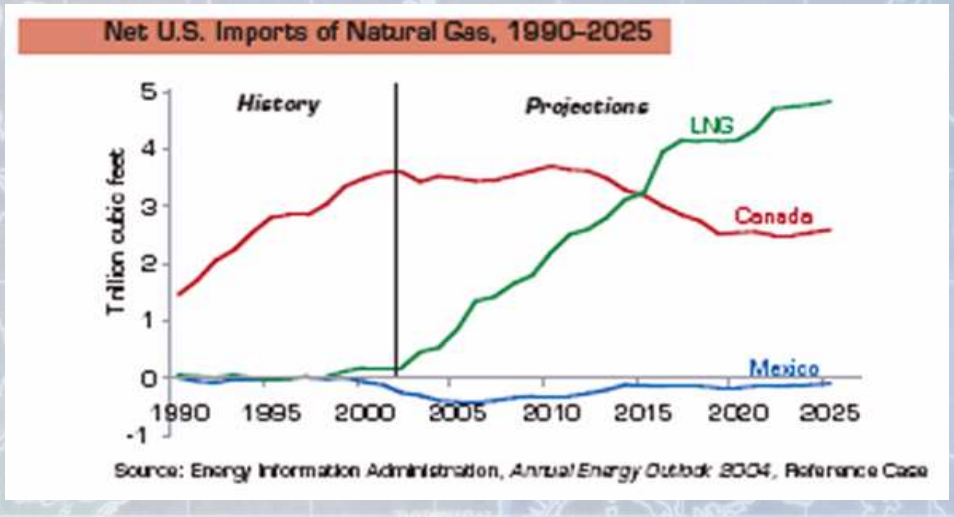
- Overall description
- Market
- Piping
- Shipping
- Pretreatment
- Liquefaction
- Regas.
- Planning
- Risk Analysis
- Questions

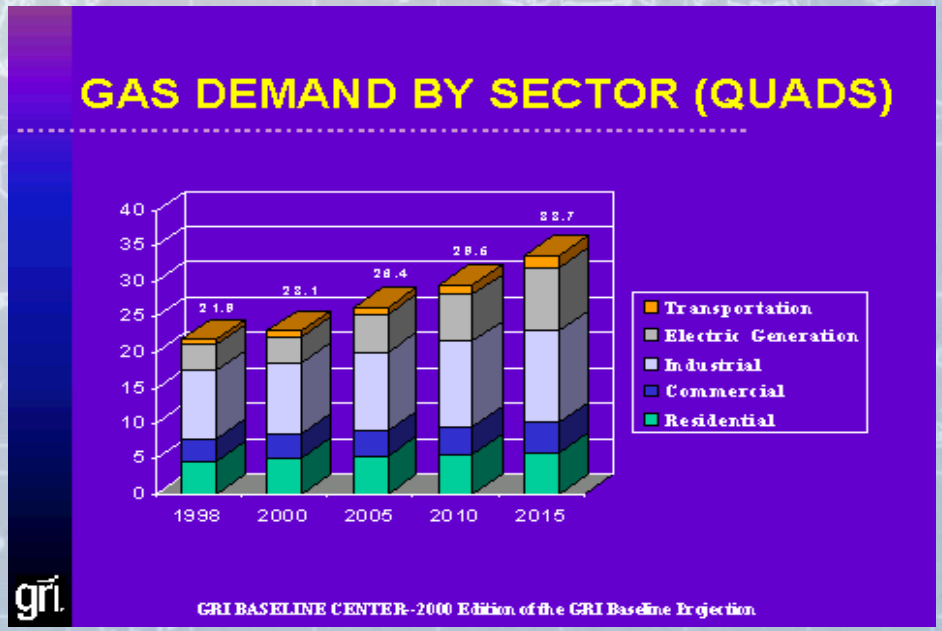
Overall Description

- Purpose
- 53 trillion cubic feet
- 1 BCFD production
- 20 % consumption



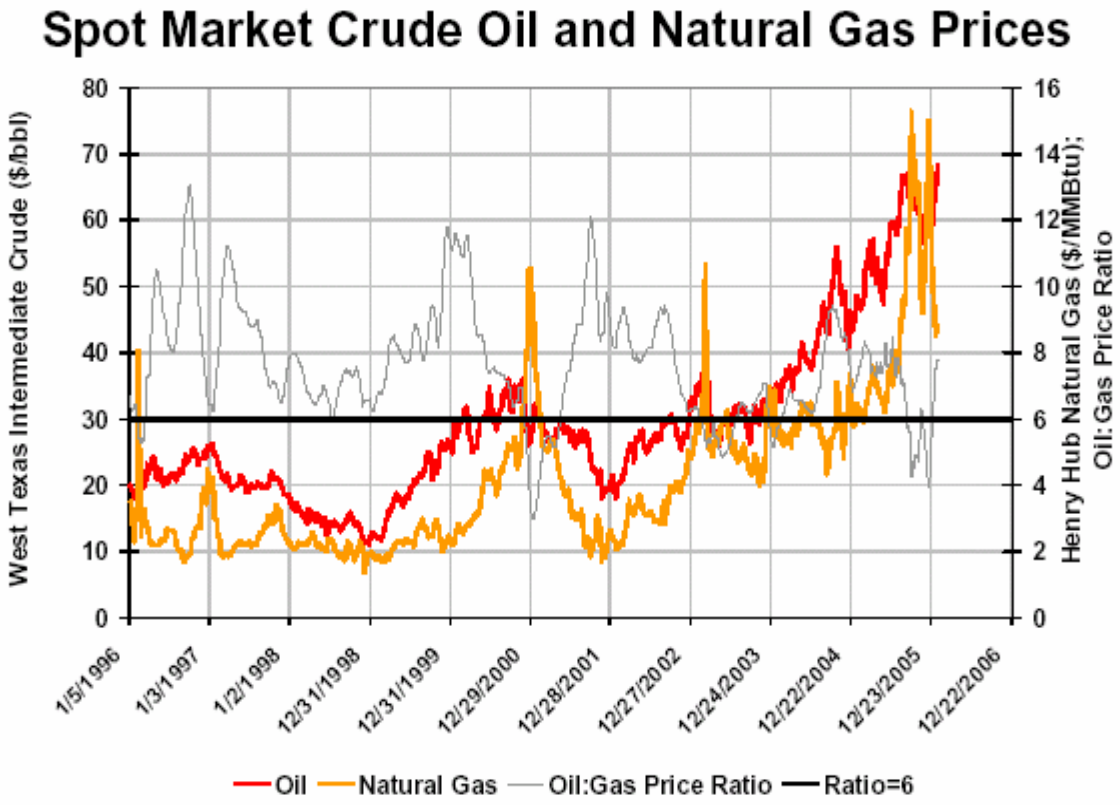
Market Analysis





Market Analysis

Oil prices have risen more than 36 percent over the past 12 months. Natural gas prices are up more than 92 percent over the same period.



Source: U.S. Energy Information Agency

Market Analysis

Petroleum (2005)

Source

In State	37.22%
Alaska	20.99%
Foreign	41.79%

Electricity (2005)

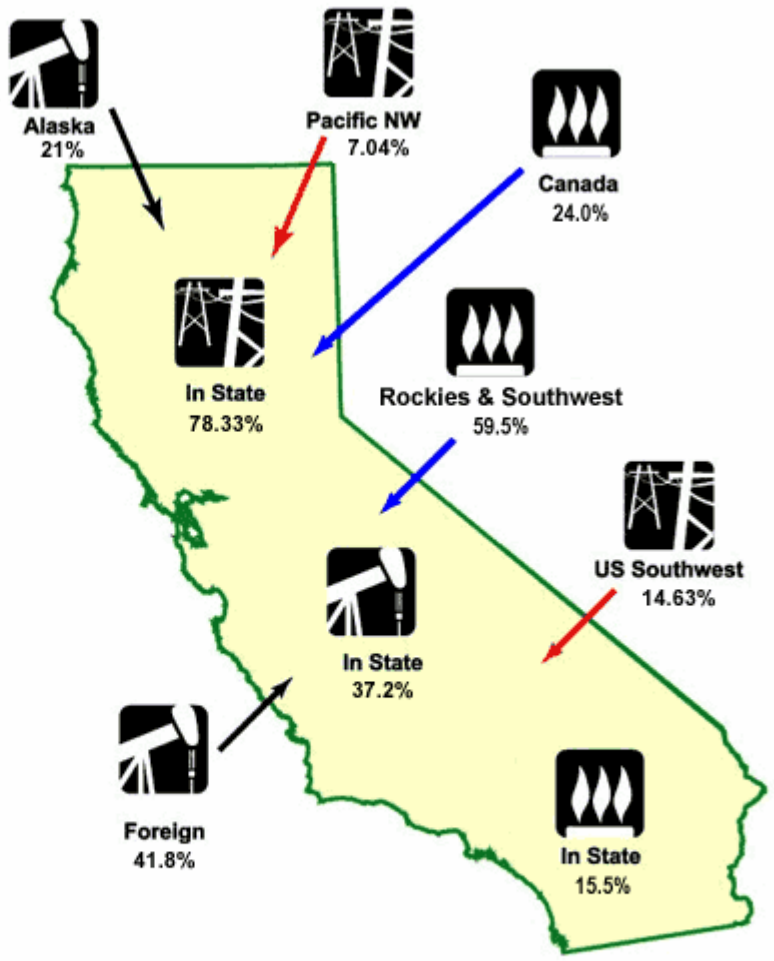
Source

In-State	78.33%
Natural Gas	37.71%
Nuclear	14.47%
Large Hydro	17.03%
Coal*	20.07%
Renewable	10.73%
Imports	21.67%
PNW	7.04%
DSW	14.63%

Natural Gas (2004)

Source

In State	15.5%
Canada	24.0%
Rockies	24.3%
Southwest	36.2%



CALIFORNIA'S ENERGY SOURCES

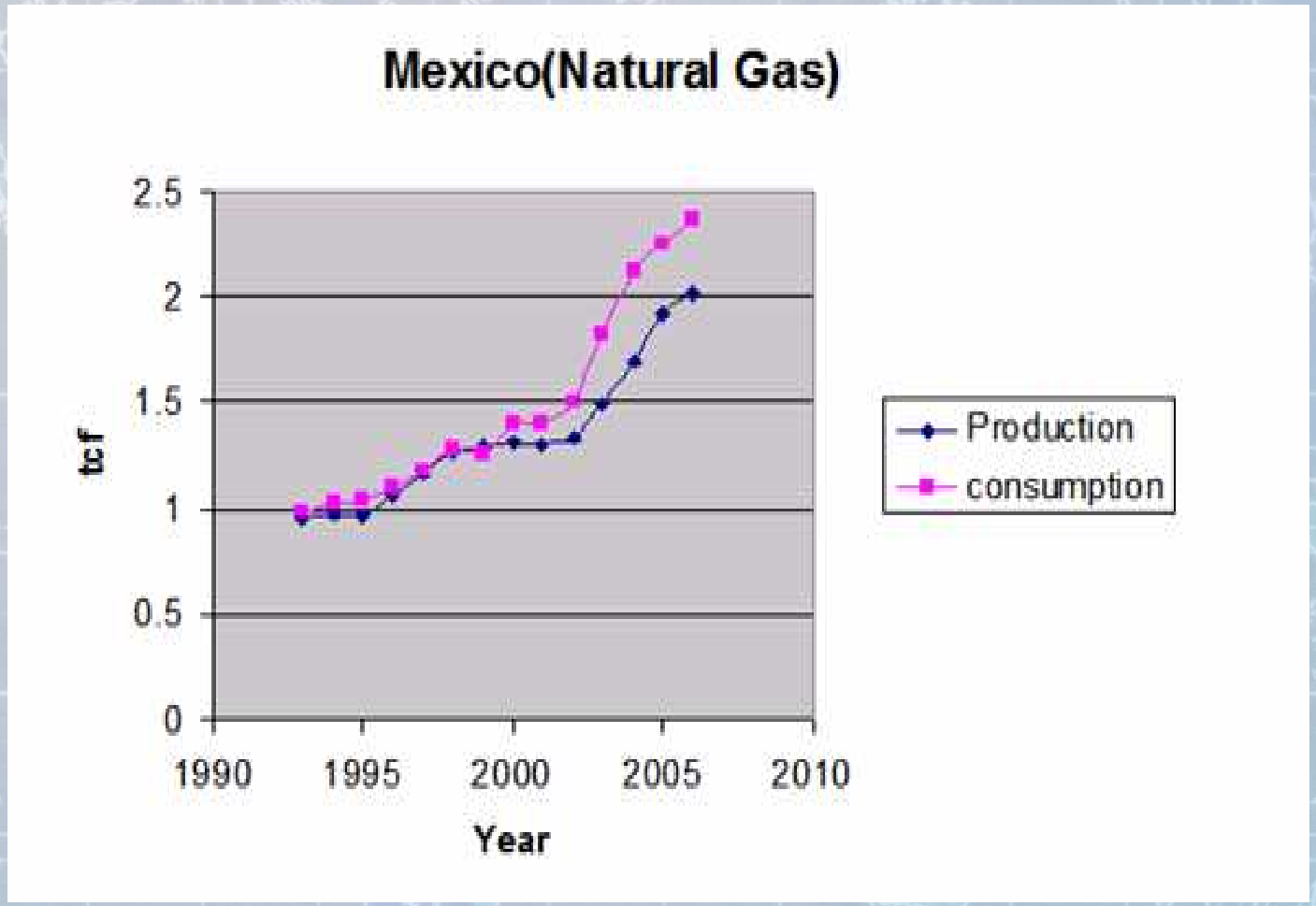
Natural Gas (MCFD)

Production: 867

Consumption: 6,700

Demand: 5,833

Market Analysis



Pipeline Optimization

- **Parameters used in simulation**
  - **Diameters considered: 36, 44, 48, 52 in I.D.**
  - **Length: 996 miles**
  - **Elevation change: 1000 m**
  - **Flow rate: 25 MMcf/h**
  - **Outlet pressure: 800-900 psi**
- **Compressors:**
  - **Not to exceed 1000 psi output**

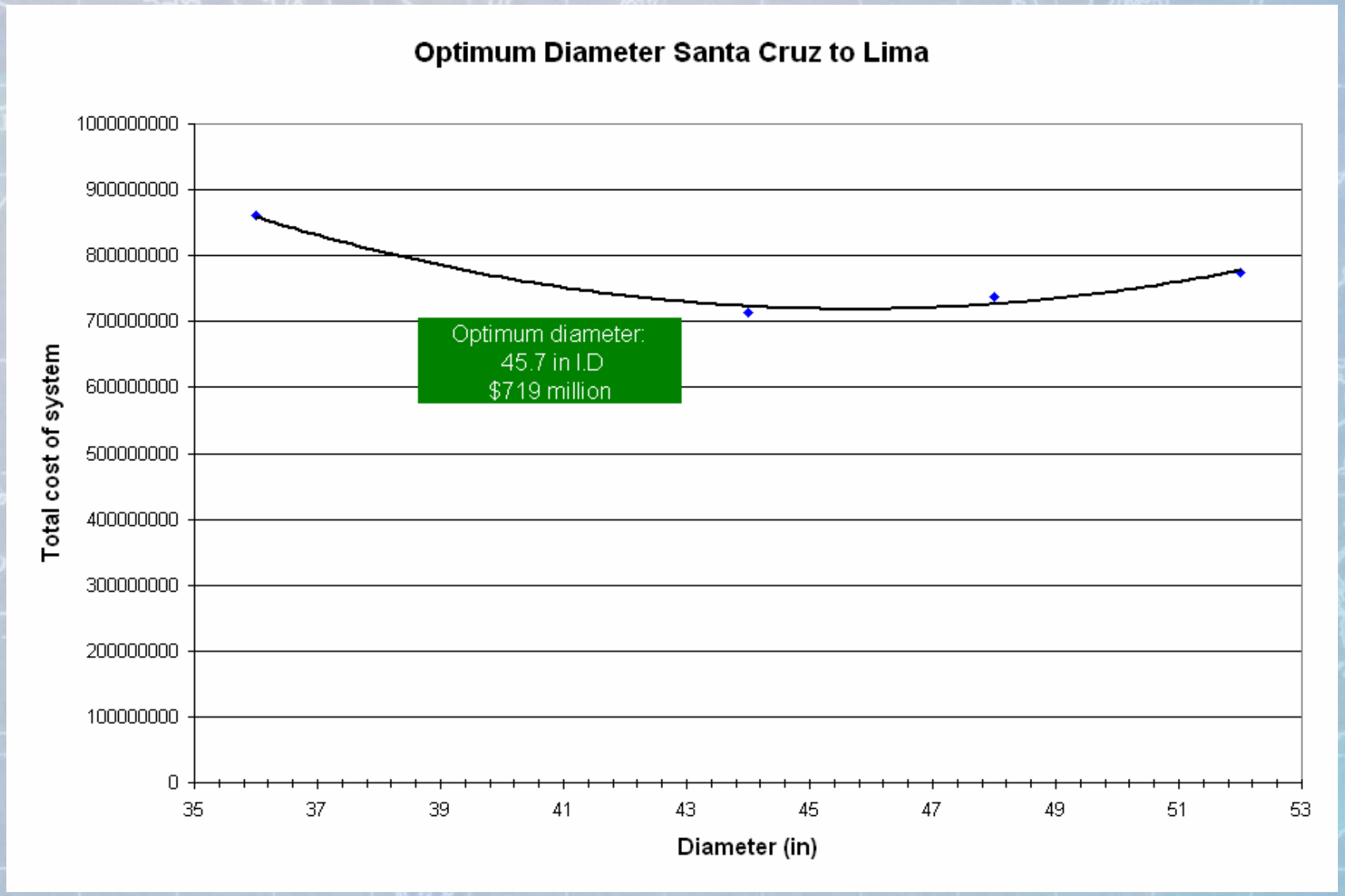
Optimization cnt.

- **Costs:**
  - **Compressors: $2500/hp**
  - **Pipe: Extrapolated from PT&W**
    - **36”: $75/ft**
    - **44”: $91/ft**
    - **48”: $100/ft**
    - **52”: $108/ft**

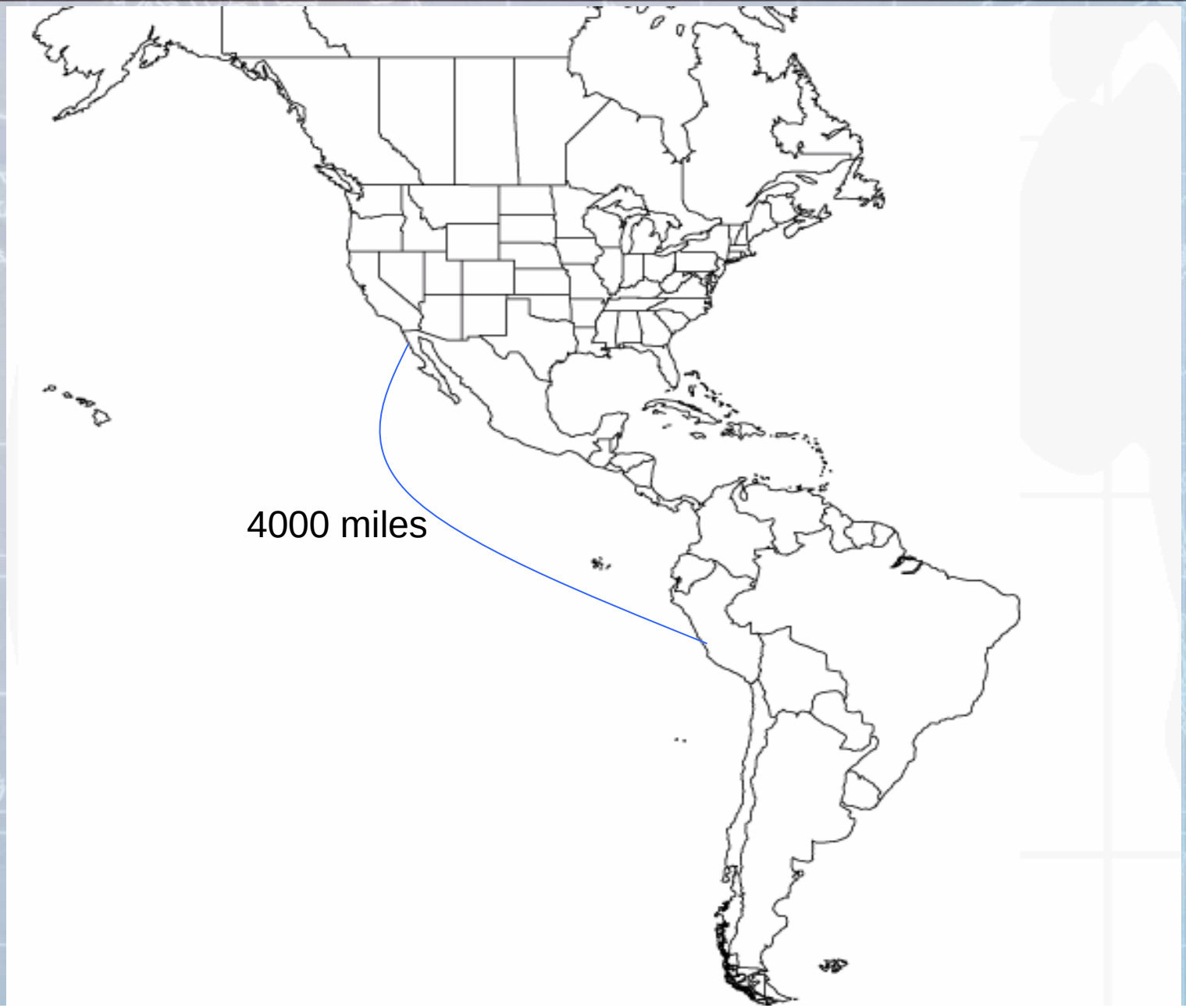
Optimization cnt.

Santa Cruz to Lima					
diameter	number of compressors	Power (hp)	Cost of compressors	cost of piping	total cost
36	4	187688.92	469222300	391030333.1	860252633
44	3	93808.6	234521500	480010582.7	714532083
48	2	85346.06	213365150	524500707.5	737865857
52	2	81913.94	204784850	568990832.3	773775682

Optimization cnt.



Shipping



Shipping

- Capacity: 138,000 m^3
- Speed: 37 Km/hr
- Distance: 4000 miles
- Travel time: 15 days
- Production: 27,520 CMD (137,600 m^3/5days)
- 2 Days to load and unload

<u>2 ships are needed</u>

Shipping

- **Panama Canal is not taken because,**

Capacity, m^3	138,000
Deadweight, tonnes	285
Length Overall, m	43
Beam, m	43
Depth, m	26
Maximum Draft, m	11.4
Ballast Draft, m	9.8

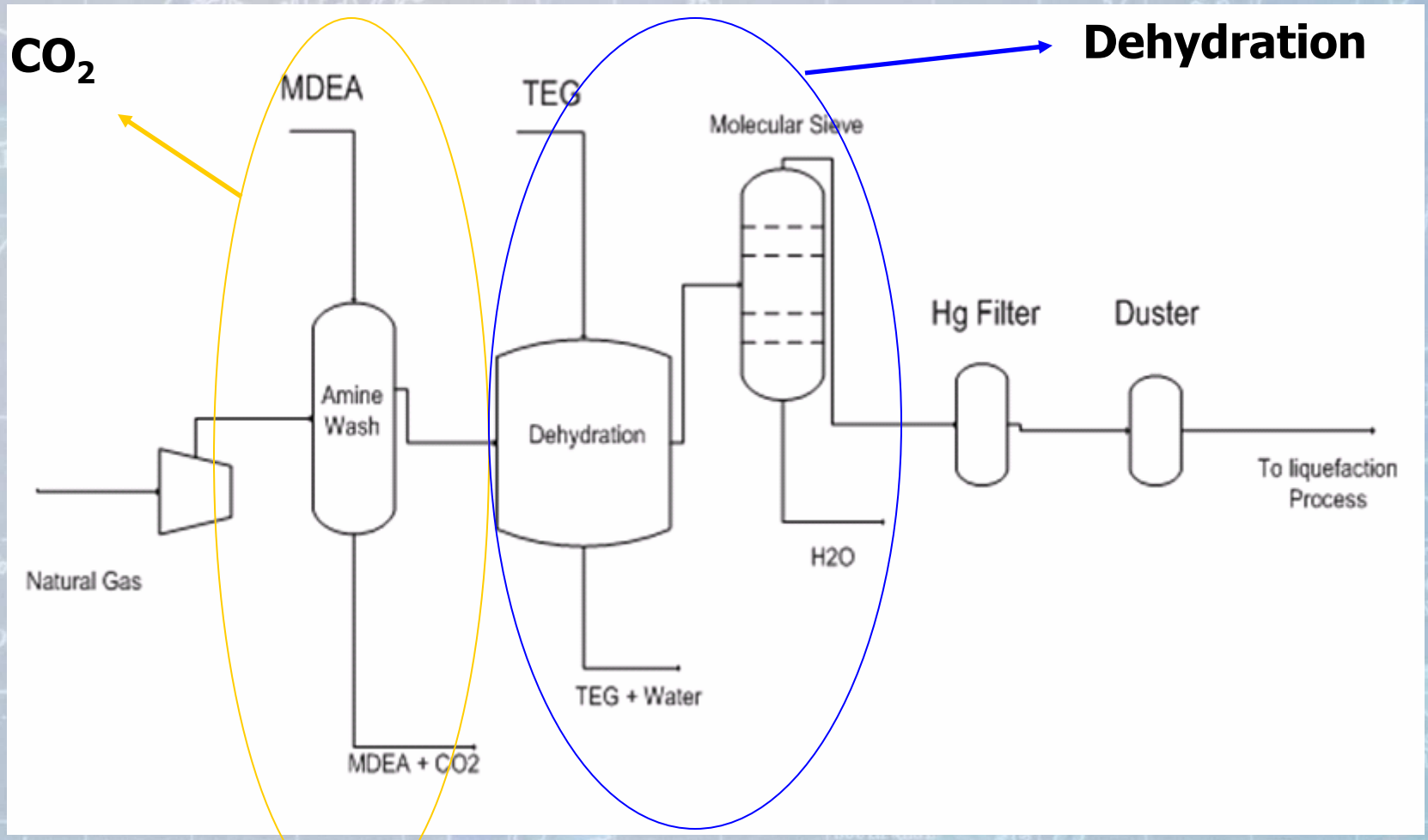
Width, m	33.5
Length, m	304.8
Beam, m	32.3
Depth, m	30

Pretreatment

- Obtain Gas specification (Required: 1,036 Btu/ft^3) (Available: 1,100 Btu/ft^3)
- Protect Equipment
- Environmental Reasons

COMPONENTES	FÓRMULAS	% MOLAR
METANO	CH_4	91,80
ETANO	C_2H_6	5,58
PROPANO	C_3H_8	0,97
I - BUTANO	C_4H_{10}	0,03
N - BUTANO	C_4H_{10}	0,02
PENTANO	C_5H_{12}	0,10
NITROGÊNIO	N_2	1,42
DIÓXIDO DE CARBONO	CO2	0,08
TOTAL		**100,00**

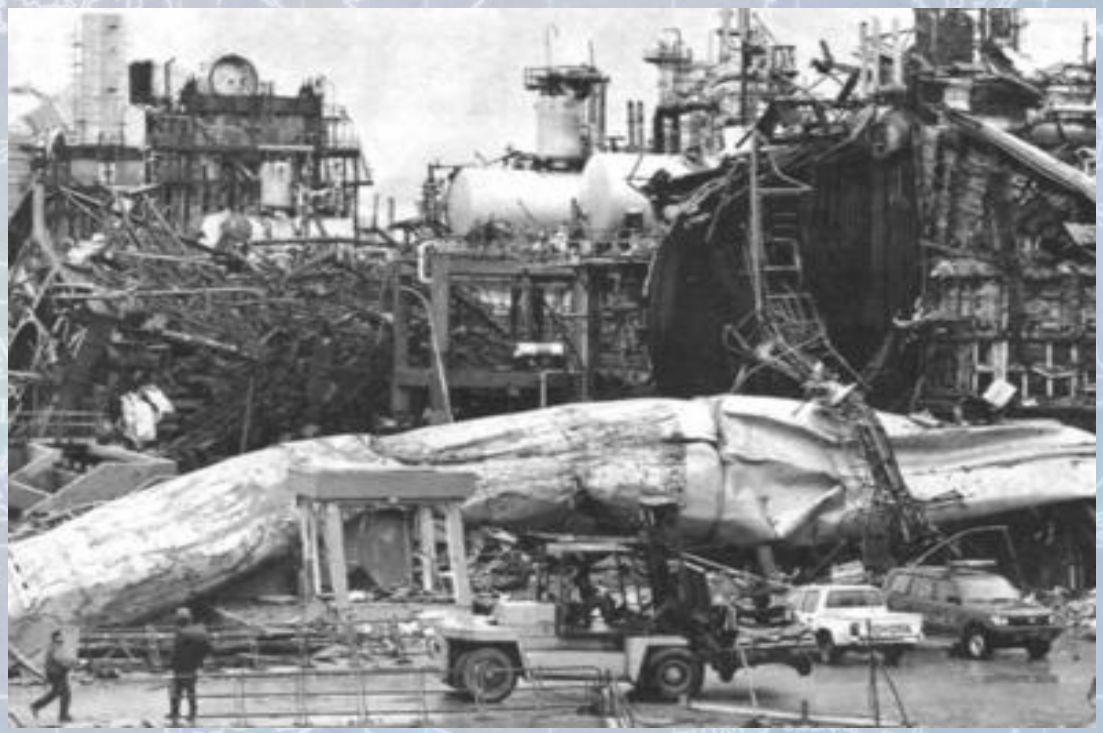
Pretreatment



Pretreatment

- CO_2 Removal (50-100 ppm)
  Sulfinol vs. MDEA
- Water Removal (<0.1 ppm)
  1- TEG
  2- Molecular Sieves (2/train)
  3- Pre-cooling
- Hg Filter (<0.01 Microgram/m^3)
  (Alumina) Sulfide to form HgS
  Safety
  Inexpensive
- Duster
  Solid particles

Mercury Catastrophe



Skikda, Algeria

Liquefaction

A (Entrance from Pretreatment @ 100F)

A – B (Air/Water HX)

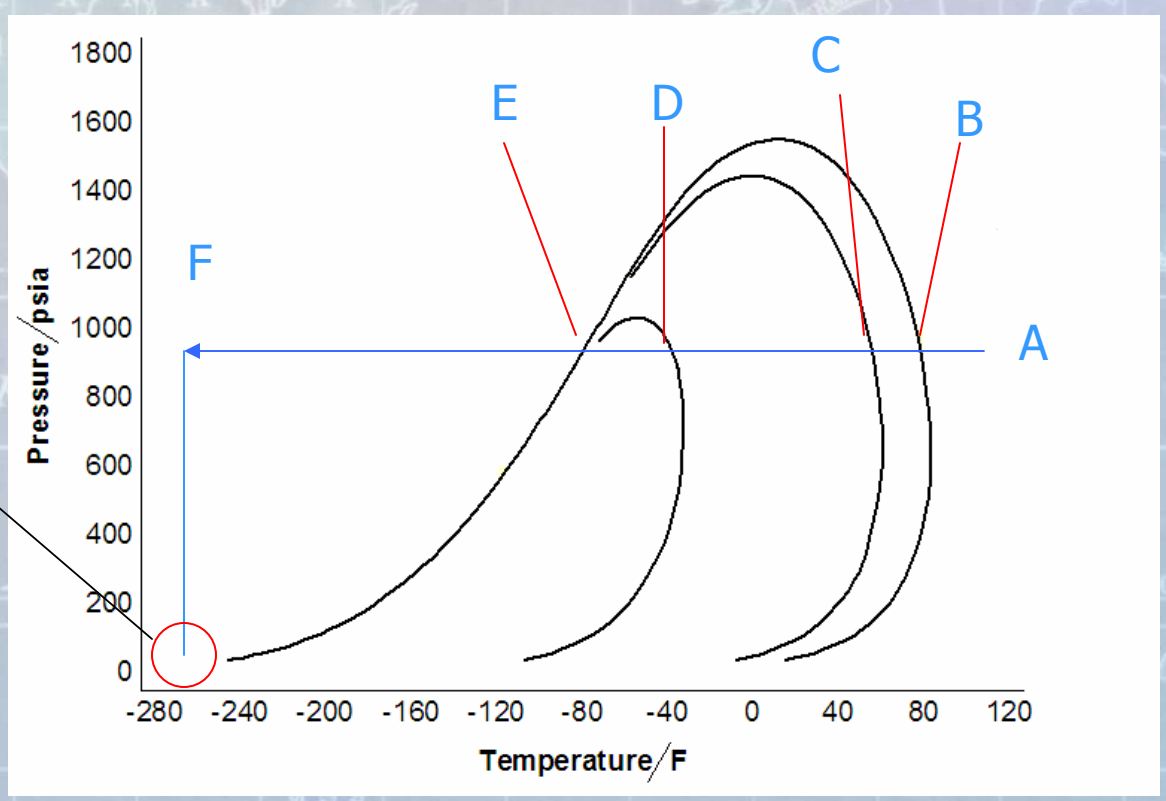
B – C (Propane Chillers)

C – D (Scrub column/ propane stage)

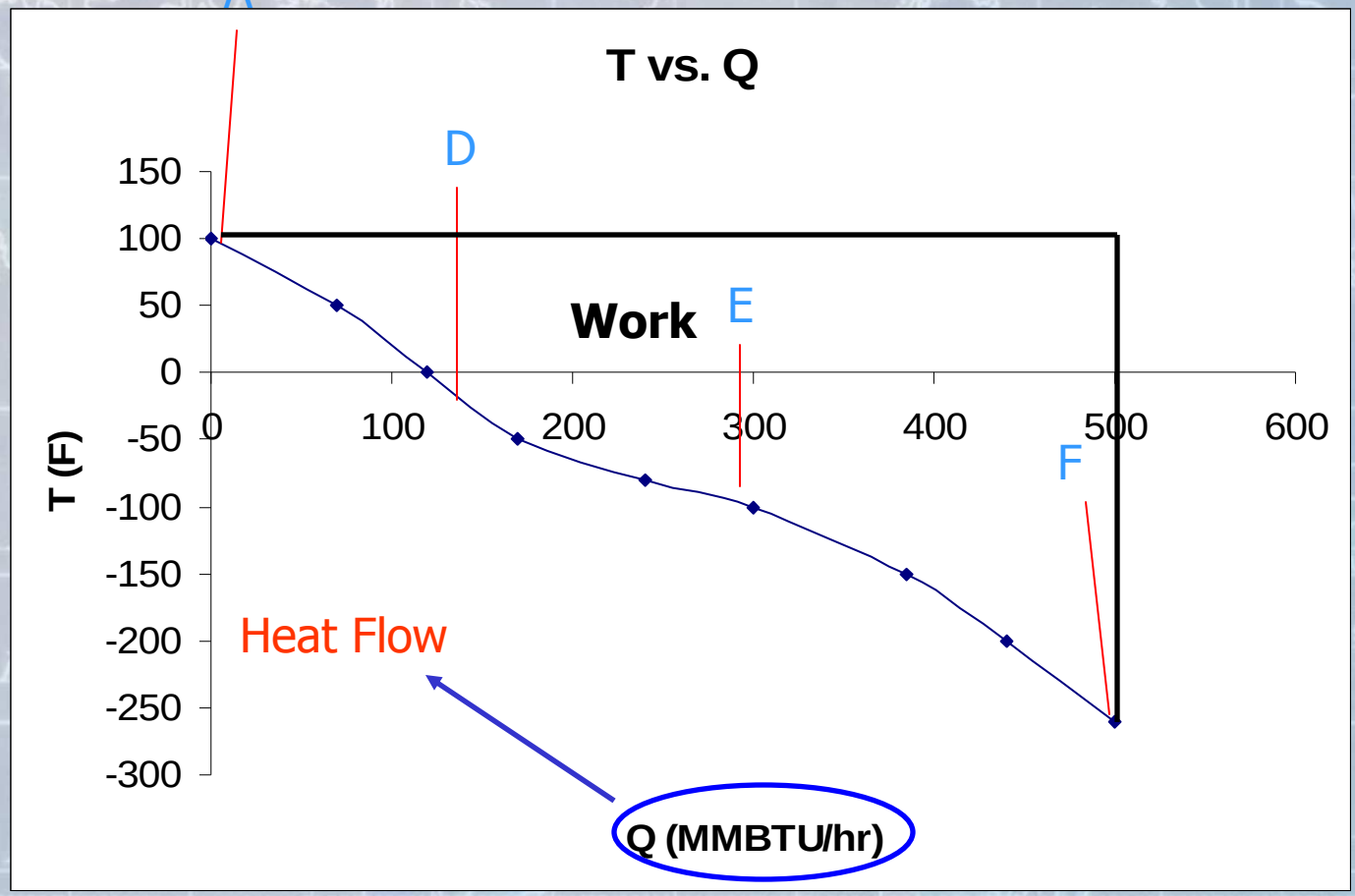
D – E (Heavy cooling to -110 F) (Heavy HC and NGLs)

Atm. Pressure

14.7psia

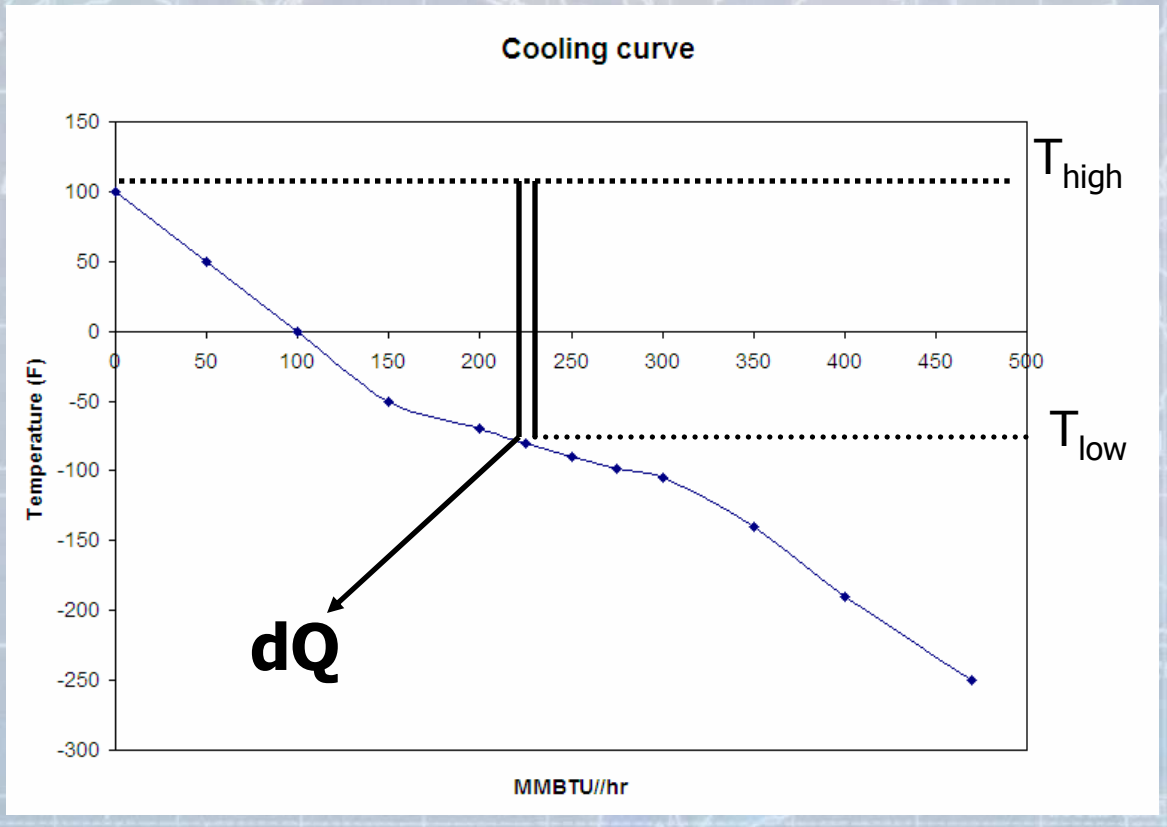


Liquefaction



T vs. Q (heat flow) for an ideal design of **4.5 mtpa**

Liquefaction

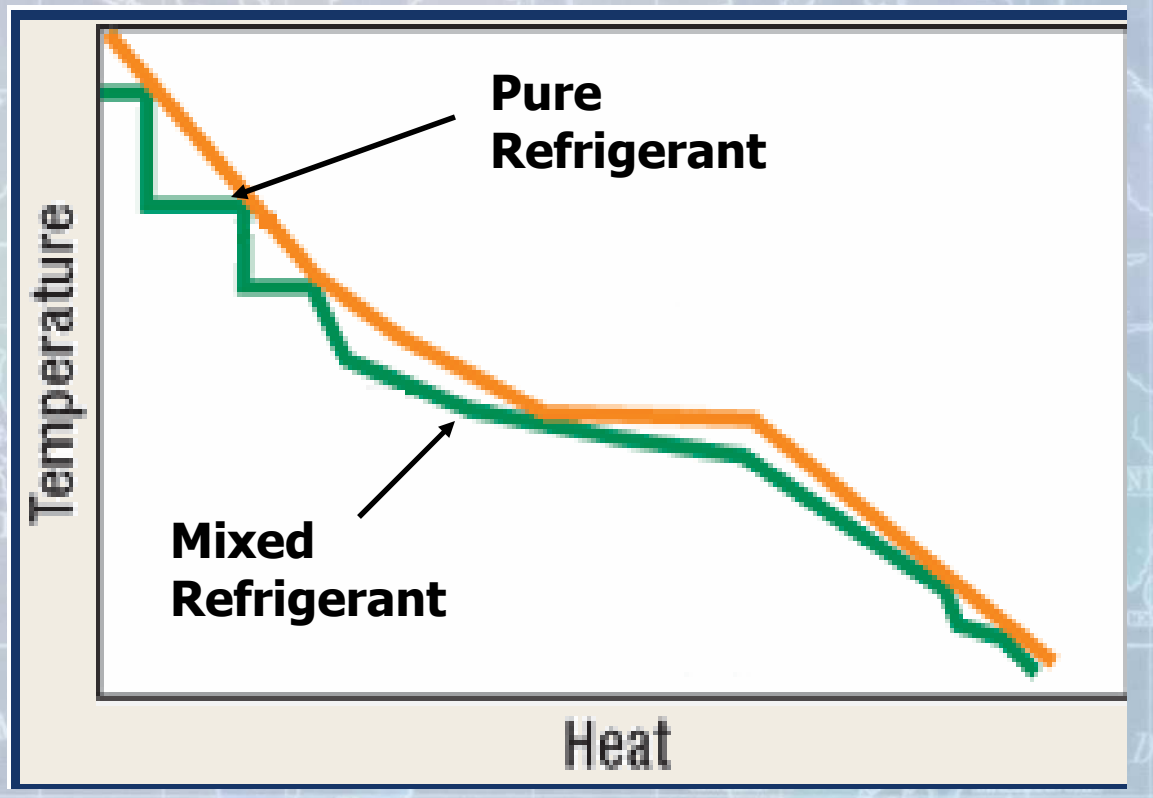


$$W = dQ\left(1 - \frac{T_{low}}{T_{high}}\right)$$

$$W = dQ\left(\frac{T_{high} - T_{low}}{T_{high}}\right)$$

$$W = \frac{dA}{T_{high}}$$

Liquefaction



APCI

- 88% of world's LNG production
- SWHE (Spiral Wound Heat Exchangers)
  - -Flexible
  - -Easy to control
  - -made for heavy efficient cooling
- Frame 7 compressors (85MW) X 2
- 4.5 mtpa and the X-technology (5 mtpa)

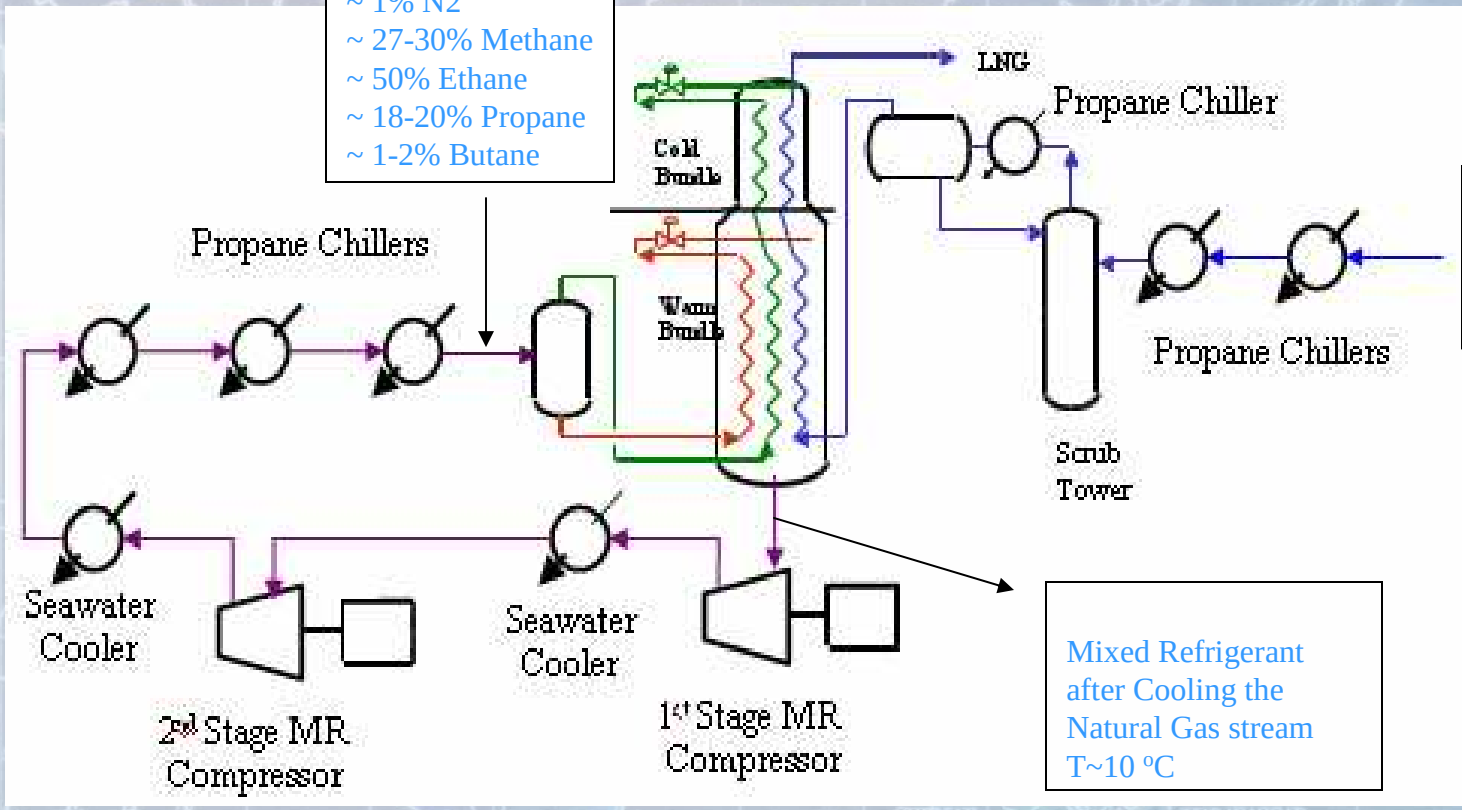
SWHE

STATOIL

SWHE

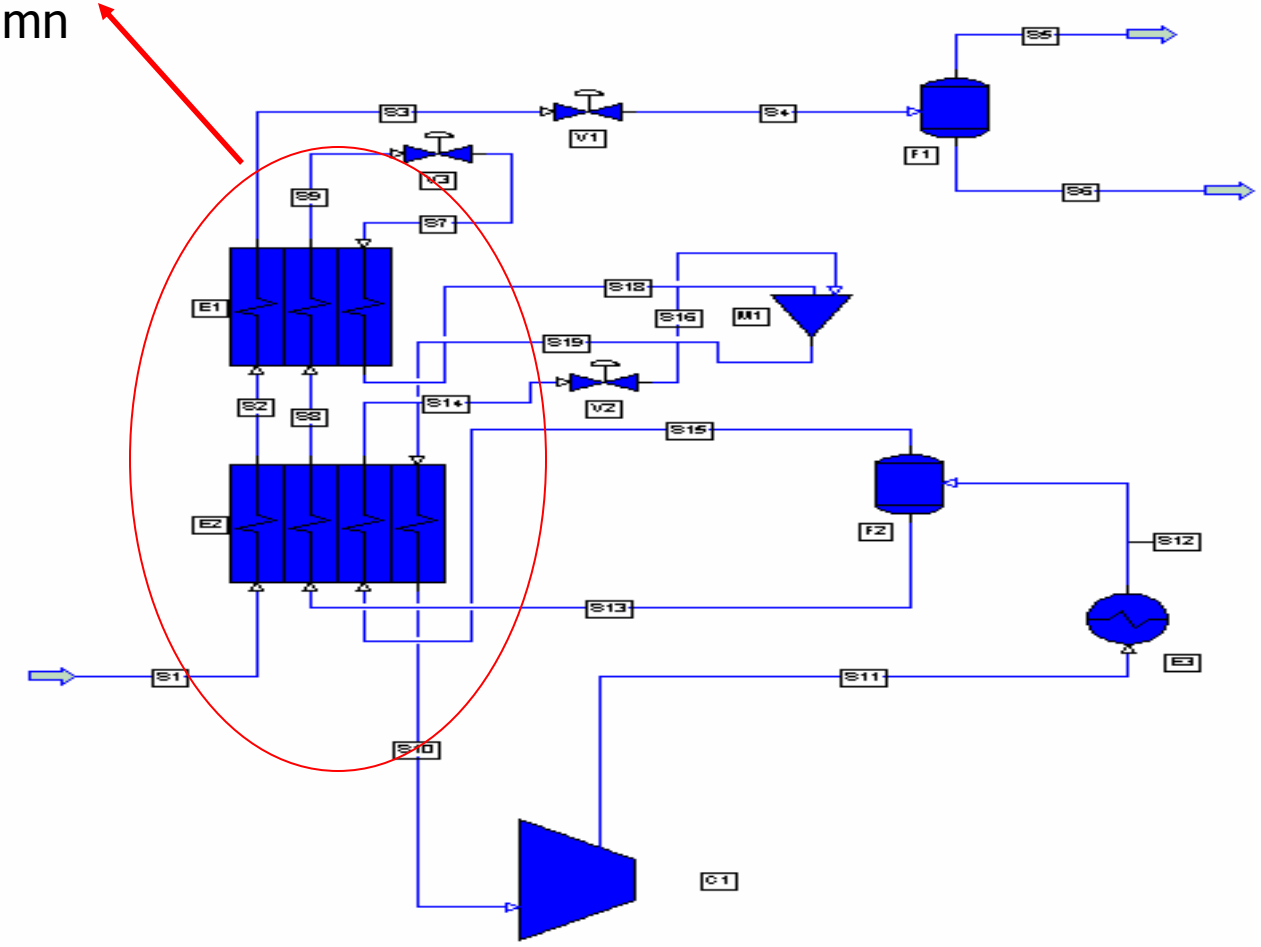
GE Frame 7 Gas Turbine

APCI


Mixed Refrigerant
(comp.)(T=-35ºC)
~ 1% N2
~ 27-30% Methane
~ 50% Ethane
~ 18-20% Propane
~ 1-2% Butane
LNG
Propane Chiller
Cold Bundle
Warm Bundle
Propane Chillers
Pretreated Natural Gas Feed
Propane Chillers
Scrub Tower
Seawater Cooler
Seawater Cooler
2nd Stage MR Compressor
1st Stage MR Compressor
Mixed Refrigerant after Cooling the Natural Gas stream T~10 ºC

APCI

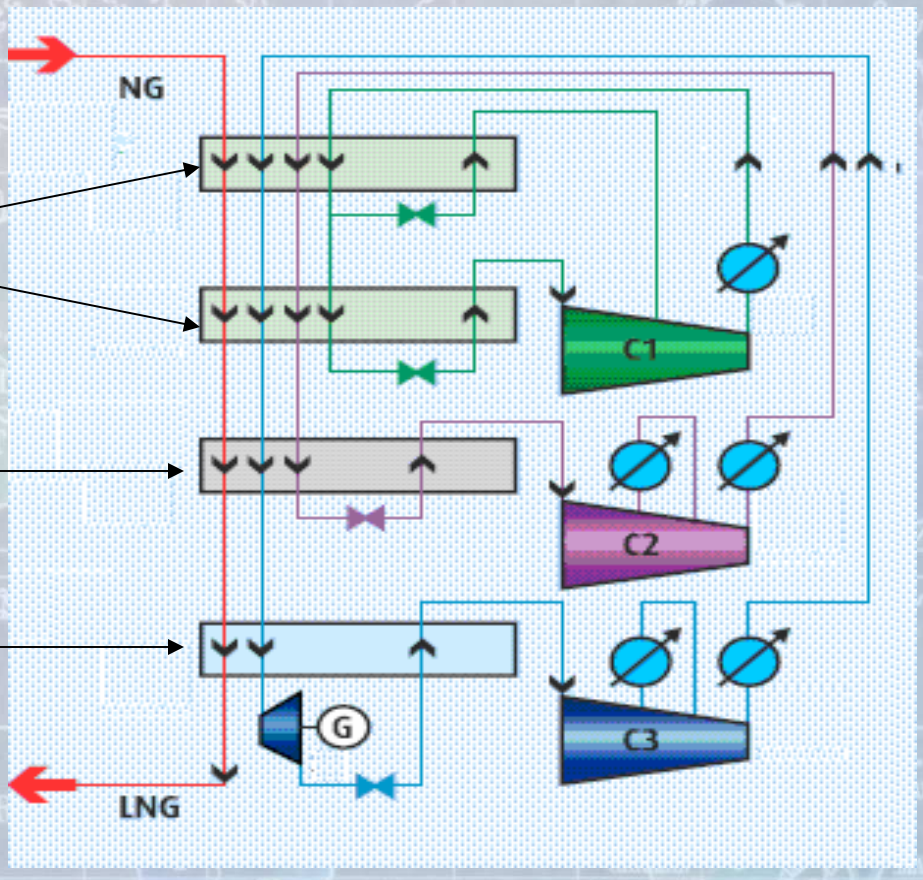
Heat Exchanging Column



Linde

- Also called MFC process
- 4 mtpa
- Only in Ekofish (Norway)
- 2 SWHE (linde)
- 2 PFHE (Precooling (mainly propane))

Linde



Pre-cooling Section (PFHE)

Liquefaction Section (SWHE)

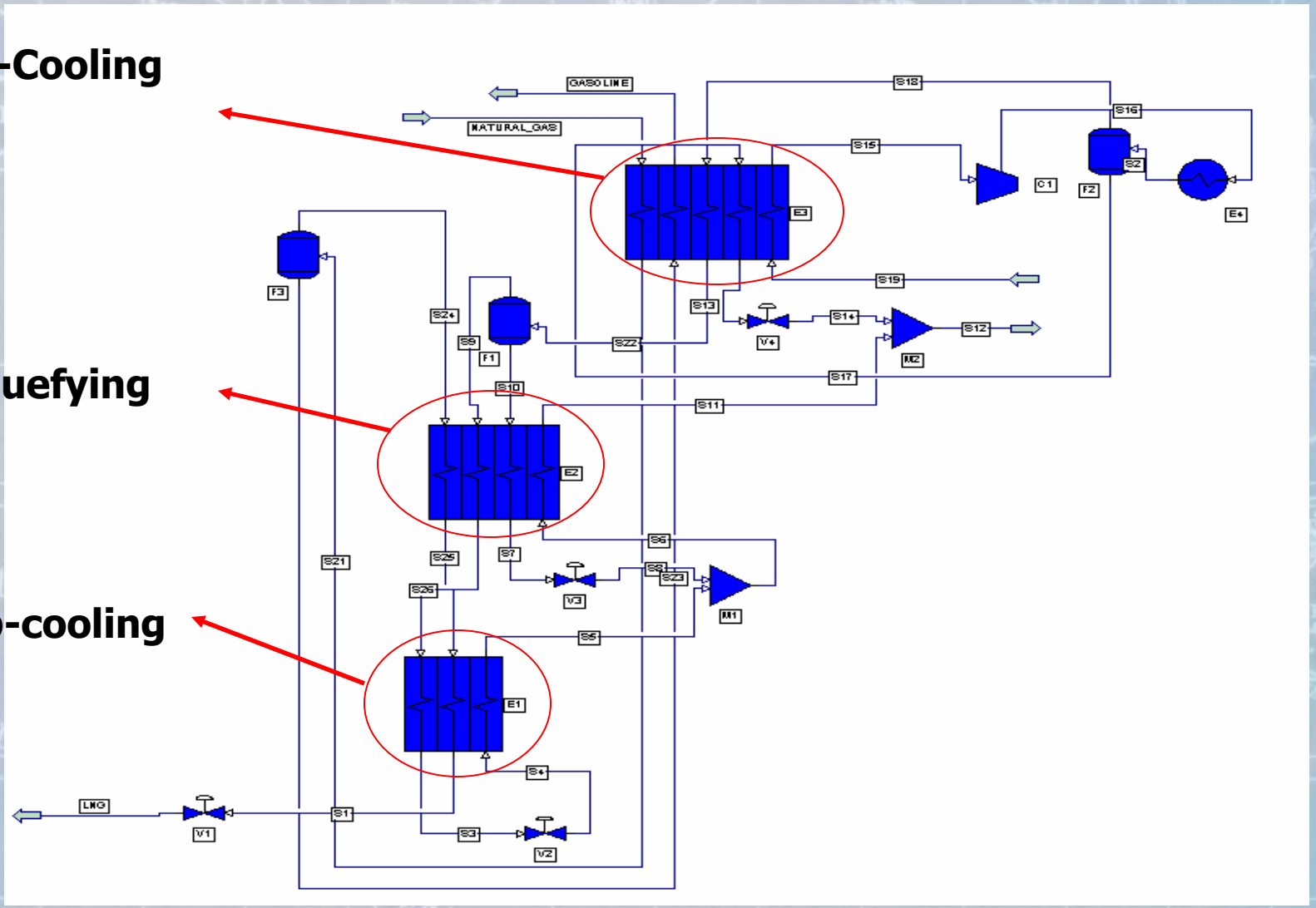
Sub cooling Section (SWHE)

Linde

Pre-Cooling

Liquefying

Sub-cooling



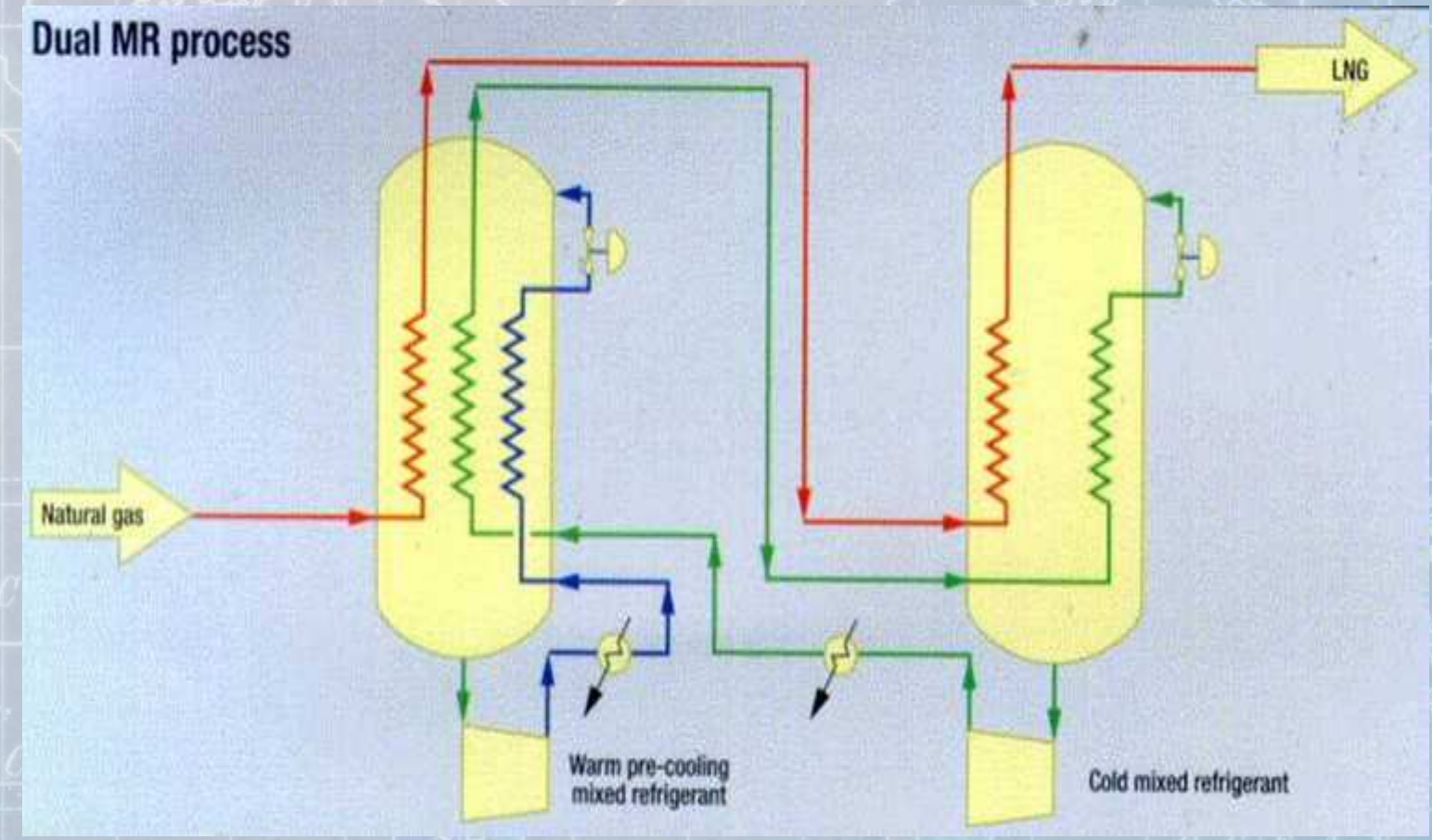
Linde

	Propane	Ethane	Methane	Nitrogen
Pre-cooling	~80%	~15%	~4%	~1%
Liquefaction	~3%	~22%	~70%	~5%
Sub-cooling	~4%	~10%	~85%	~1%

DMR

- Dual Mixed Refrigerant
- Two stages (Light _ Heavy)
- Two different mixed refrigerants
- 4.5 mtpa
- 2 SWHE
- 2 frame 7 compressors
- More reliable than the APCI
- Shell (Sakhalin Island, Russia)

DMR

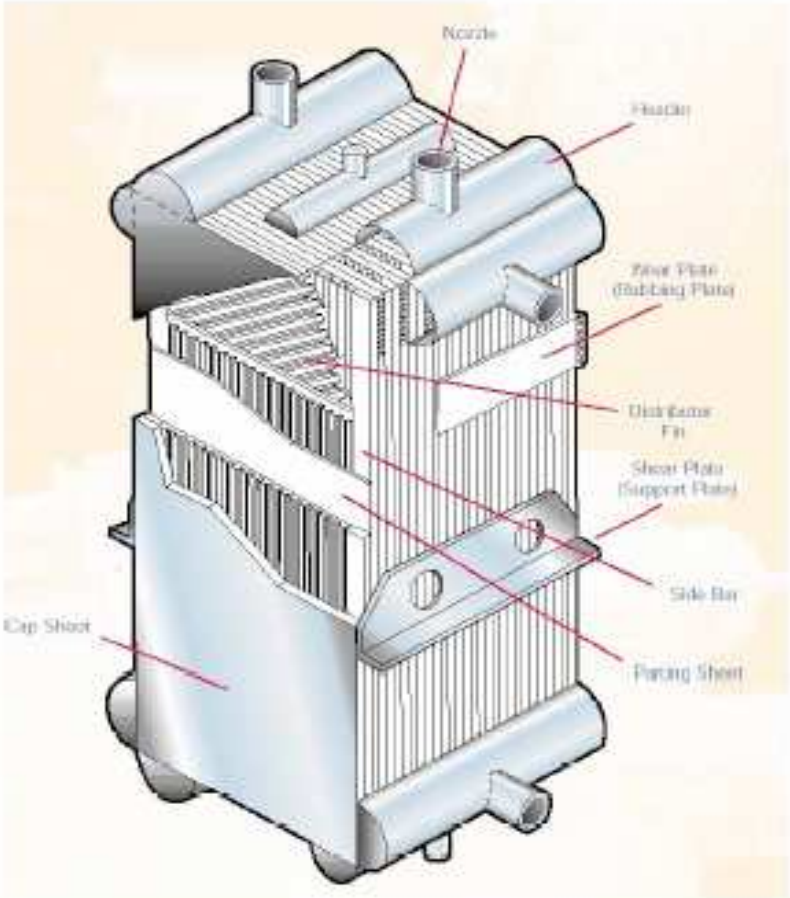

Dual MR process
LNG
Natural gas
Warm pre-cooling
mixed refrigerant
Cold mixed refrigerant

Conoco Phillips Cascade

- 5% of world's LNG production
- Oldest design (since 1969)
- Uses regular compressors (i.e., frame 5)
- Uses simple Heat exchangers (PFHE)
- Single Train (3-3.5 mtpa)
- "2 in 1" train (4.5 mtpa)

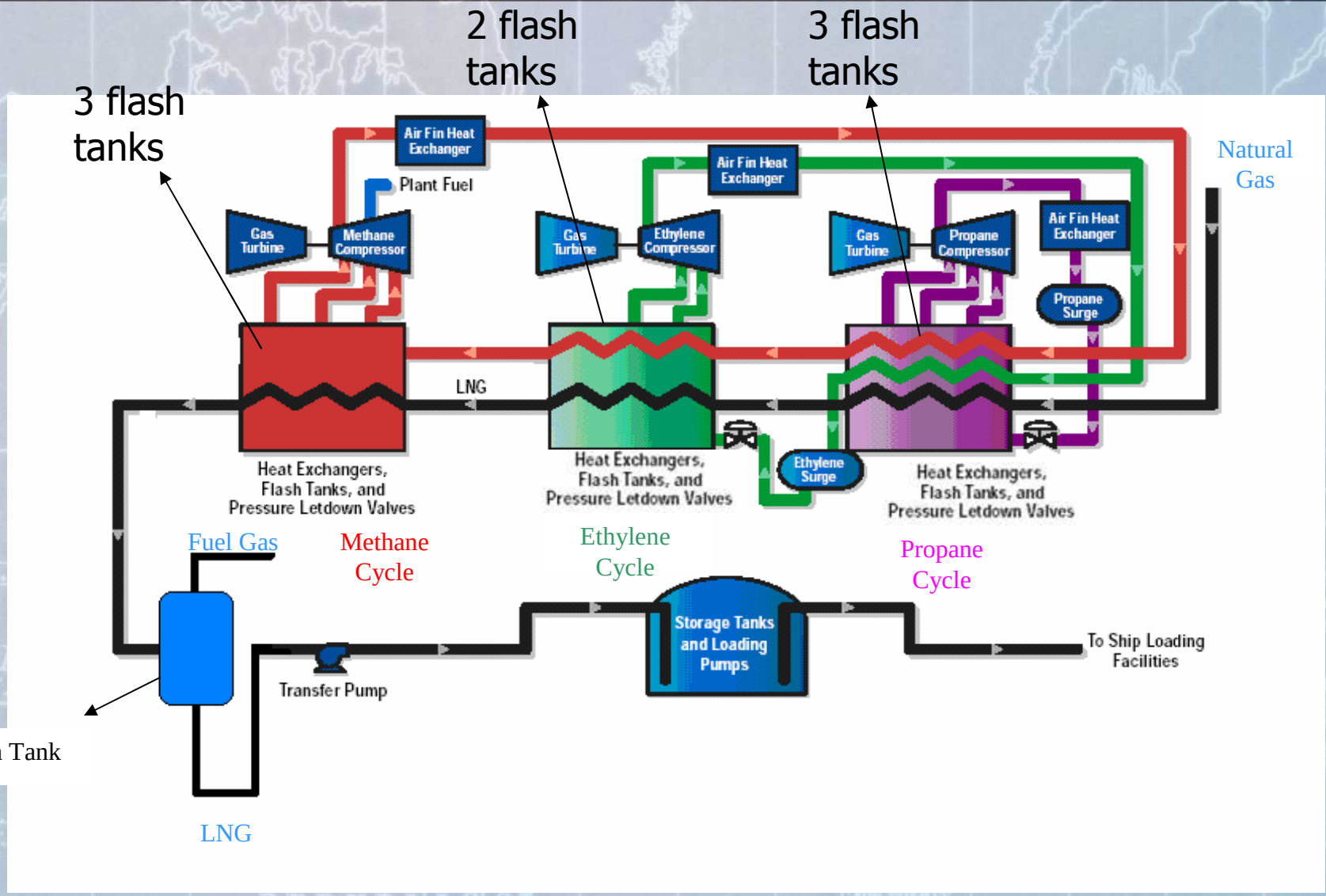
Conoco Phillips Cascade

PFHE

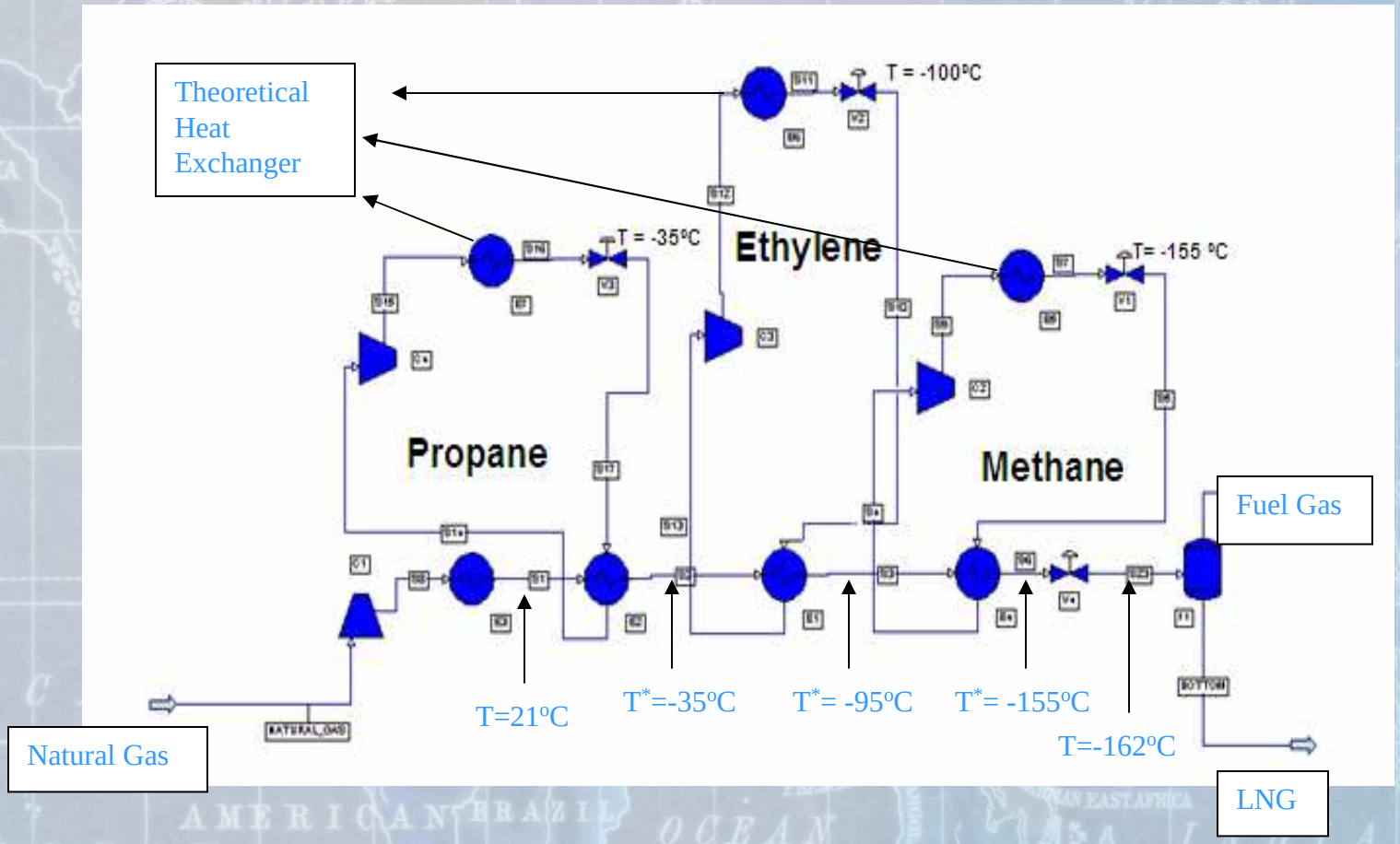


STATOIL

Conoco Phillips Cascade

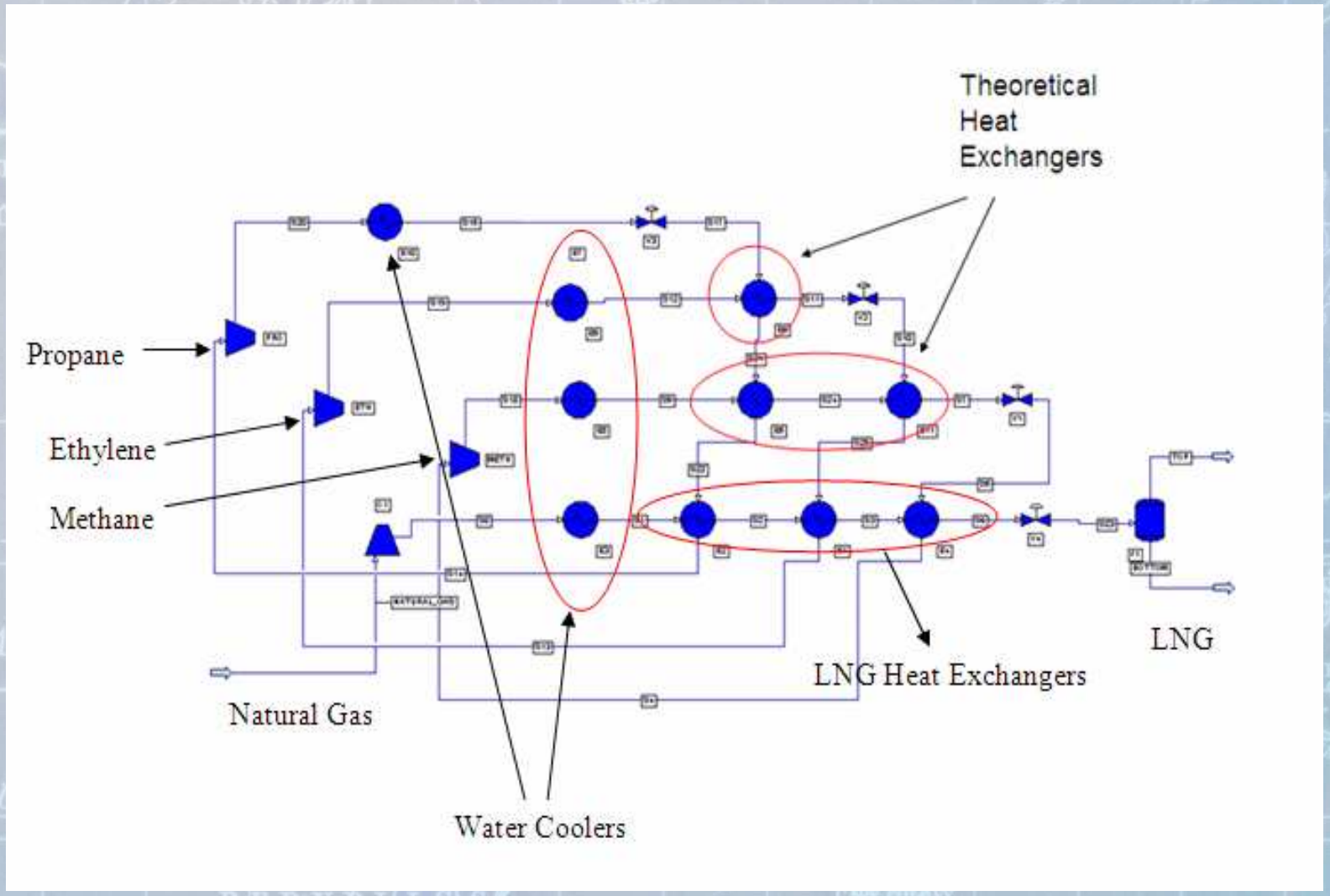


Conoco Phillips Cascade

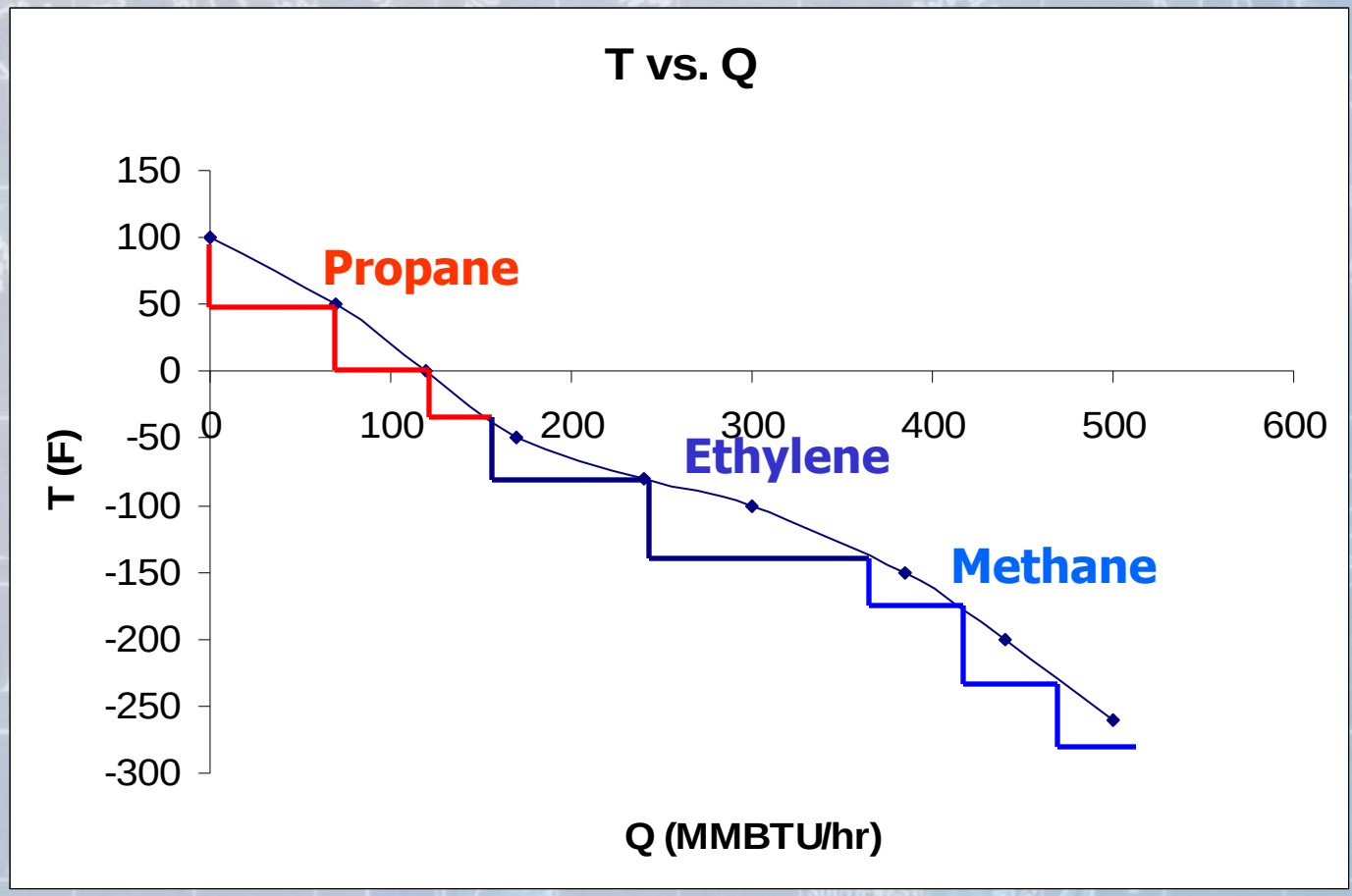


	Boiling Point (°C)
Propane	~-42
Ethylene	~-103
Methane	~-161

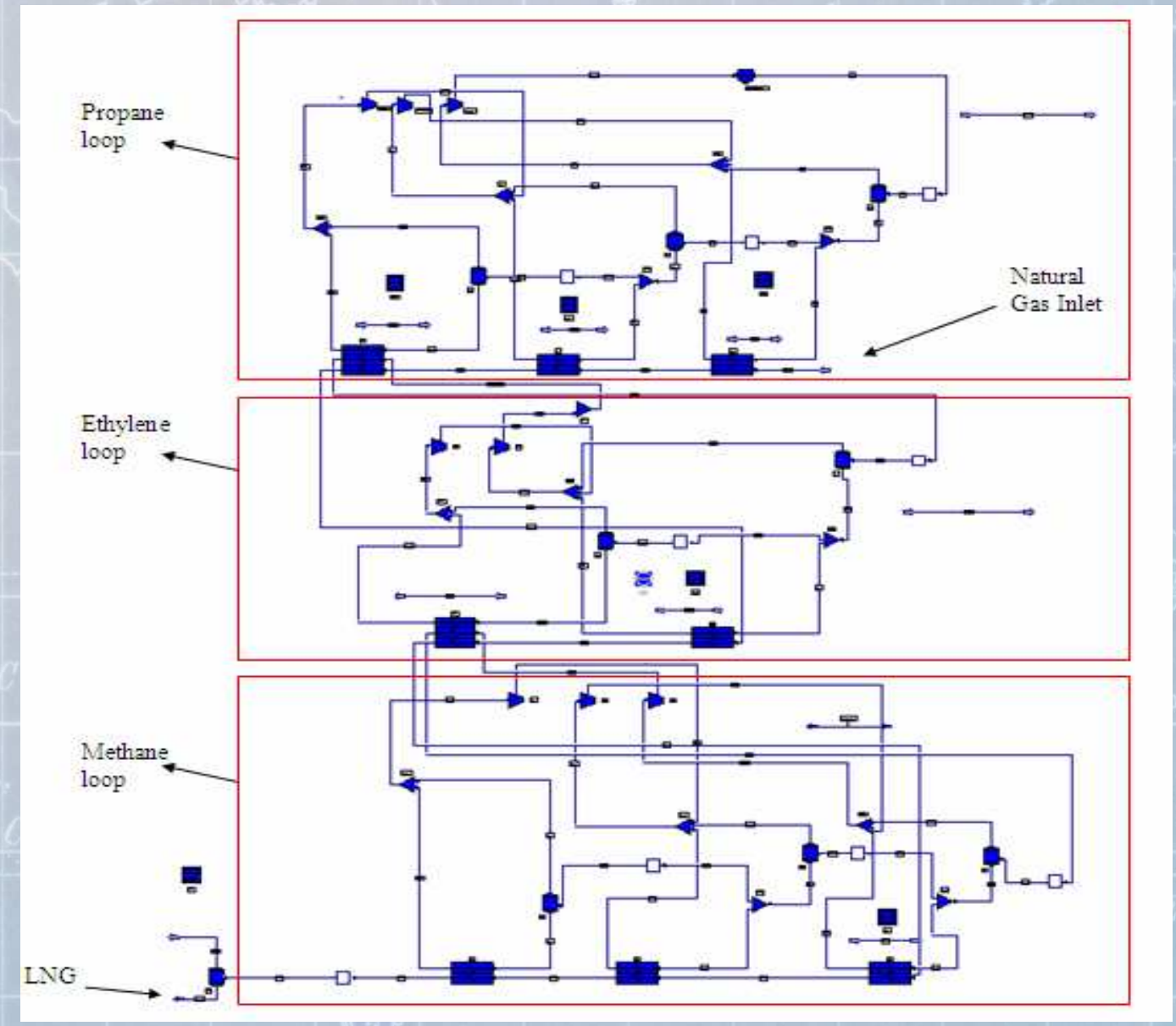
Conoco Phillips Cascade



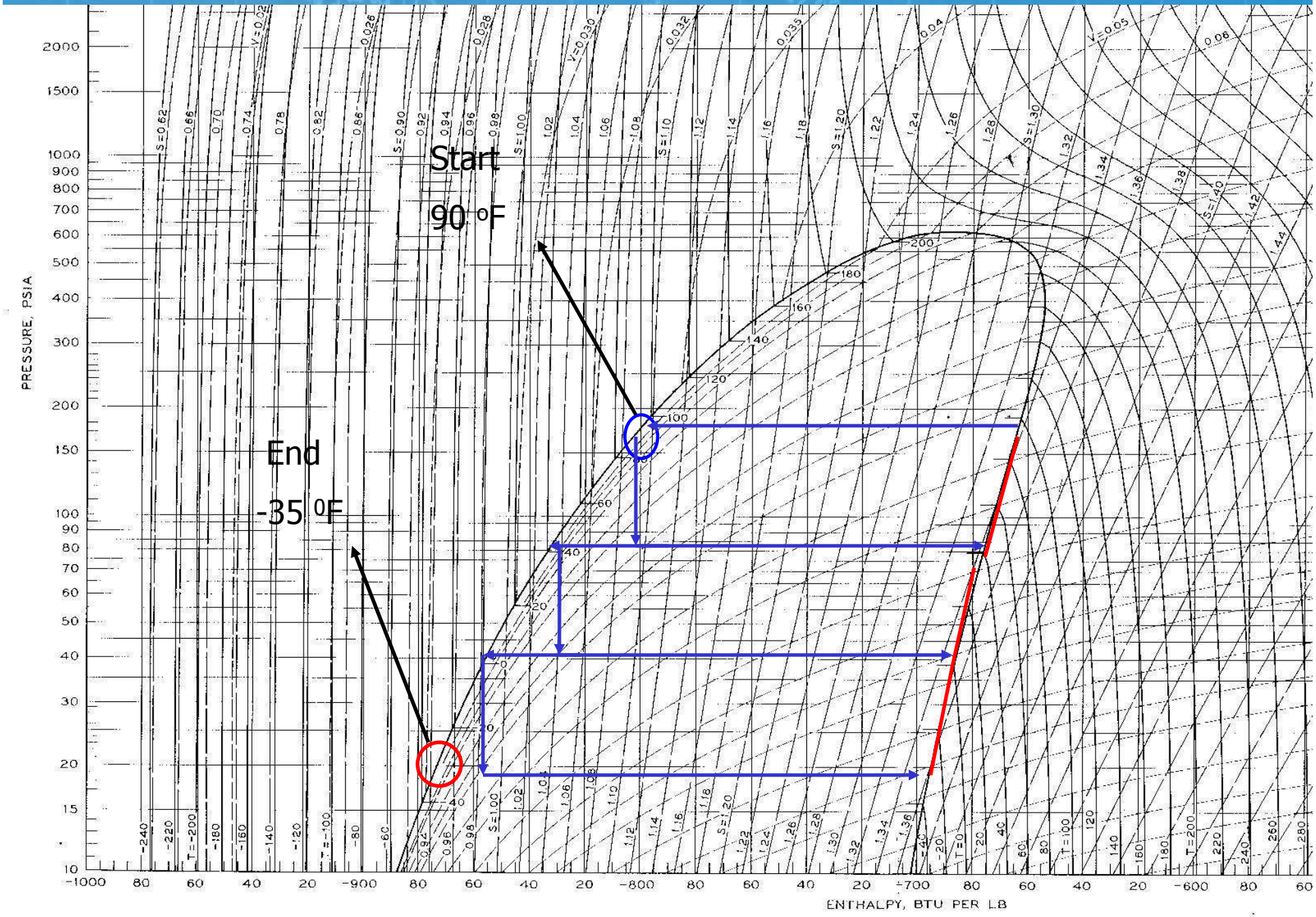
Conoco Phillips Cascade



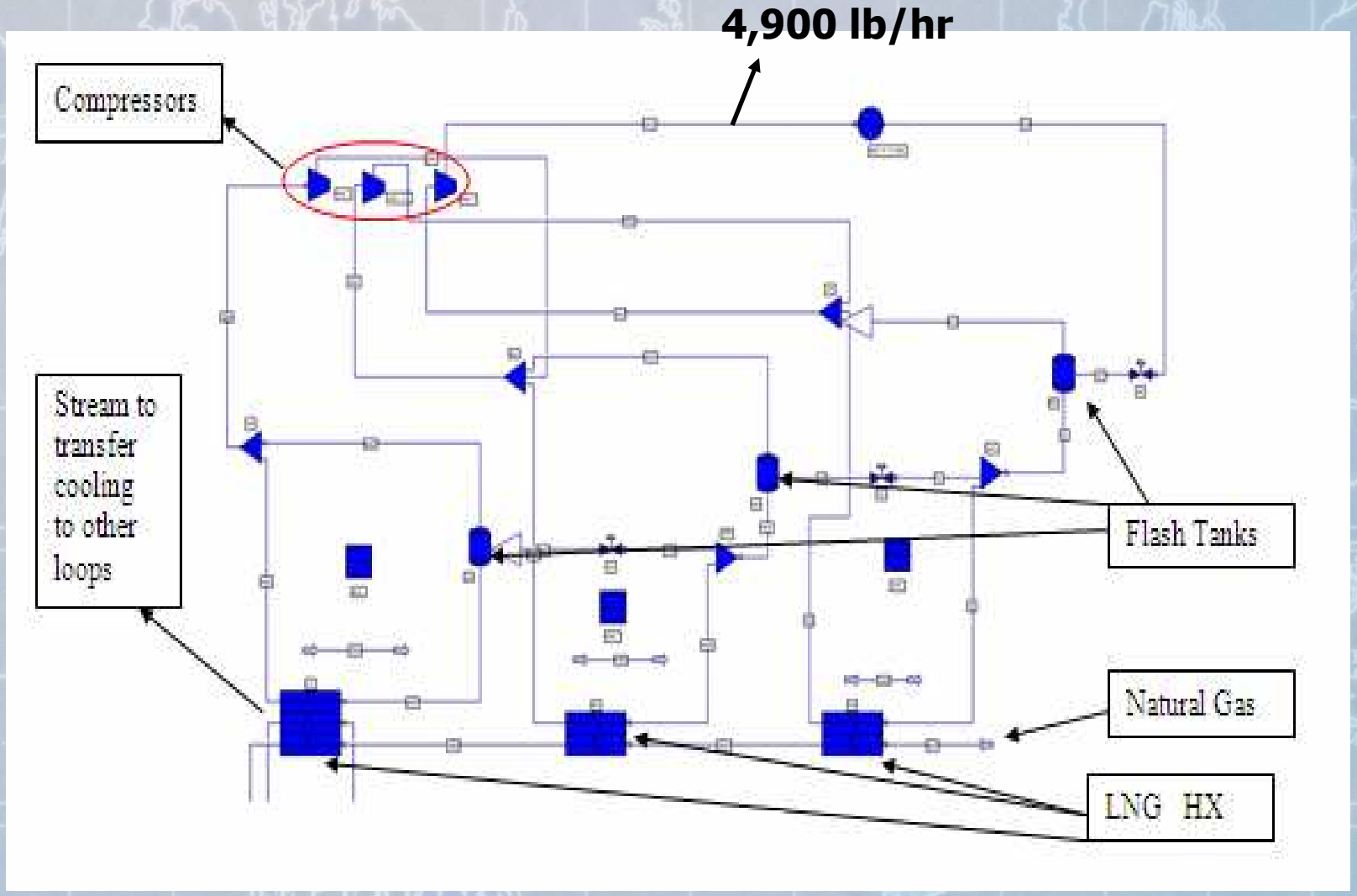
Conoco Phillips Optimized Cascade "2 in 1"



Propane



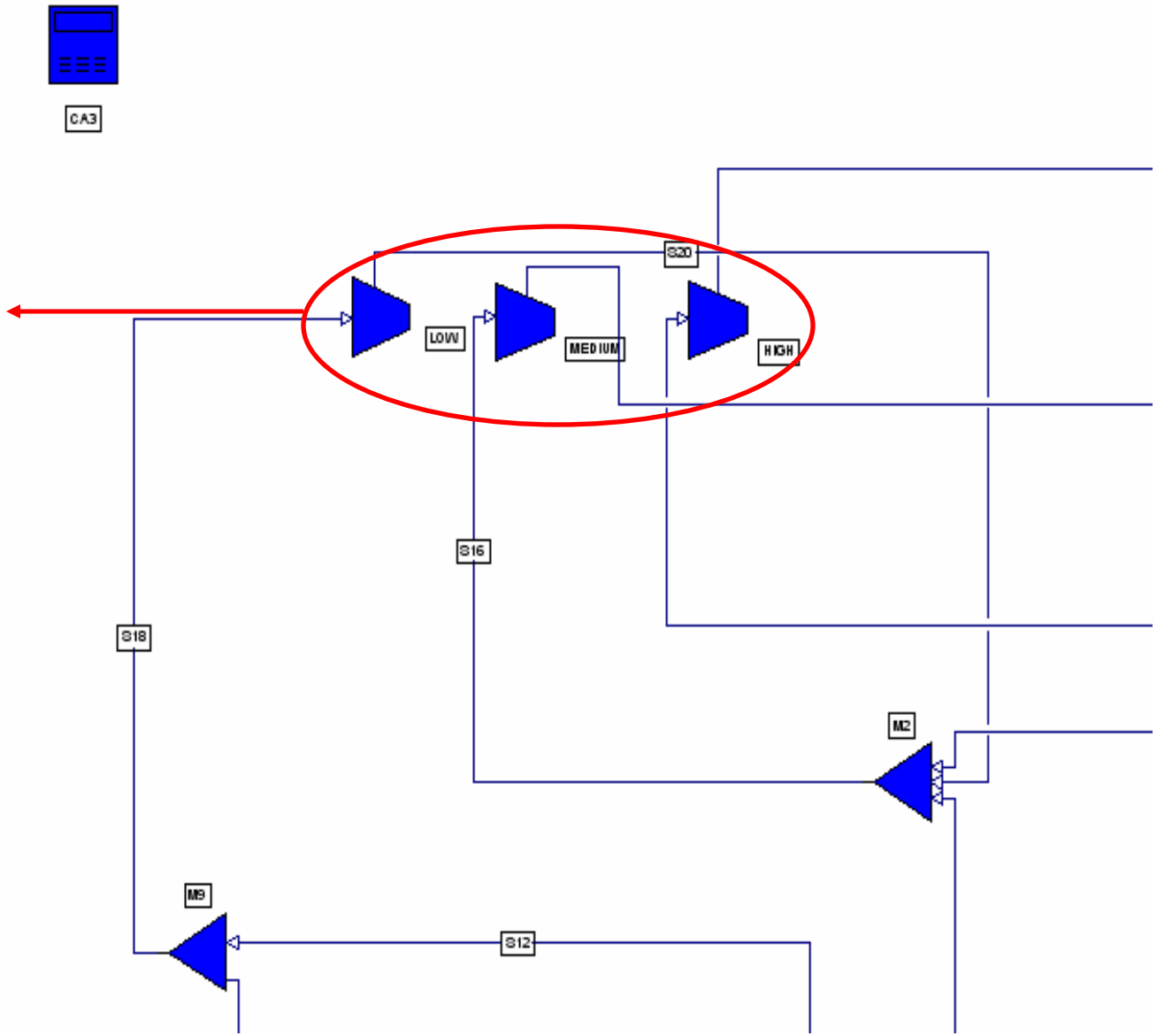
Conoco Phillips Optimized Cascade

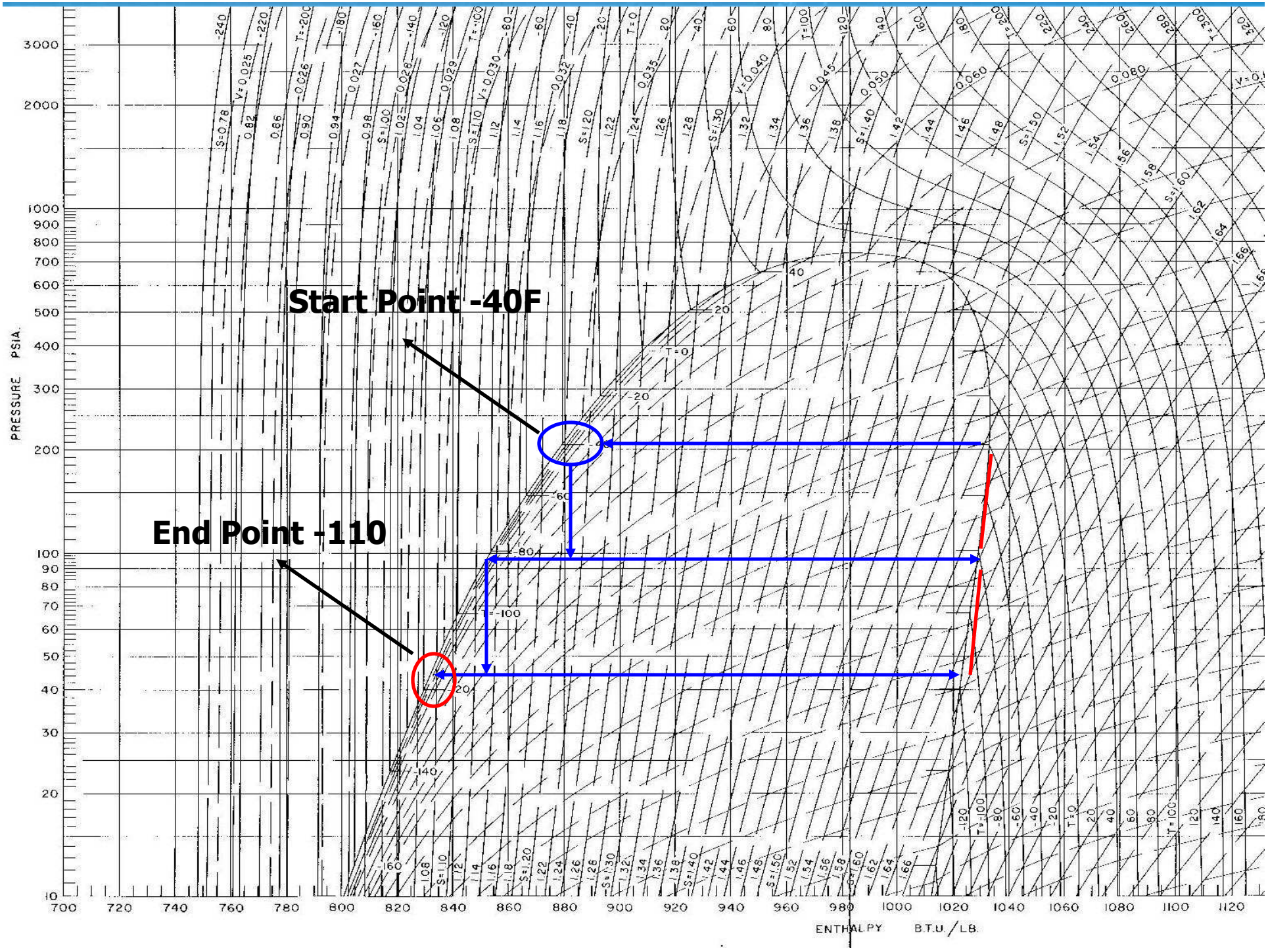


LNG HX	Right	Middle	Left
Duty (MMBtu/hr)	90.75	385.76	180.77

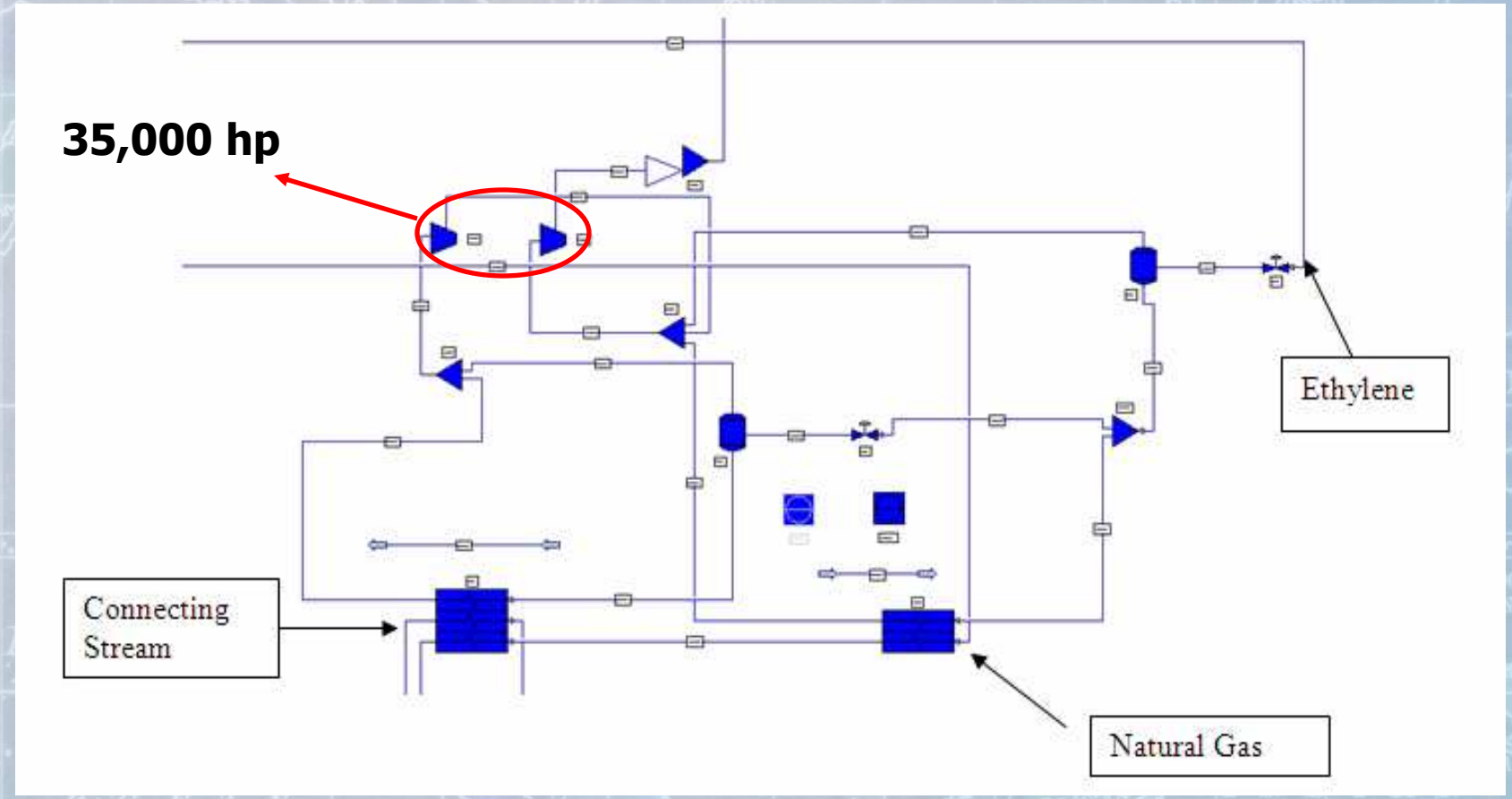
Conoco Phillips Optimized Cascade

Calculator Name Calculator Description		CA3
Result 1		14124.8916
Result 2		38600.9375
Result 3		29782.4648
Result 4		82508.2969
Result 5		n/a

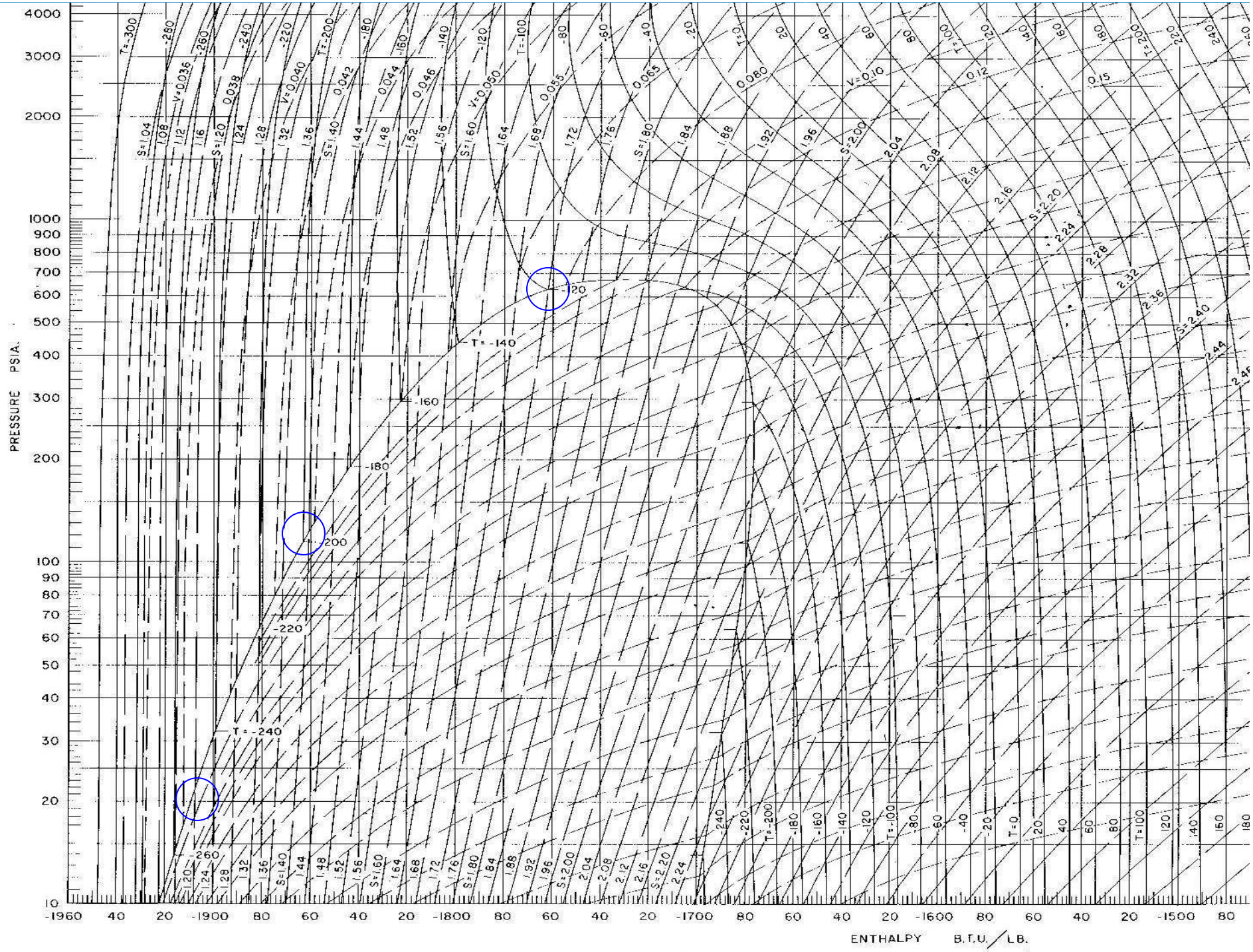



Start Point -40F
End Point -110
PRESSURE PSIA.
ENTHALPY B.T.U./LB.

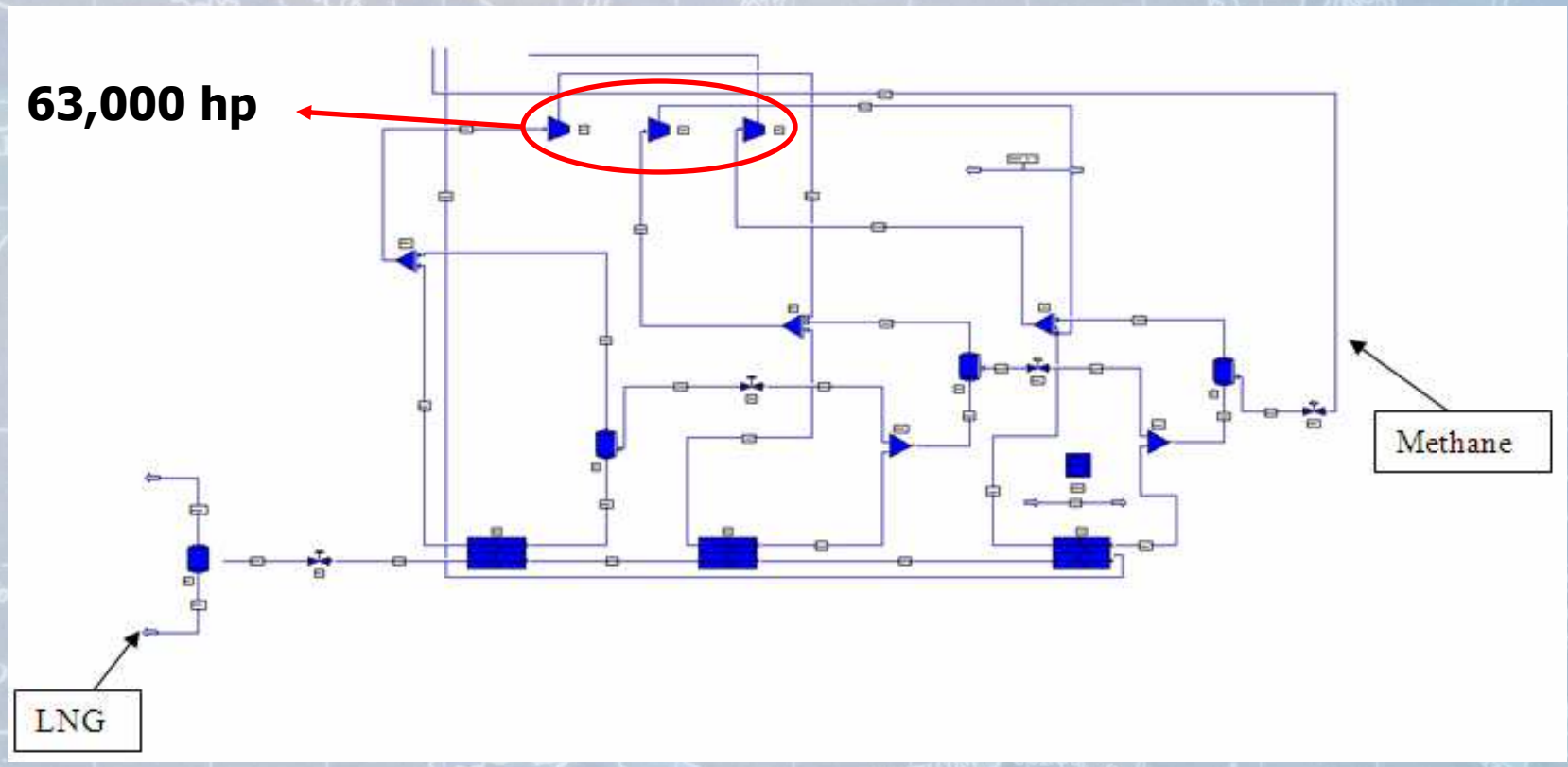
Conoco Phillips Optimized Cascade



LNG HX	Right	Left
Duty (MMBtu/hr)	400.1	140.4


PRESSURE PSIA.
ENTHALPY B.T.U./LB.
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
20
10
-1960
-1900
-1800
-1700
-1600
-1500
T=-300
T=-200
T=-100
T=0
T=100
T=-140
T=-240
-160
-180
-200
-220
-260
V=0.035
V=0.040
V=0.050
V=0.10
S=1.04
S=1.20
S=1.40
S=1.60
S=1.80
S=2.00
S=2.20
S=2.40

Conoco Phillips Optimized Cascade



LNG HX	Right	Middle	Left
Duty (MMBtu/hr)	367.1	46.6	260.6

Selection

- **Handles less in flow**
- **More reliable**

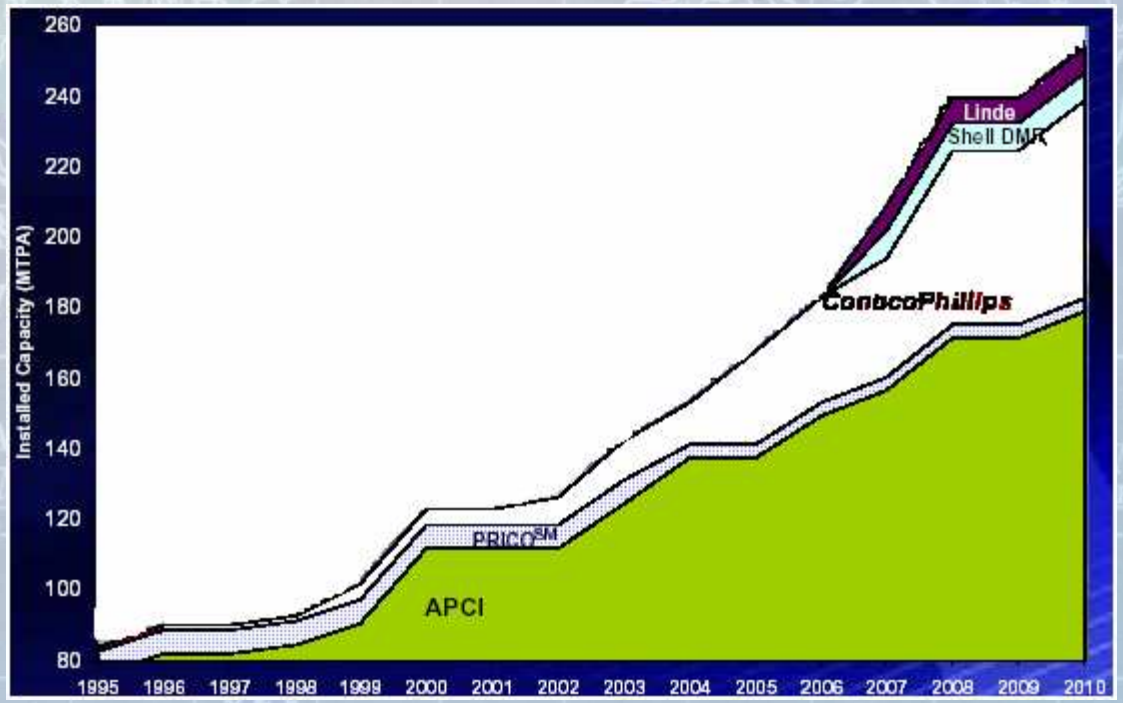
Overall Plant Production Efficiency = 90%	
Operating Range	**Production**
Full plant	100%
One Turbine offline	0%
Three Turbine offline	0%
Plant Idle	0%

Overall Plant Production Efficiency = 95%	
Operating Range	**Production**
Full plant	100%
One Turbine offline	60% to 80%
Three Turbine offline	30% to 60%
Plant Idle	0%

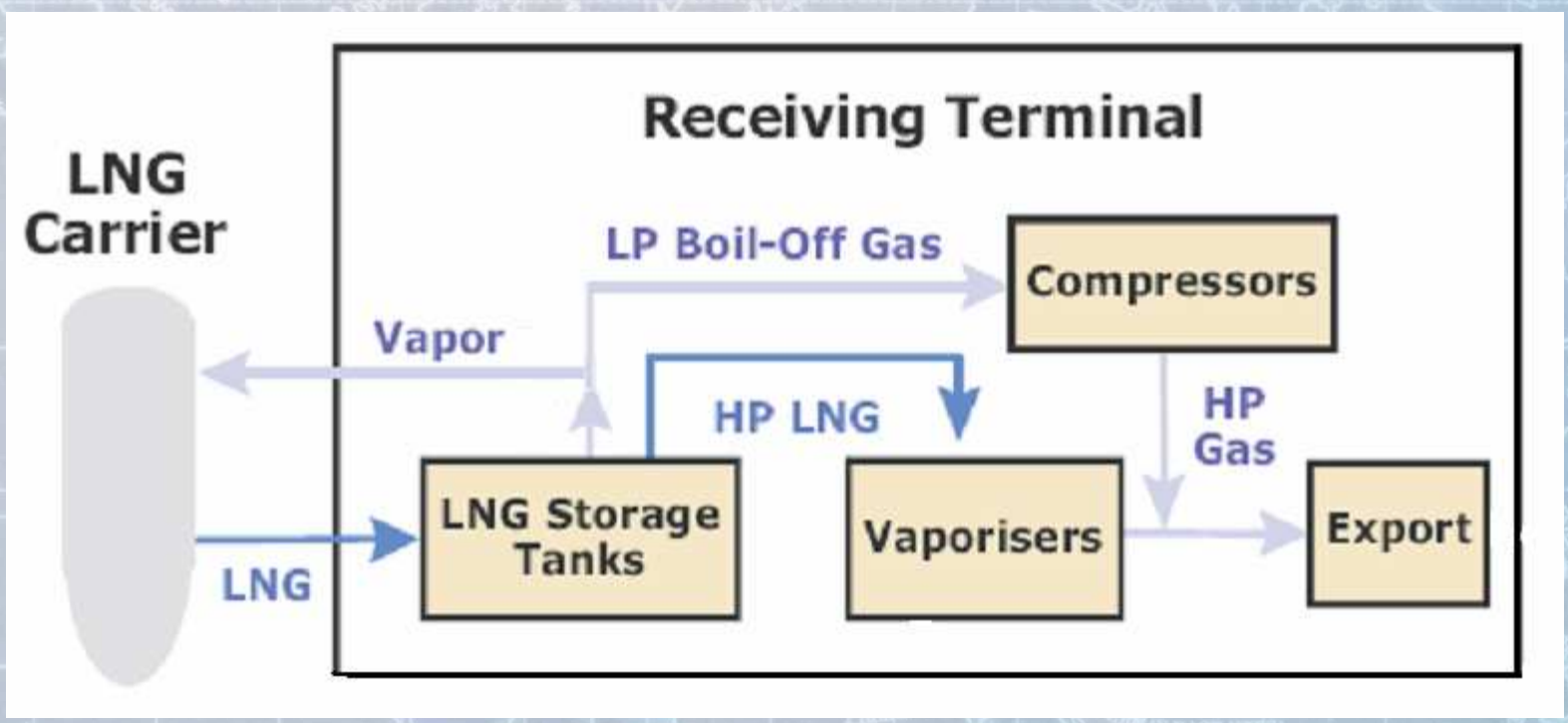
- **Pure refrigerant vs. Mixed Refrigerant**
- **Easier to scale up**

Selection

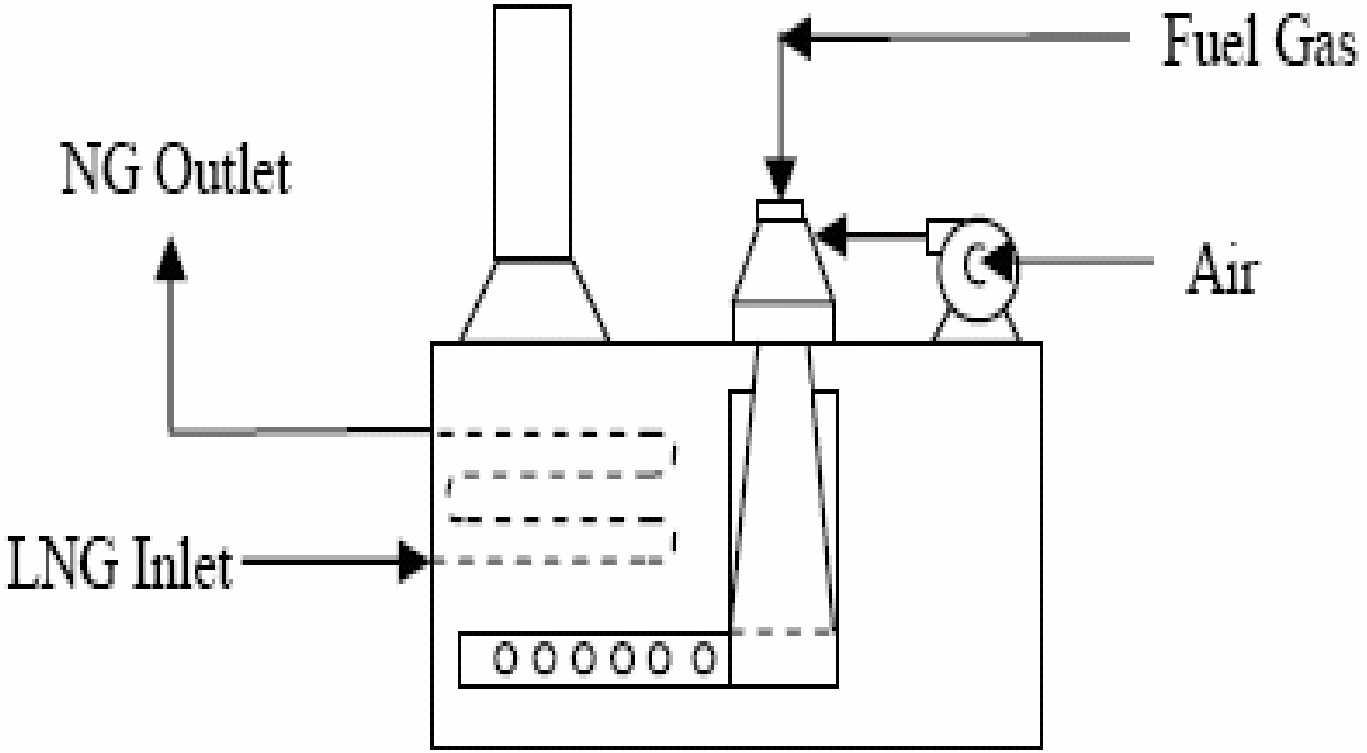
- Quicker Start up and Shut down time
- Less instrumentation and control loops
- Since 1969 (Risk and testing)



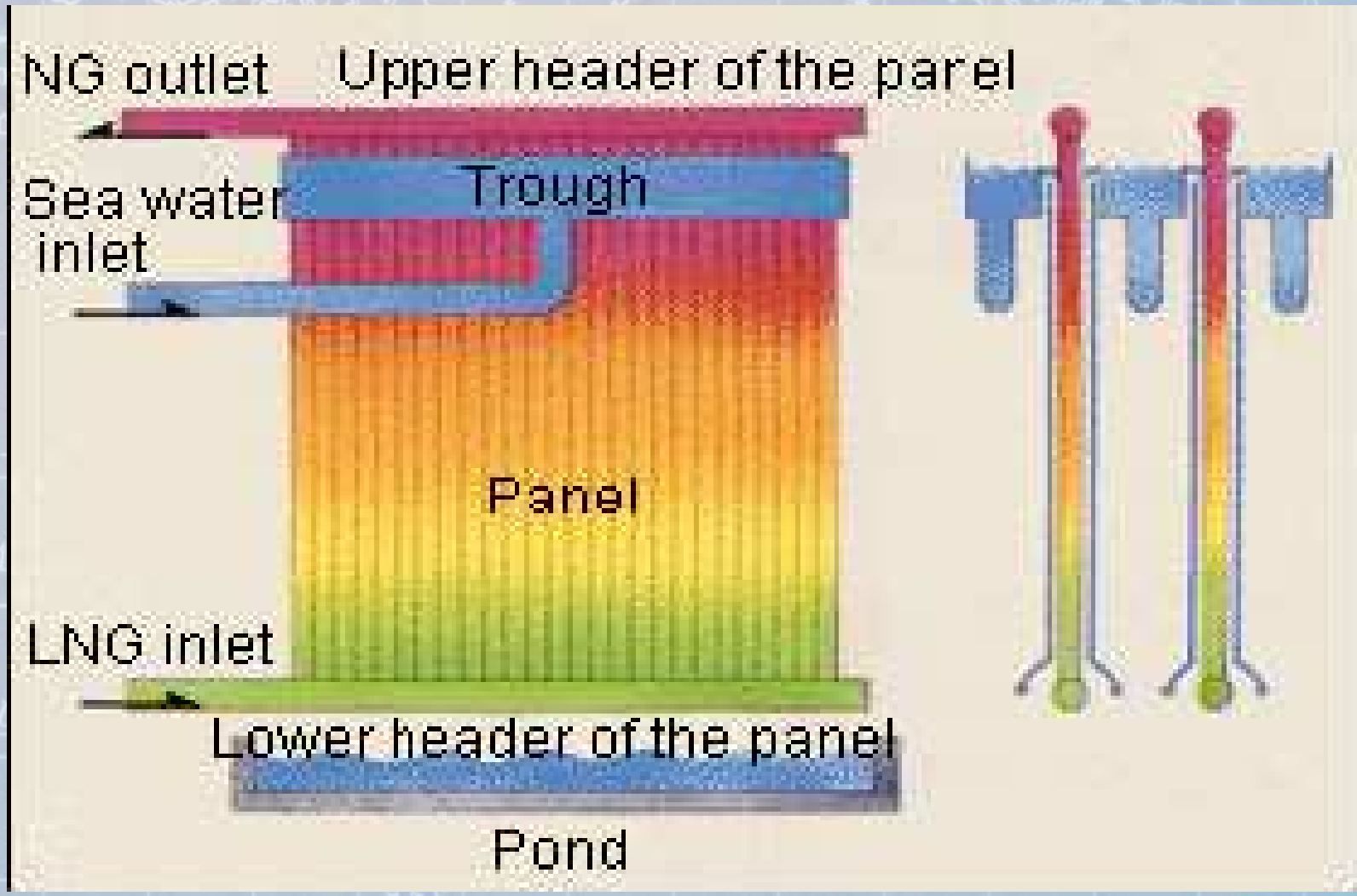
Regasification Plant



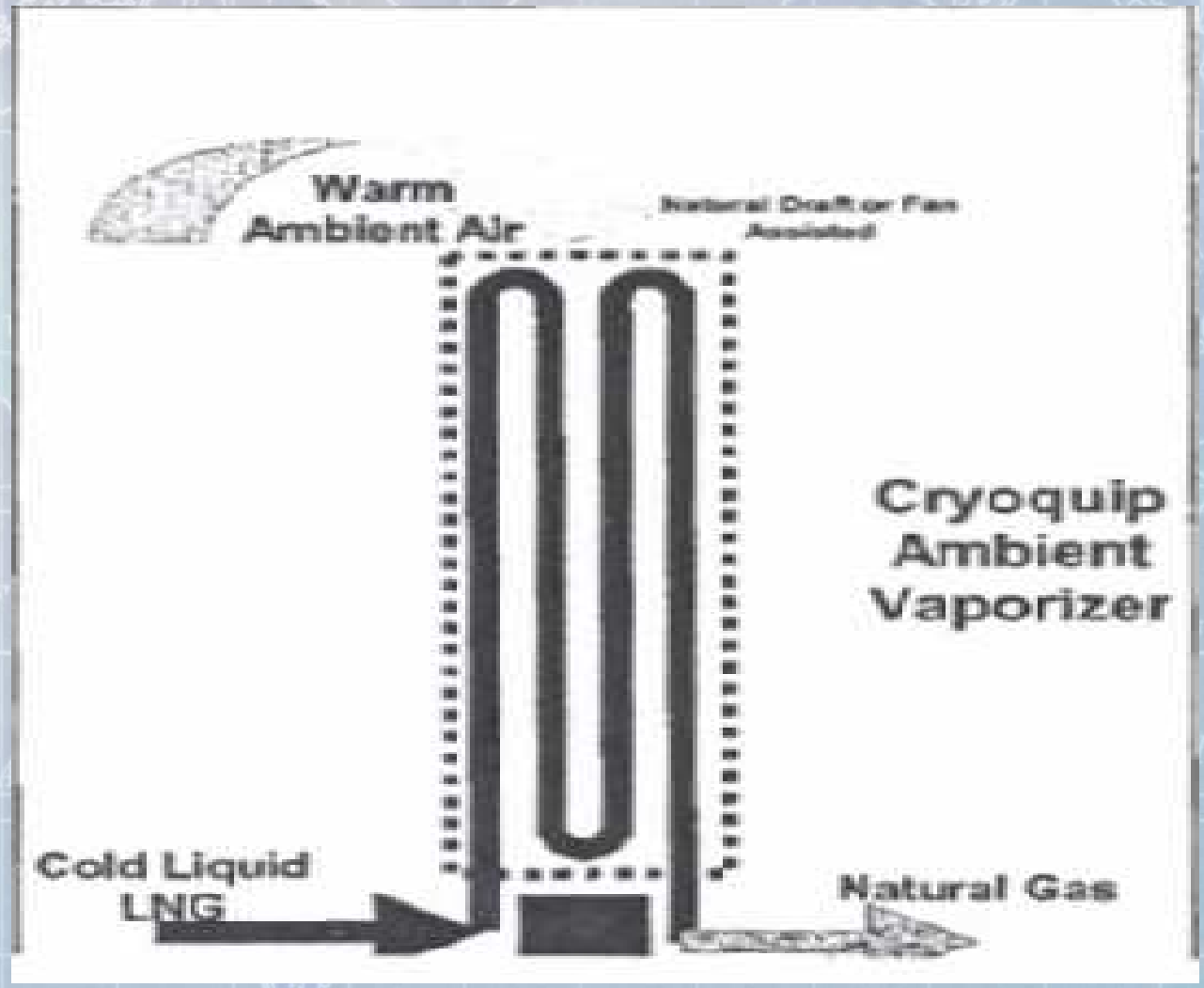
Submerged Combustion Vaporization



Open Rack Vaporization



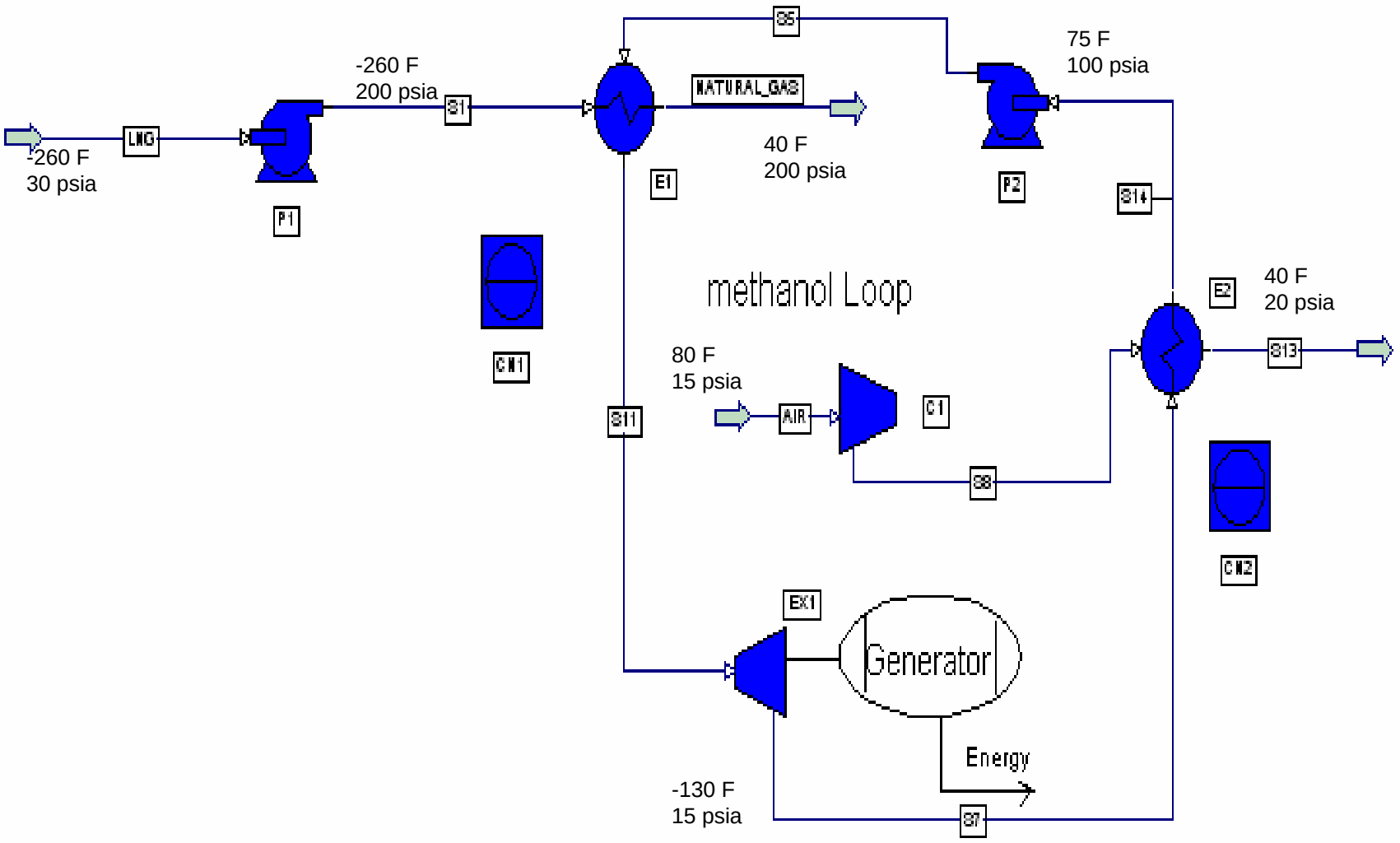
Ambient Air Vaporization



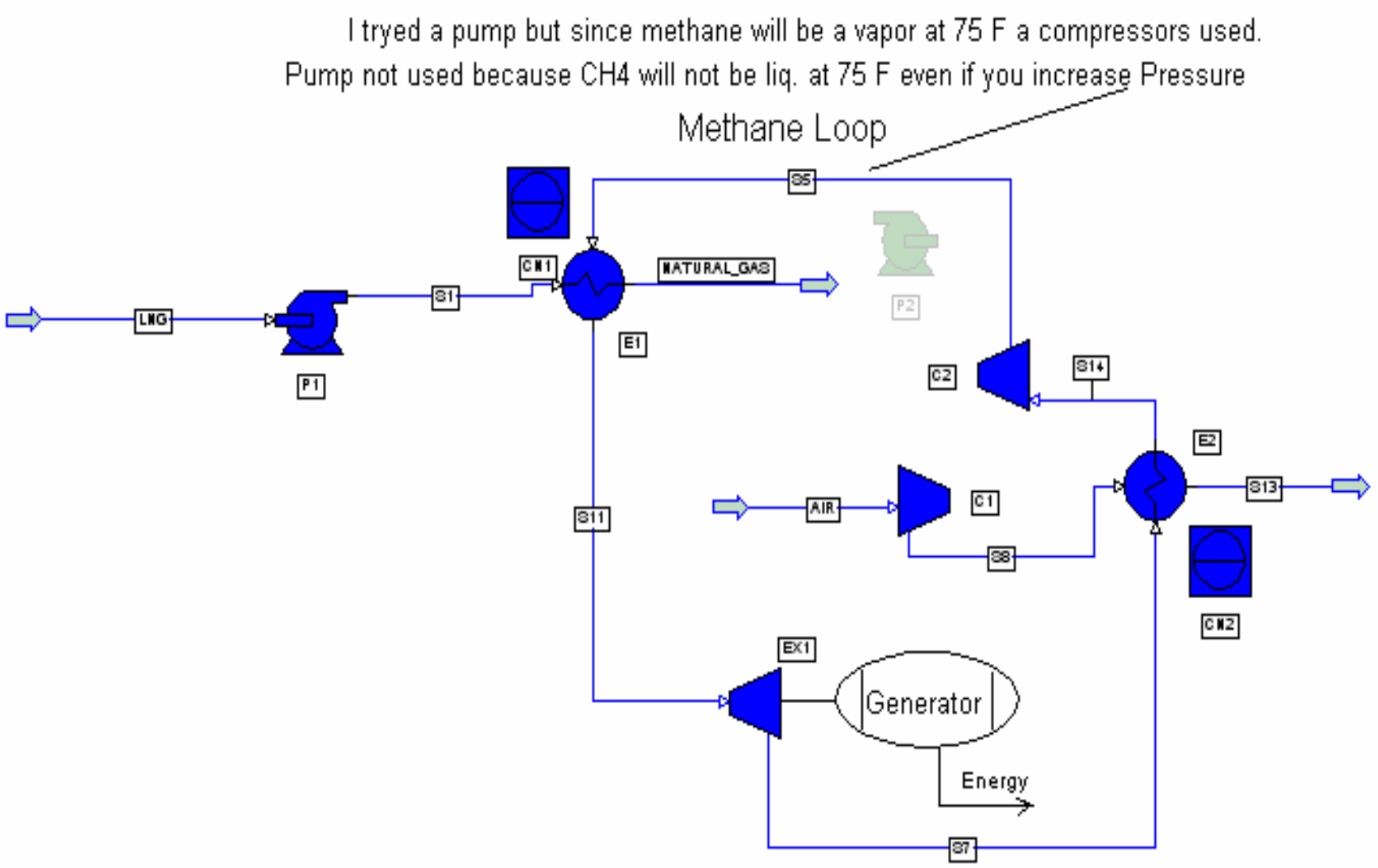
Vaporization Choice

For 1000 m^3 / hr send-out rate	Submerged Combustion Vaporization	Open Rack Vaporization	Forced Draft Heat Integrated Ambient Air Vaporization
Costs Comparison			
Estimated Capital Costs Factor	1	1.38	1.317
Capital Costs Comparison	$107.75	$148.70	$141.91
Fuel Gas Usage			
Usage ($MMft^3/d$)	6.77	0.00	0.00
Fuel Gas Cost	12.60	0.00	0.00
Electrical Usage			
Usage (MW)	1.39	1.88	1.81
Cost of Power	0.63	0.85	0.81
Annual Operating Costs (millions)	$13.23	$0.85	$0.81
Environmental Emissions and Effluents			
Chlorine Emissions	No	Yes	No
CO Emissions (tpy)	132.39	6.78	6.53
NO_x Emissions (tpy)	88.44	6.71	6.41

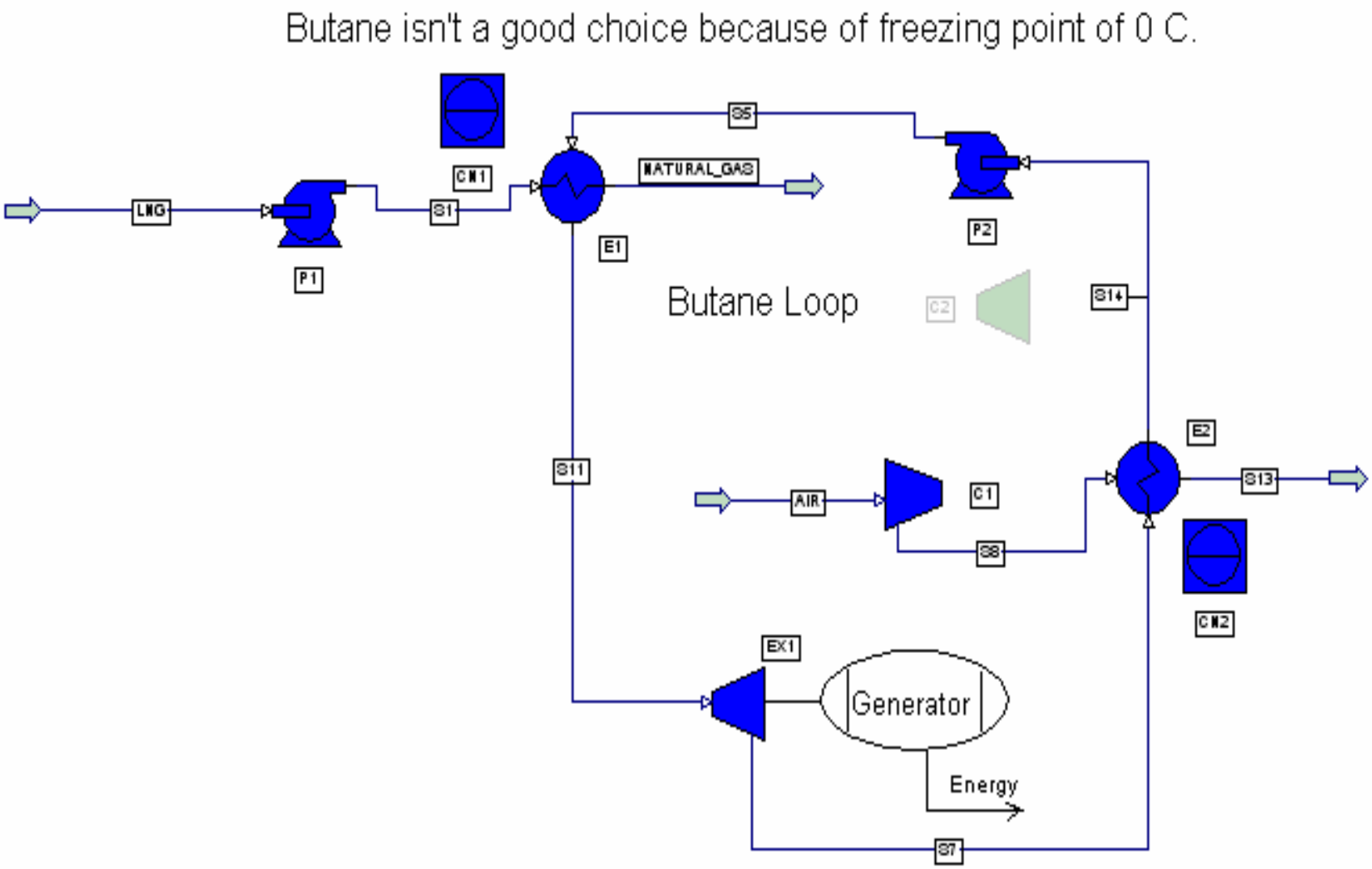
Cold Energy Recovery



Cold Energy Recovery



Cold Energy Recovery



Intermediate Liquids Used				
	Methanol	Propanol	Isopropanol	Propylene Glycol
Boiling Point (14.7 psia) (F)	**148.46**	**179.6**	**179.6**	**370**
Melting Point (14.7 psia) (F)	**-144.4**	**-126.4**	**-126.4**	**-74**
Hottest Temperature Used (F)	**75**	**75**	**75**	**75**
Coldest Temperature Used (F)	**-120**	**-90**	**-90**	**-50**
Flow Rate of Air (lbmol / hr)	**396801.59**	**396402.59**	**396355.41**	**396712.59**
Flow Rate of Liquid (lbmol / hr)	**45067.99**	**39294.27**	**38001.79**	**39797.14**
Pump Work Used (hp)	**182.29**	**293.62**	**290.31**	**209.39**
Expander Work Produced (hp)	**218.93**	**313.56**	**312.80**	**238.98**
Net Work (hp)	**36.64**	**19.94**	**22.49**	**29.59**

Other Options For Utilizing Cold Energy

- **Integrate Receiving Plant with Chemicals Plant**
- **Integrate Receiving Plant with Cryogenic Plant**

TCI

- **TCI**
  - **Liquefaction facility: $1.54 Billion**
  - **Shipping: $155 Million/ship**
  - **Piping: $1.26 Billion**
    - **Additional 75% added for installation**
- **Total: $3.11 Billion**

Equipment	No. of pieces	Basis	cost (million)
Compressors	8	284302 hp	284.302
Flash Column	9	120,000 ea	1.08
Heat Exchangers	8	1.5 million ea	12
	Total Equipment		297.382

Cost Item	Measurment Criteria	Amount
Direct Costs		
Purchased equipment	100	297
Installation	45	134
Instrumentation (installed)	18	54
Piping	16	48
Electrical systems (installed)	10	30
Buildings (including services)	68	202
Yard improvements	15	45
Service facilities	40	119
Total Direct Cost		928
Indirect Costs		
Engineering and Supervision	33	98
Construction expenses	39	116
Legal expenses	4	12
Contractor's fee	17	51
Contingency	35	104
Total Indirect Cost		381
FCI	440	1308
Working Capital	78	232
TCI (Million)	518	1540

Operating Costs

- **Pipeline:**
  - **1.9 BBTU/yr ~1% Fuel usage**
- **Liquefaction:**
  - **Varies according to price of NG**

Operating costs		
One Train		2007
Cost Item		5.00
Raw material	**Basis of Estimate**	
Natural gas	1 train requires 256.7MMBTU NG for 4.5 Mtpa	1283241758
Propane	$800/MT system charged and additional onhand to 1MT	800
Ethylene	$893/MT same as above	893
Operating labor	Highly complex process, many workers/engrs needed	
Skilled	5 @ $34/hr, 24 hr. op, 365 d/yr	1489200
Unskilled	15 @ $23/hr, 24 hr. op, 365 d/yr	3022200
Operating supervision	15% of operating labor	676710
Maintenance and repair	7% of TCI	217700000
Operating supplies	15% of maintenance and repair	32655000
Laboratory charges	11% of operating labor	496254
Royalties (not on lump sum)	5% of total product cost	130018443
Taxes (property)	2% of FCI	52870000
Financing (interest)	5.5% of TCI	171050000
Insurance	1% of FCI	26435000
Overhead Costs	60% of maintenance, labor, and supervision	133732866
General Expenses		
Administrative costs	20%of operating labor	992280
	Total Product Cost (Billion)	2.600

Design Planning

- 6 plans considered
  - 1 Train in yr 1
  - 1 Train every 5 years (1,5,10)
  - 1 train in yrs 1, 7, 9 & 12
  - 1 train in yrs 1,3,6,10,13
  - 1 train in yr 1, 2 trains in yr 5 and 1 train in yr 10
  - 2 trains in yrs 1, 5 & 10
- 5 scenarios
  - Low selling price/low buying price
  - Low selling price/high buying price
  - Medium buying & selling prices
  - High selling price/low buying price
  - High selling price/high buying price

Planning cnt.

- **Single train:**

Scenario	NPW
1	-4746593709
2	-9496337646
3	-7265679927
4	-11406424257
5	-6656680320

- **Design 5:**

Scenario	NPW
1	3204031553
2	-1962506491
3	-647963168
4	-8548876956
5	-3799133020

- **Design 2:**

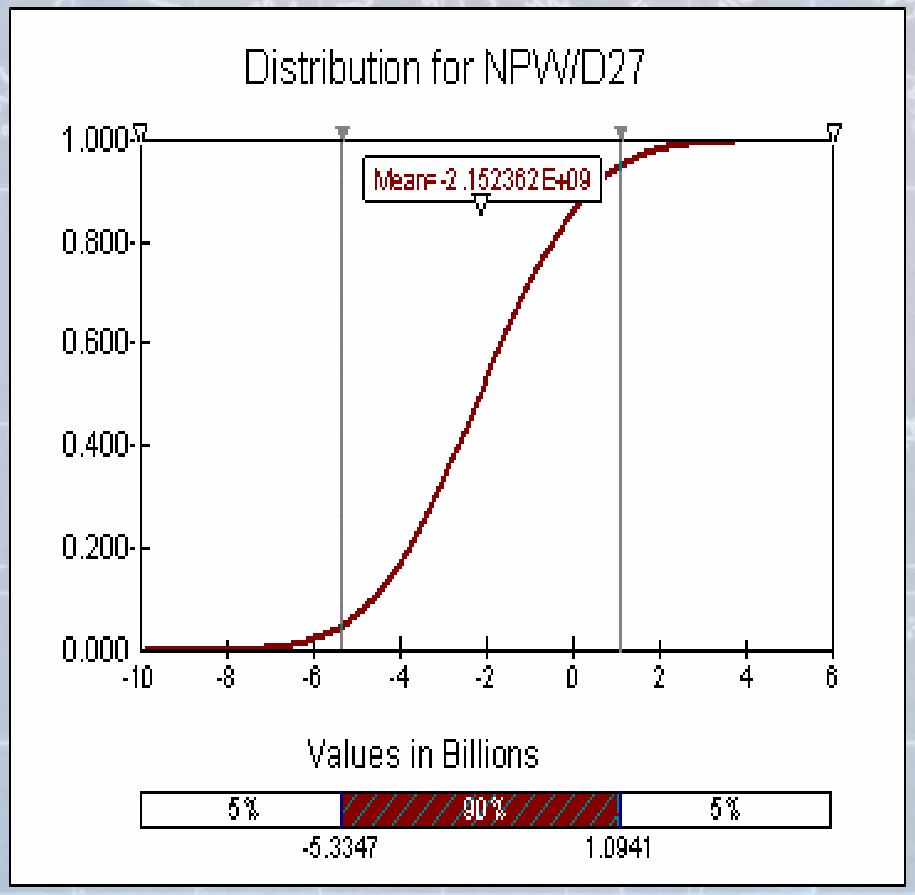
Scenario	NPW
1	-292223855.6
2	-5041967792
3	-3226885756
4	-10158643765
5	-5408899828

- **Design 4:**

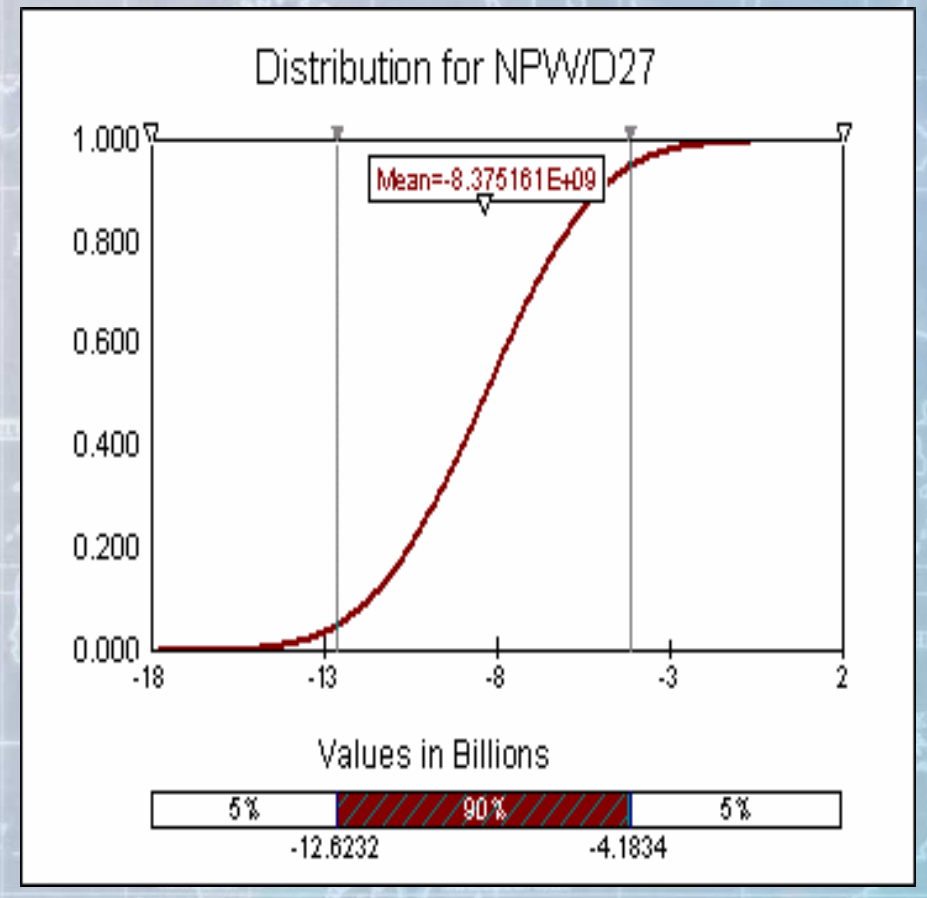
Scenario	NPW
1	30638863.61
2	-4690875728
3	-2750140587
4	-9367159583
5	-4645644991

Risk Analysis

- **Design 4:**



- **Design 5:**



Conclusions/Recommendations

- **Not profitable**
  - **High TCI**
  - **High operating costs**
  - **Fuel usage in pipeline**
- **Determine better location**
  - **Inside Peru**


Questions?