Unconventional Gas Production

Commercialization of Hydrated Gas

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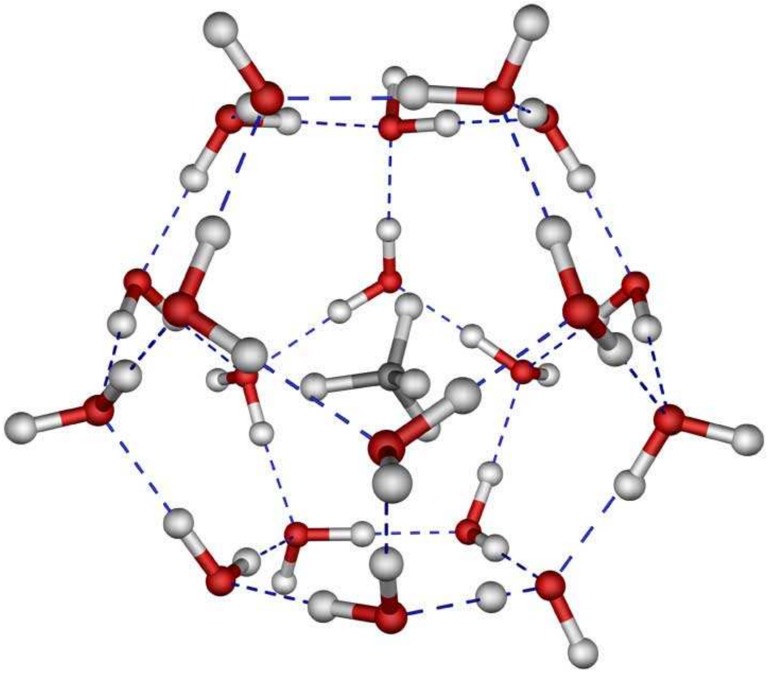
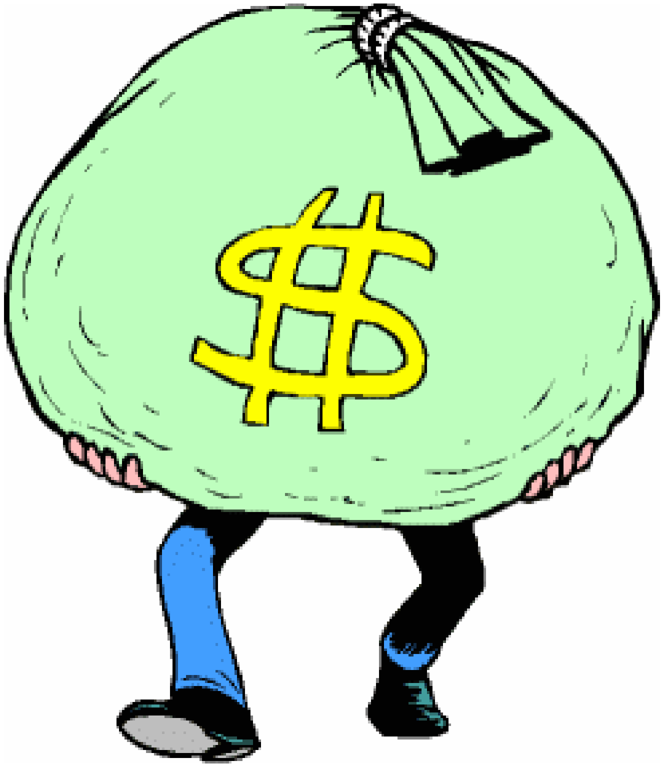
Objective Statement

- Methane hydrates hold a massive potential for production of natural gas, so we set out to find an economical way to produce hydrated gas and deliver it to market

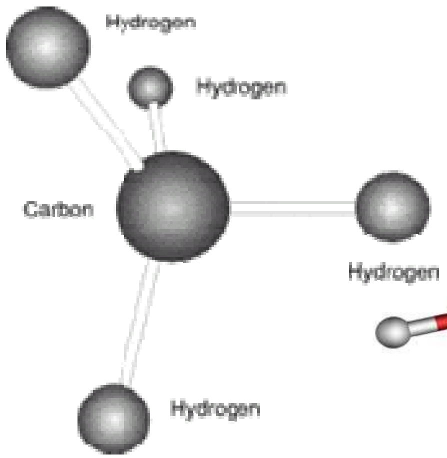


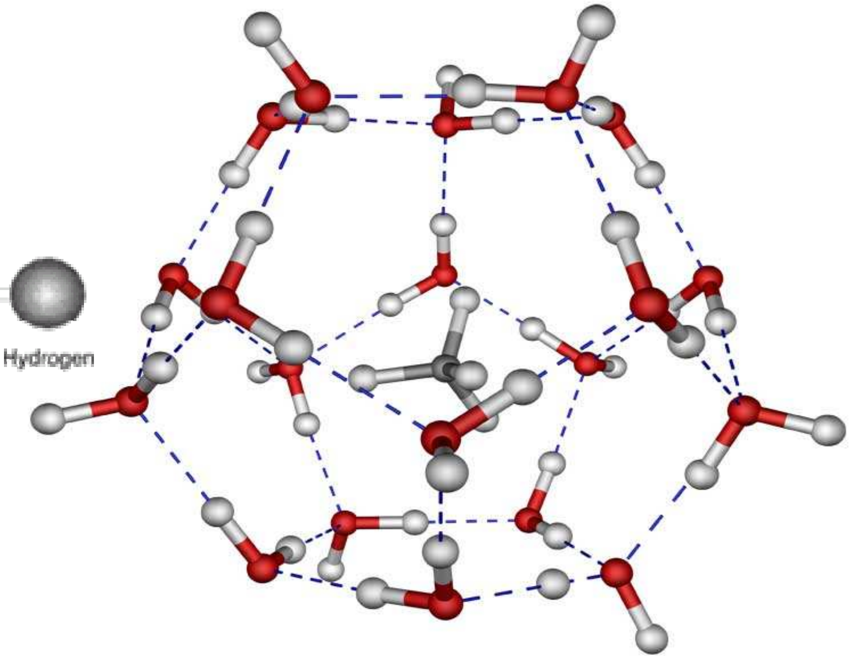


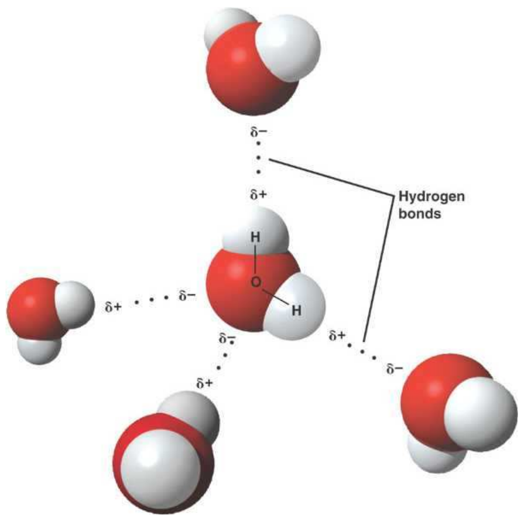
Intro to Hydrates

- Methane & water have the ability to form hydrates.

Methane **Hydrate** **Water**

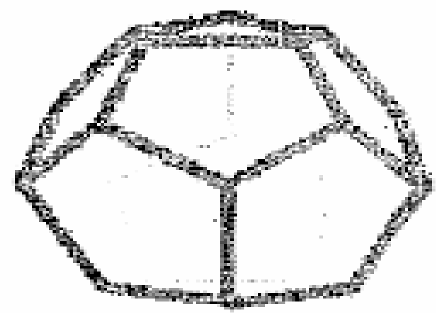




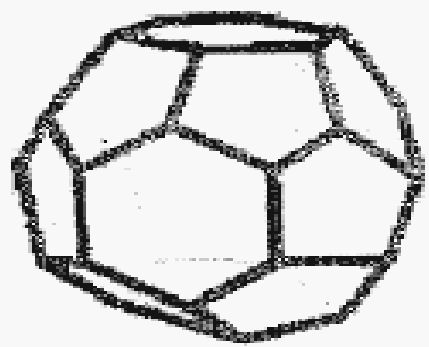


Clathrates

- Methane trapped in a cubic water crystals
- Unstable at standard temperature and pressure
- Estimated to produce 150 units of gas



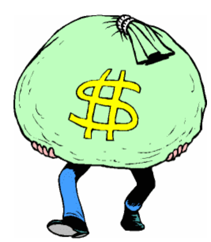
Structure I Hydrate
(Source: Sassen)



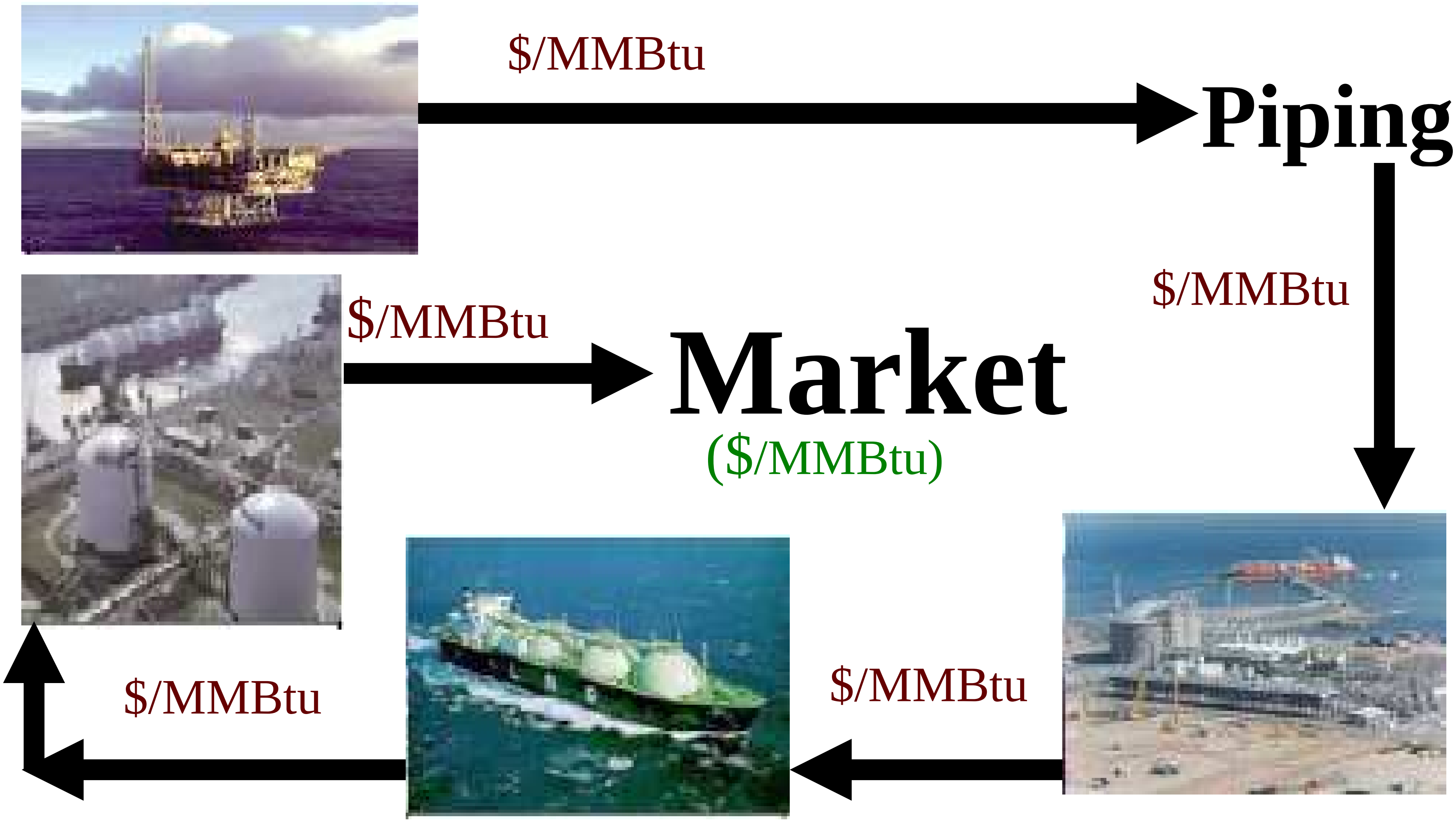
Structure II Hydrate
(Source: Sassen)

Overview

- Operations
  - Locating
  - Drilling
  - Production
  - Piping
  - Liquefaction
  - Shipping
  - Regasification
  - Sales



Value Chain



Locating

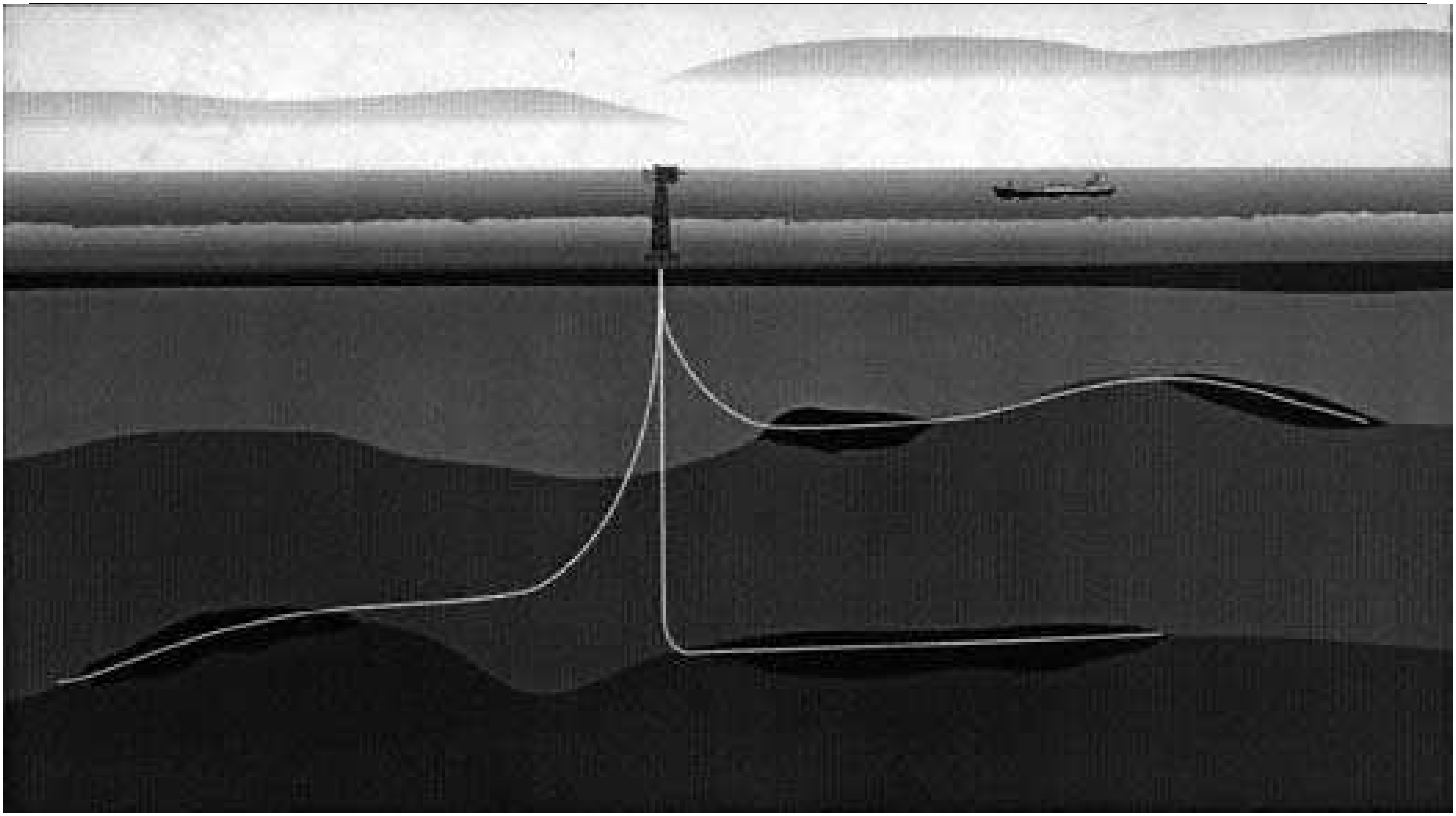
Locating

- Seismic Surveying
  - Acoustic
- Seismic Analysis
  - 2 month project, 3 man team
  - Block = 3 square miles
  - Usually shoot 30-60 blocks at a time
  - Project a 2000 square km area with a depth of 1200ft to 3300ft

Locating cont’

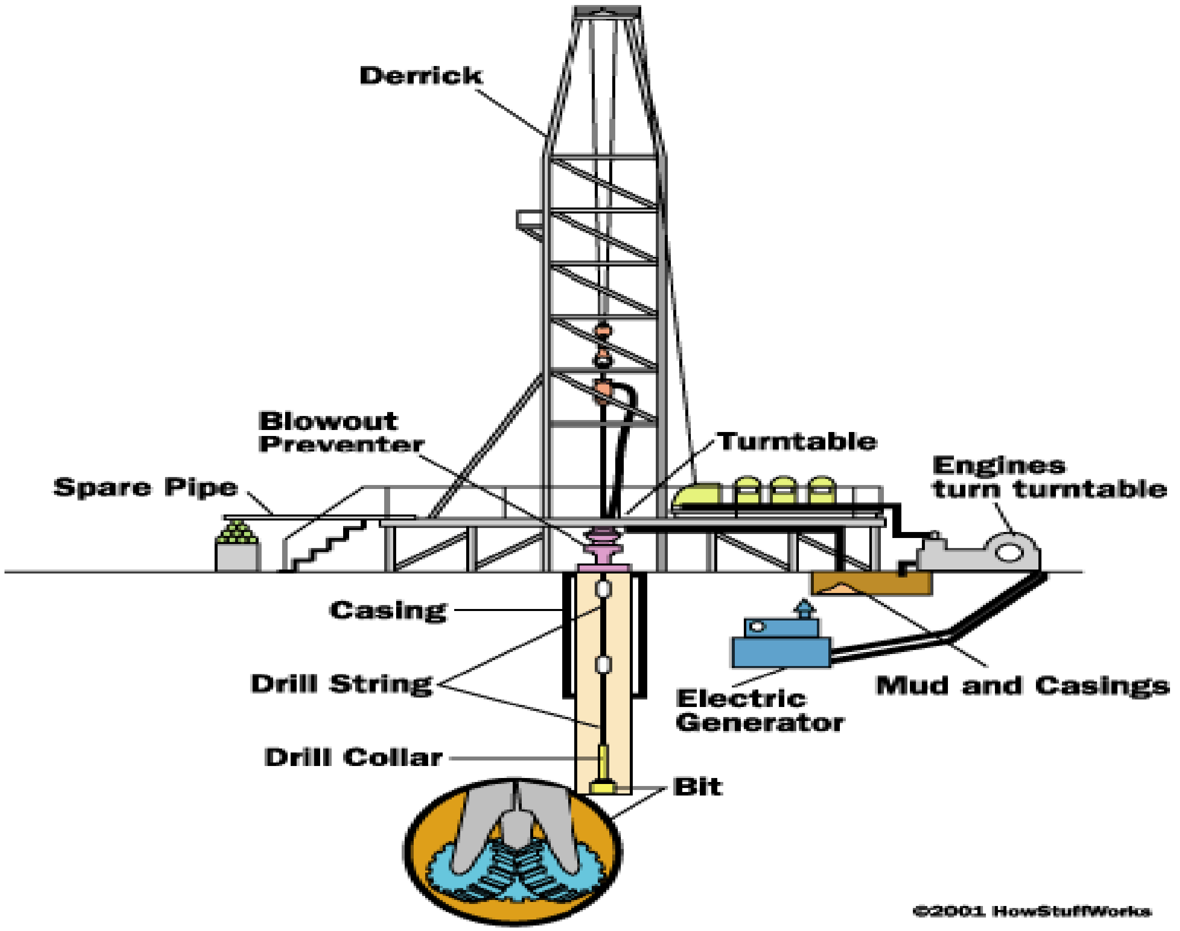
- Seismic Survey Costs
  - \$30,000 for shooting a block
  - \$12,000,000 for the 2000 km^2 area with a depth of 400m-1000m
  - \$3,000,000 for reprocessing cost and time for the seismic survey
  - Total Cost = \$15,000,000

Drilling



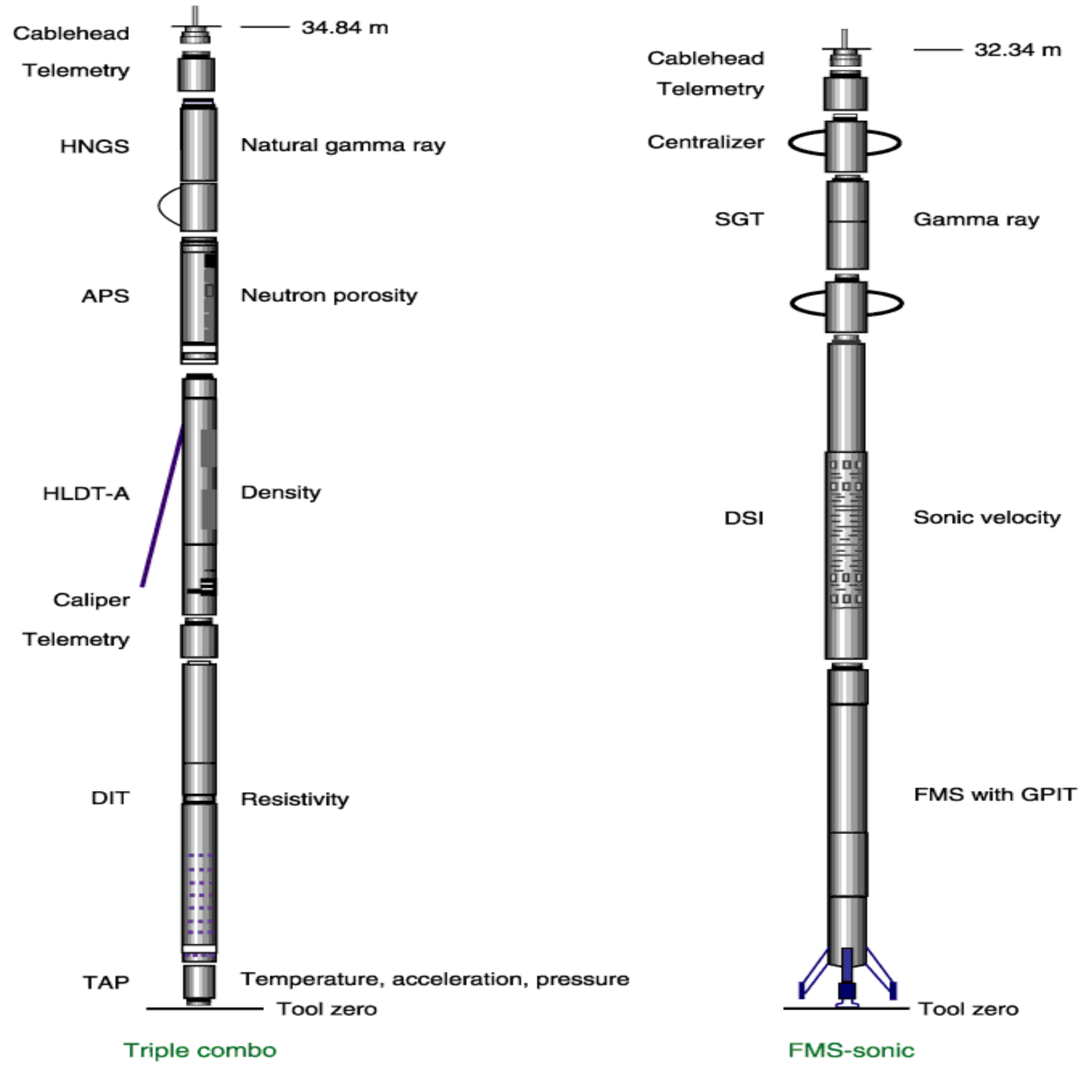
Drilling

- Drilling and Measurements
  - Directional drilling and basic logs to locate promising zones



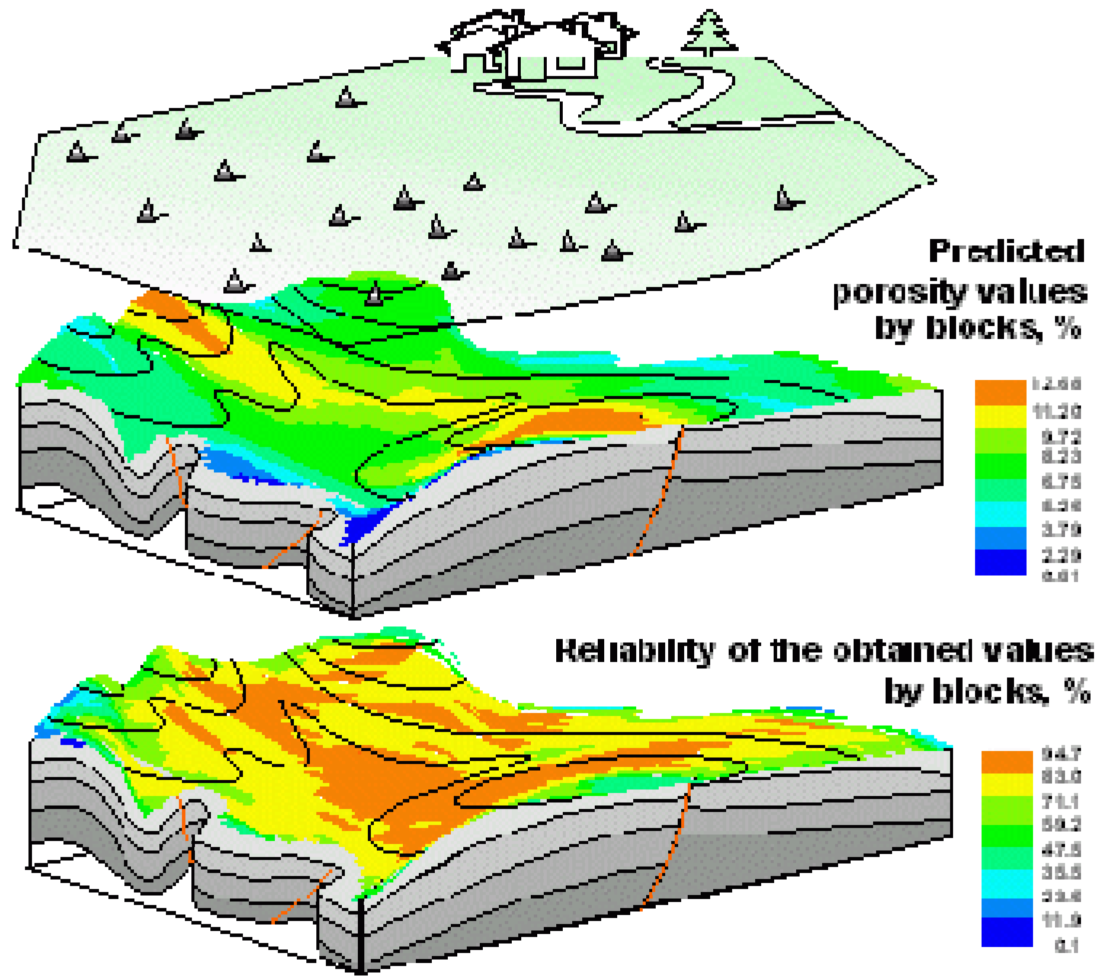
Drilling

- Reservoir Evaluation
  - In depth logs of promising areas
  - Perforations into methane hydrated areas



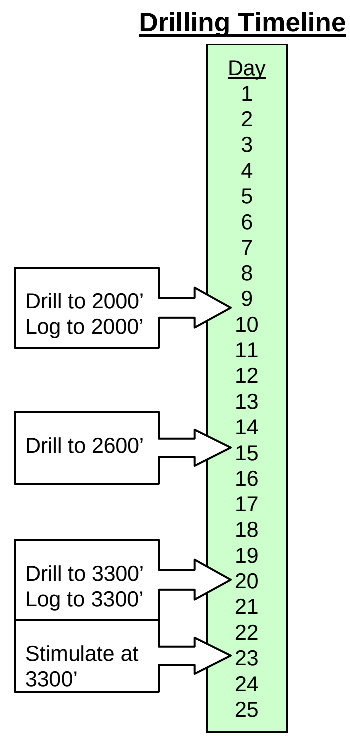
Drilling

- Well Stimulation
  - Pressurized solution addition into the formation to stimulate backflow of desired product



Drilling cont’

- Drilling and Measurements
  - 17 day projects
  - 90fph thru basic formation
  - 10fph thru hydrate formation
- Reservoir Evaluation
  - 2 separate day projects
  - Log 1200ft to 3300ft
  - HILT with FMI and Sonic
  - Two 3ft perforations at 2100ft & 2200ft
- Well Stimulation
  - 3 separate fracturing day projects, 1 casing job, 1 cementing job
  - 70 miles each way to get to location



Drilling Cont’

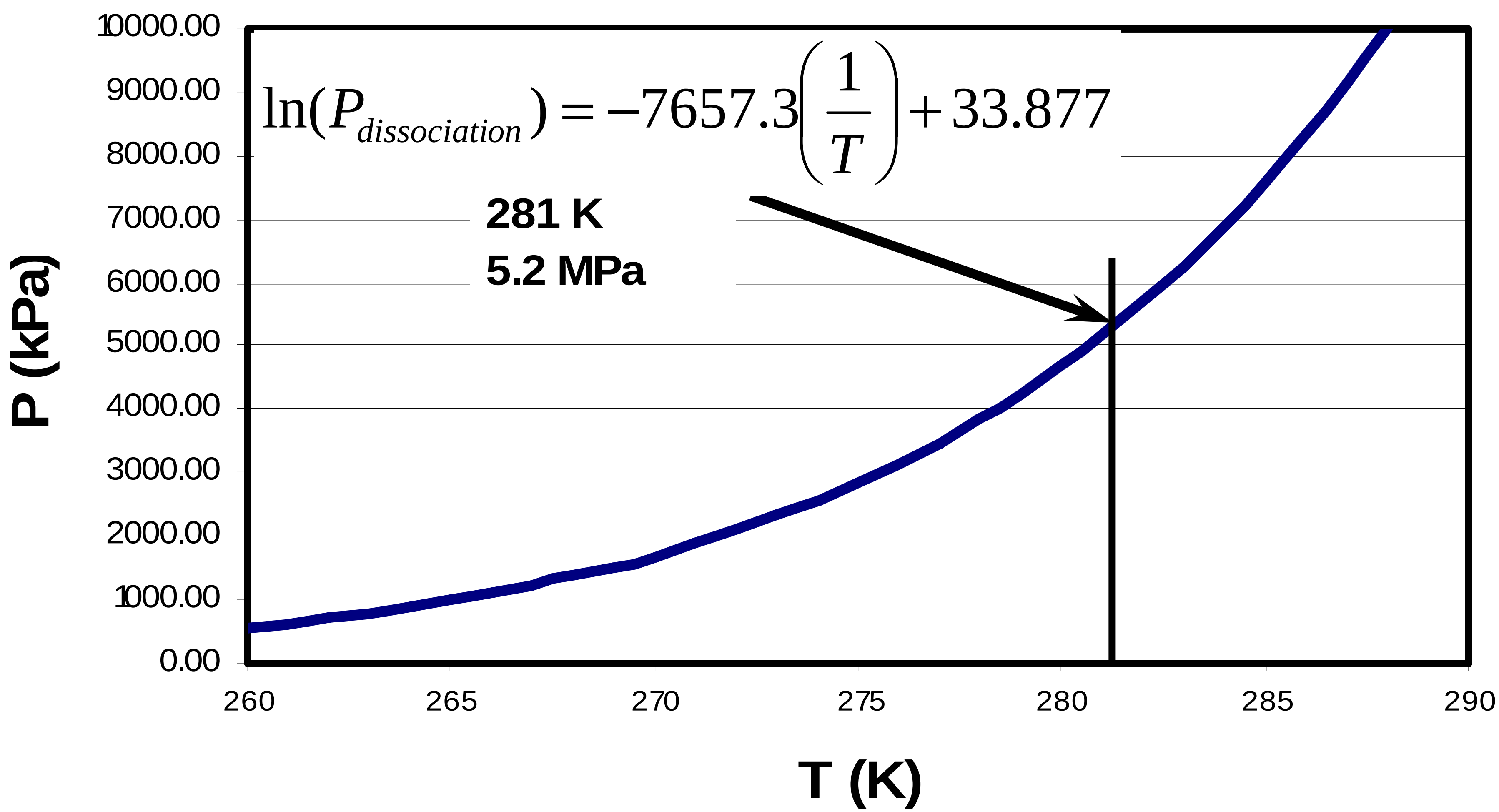
- Basis for a well
  - 25 day project
- Initial investment
  - $20.5 million
- Yearly operating cost
  - $8.2 million

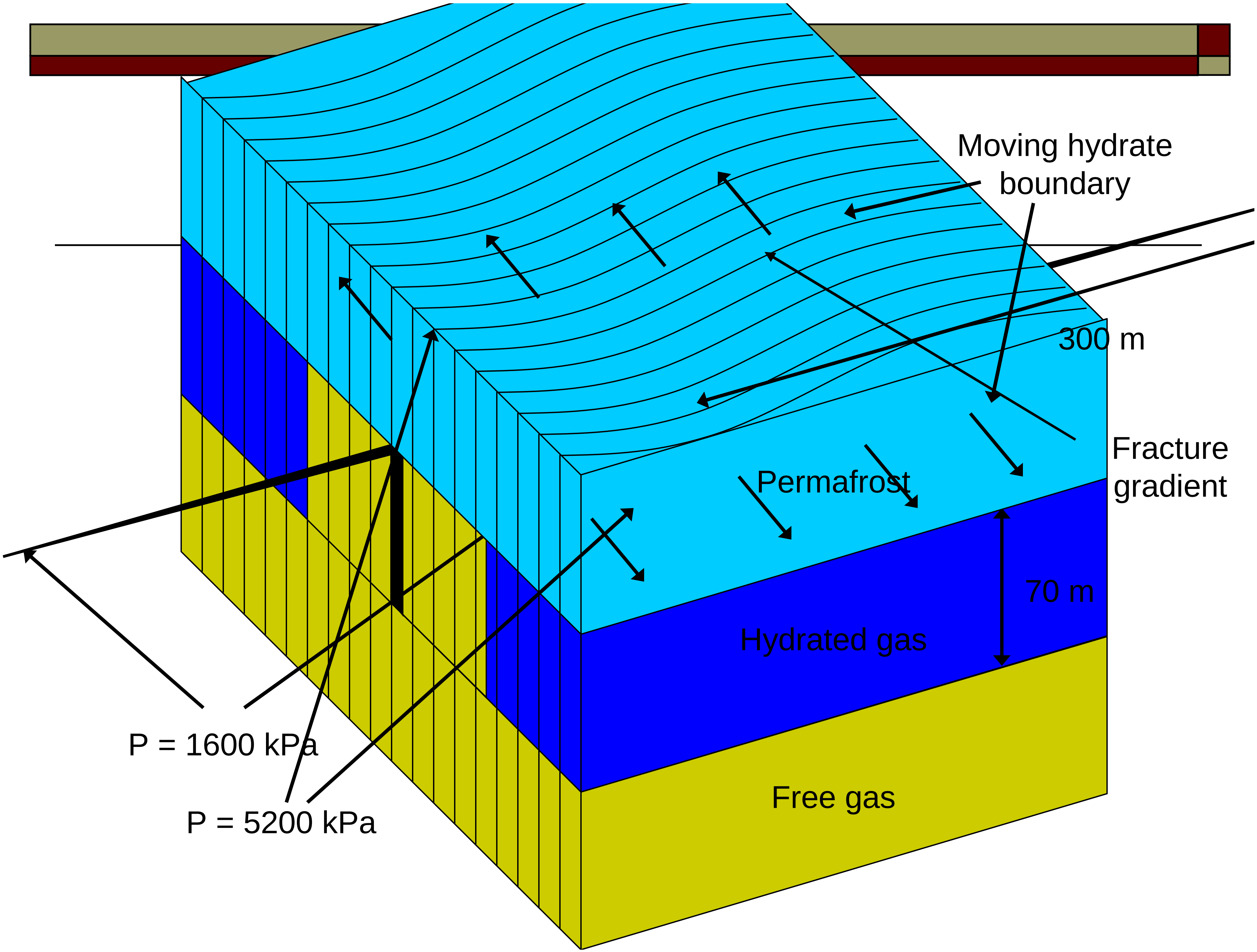
- Drilling and Measurements
  - $895,500
- Reservoir Evaluation
  - $14,700
- Well Stimulation
  - $5,840,000
- Well Completions
  - $68,300

Production

- Assumptions
  - 165 scm gas per cubic meter of hydrate
  - Formation behaves as a tank
  - Formation is homogenous and isotropic
  - No intermediate phases
  - Isothermal process
  - Rock expansion is negligible
  - 300 m vertical fractures in 2 directions, 180° separation
  - Negligible pressure gradient along fractures
  - Hydrate formation is on average 70 m deep

Production – hydrate stability





Moving hydrate
boundary
300 m
Fracture
gradient
Permafrost
70 m
Hydrated gas
Free gas
P = 1600 kPa
P = 5200 kPa

Production cont'

- Kinetics
  - Dissociation is faster than diffusion under down hole conditions
  - Flow through the formation is much slower
  - Focus on flow through formation
  - Linear Pressure gradient

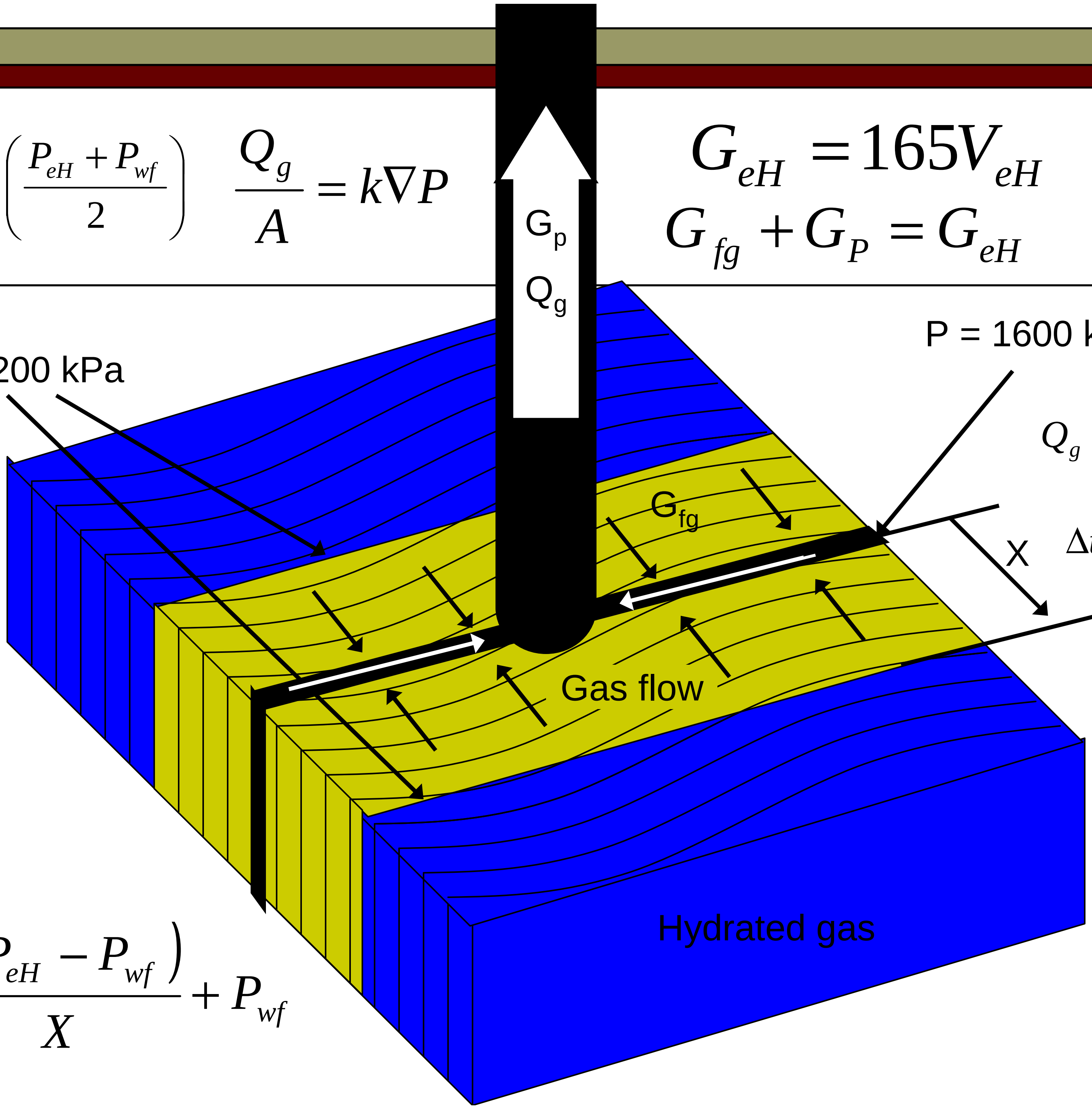
$$\frac{dx}{dt} = K_0 e^{\frac{-E}{RT_s}} \left(f_{eH} - f_\infty \right)$$

$$G_f = \frac{V_f}{Z\Re T}\left(\frac{P_{eH} + P_{wf}}{2}\right)$$

$$\frac{Q_g}{A} = k\nabla P$$

$$G_{eH} = 165V_{eH}$$

$$G_{fg} + G_P = G_{eH}$$



$$Q_g = \frac{dG_P}{dt}$$

$$\Delta t = \frac{\Delta G_P}{Q_g}$$

$$\nabla P = \frac{dP}{dx} = C$$

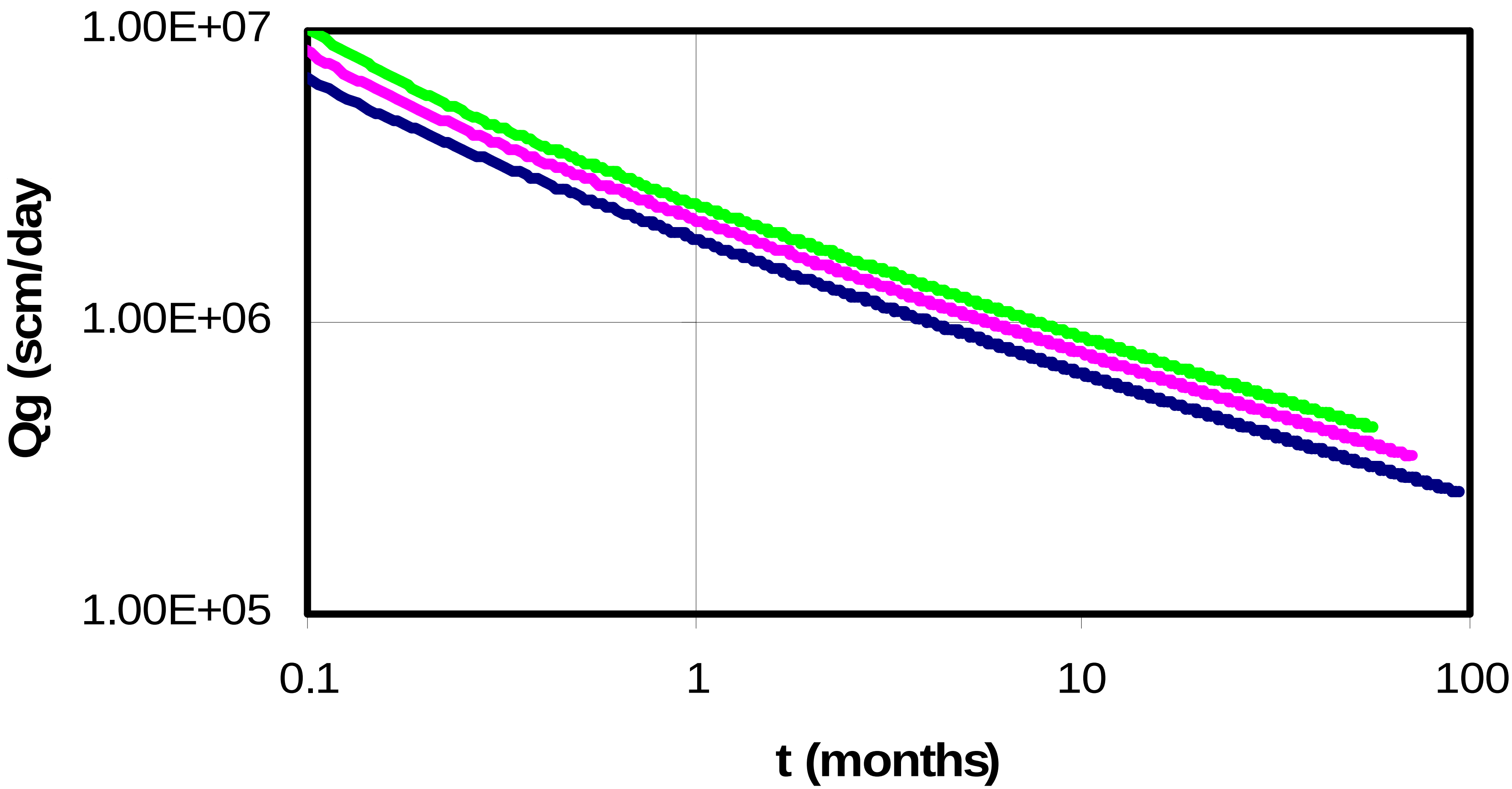
$$C = \frac{P_{eH} - P_{wf}}{X}$$

$$P(x) = \frac{x\left(P_{eH} - P_{wf}\right)}{X} + P_{wf}$$

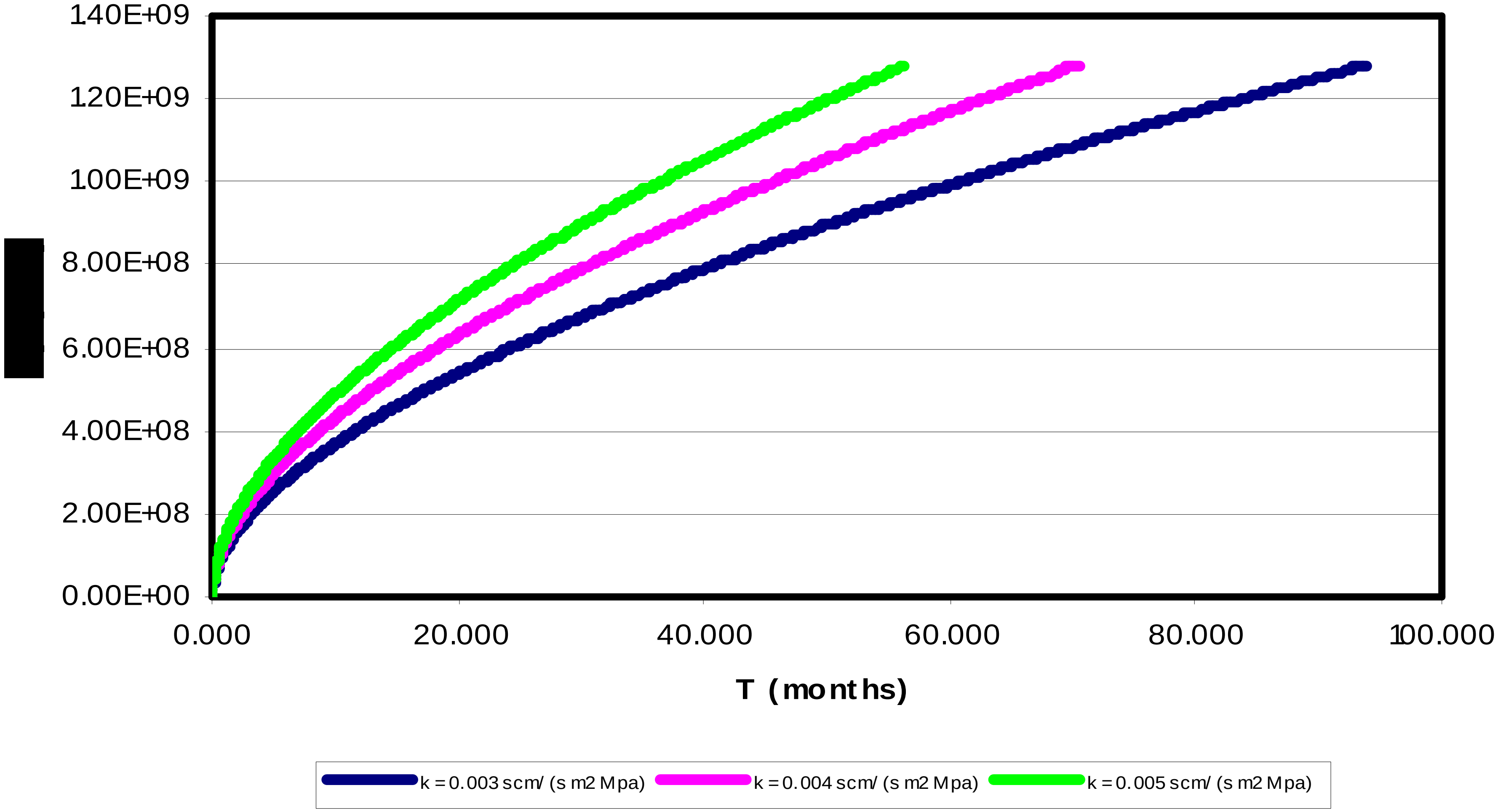
Production

- Rates may seem high, but an analysis of the velocity of the hydrate boundary shows that a max velocity of 3mm/min at the beginning of dissociation, slows to 0.24 mm/min at the end of a year.

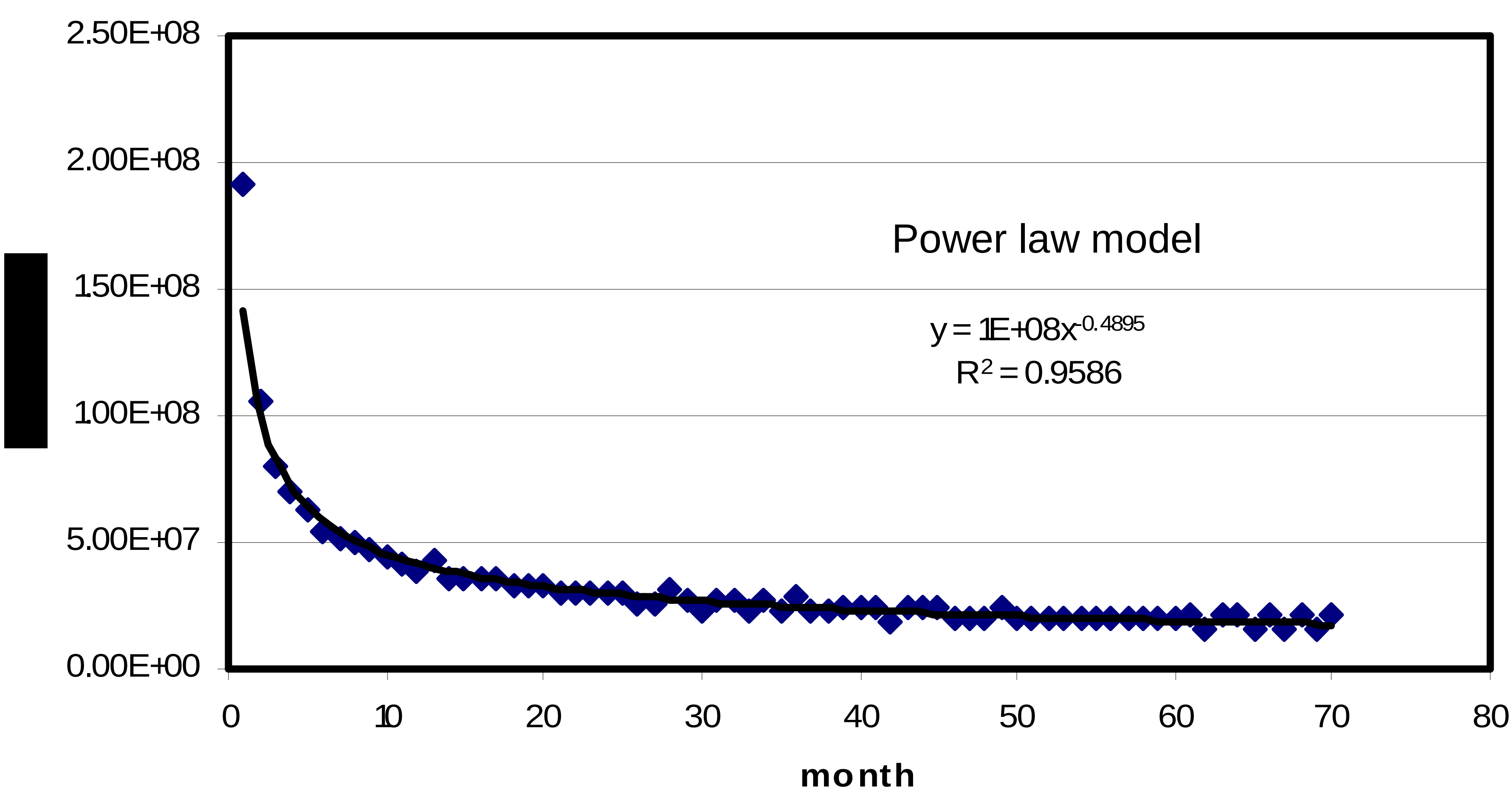
Production cont'



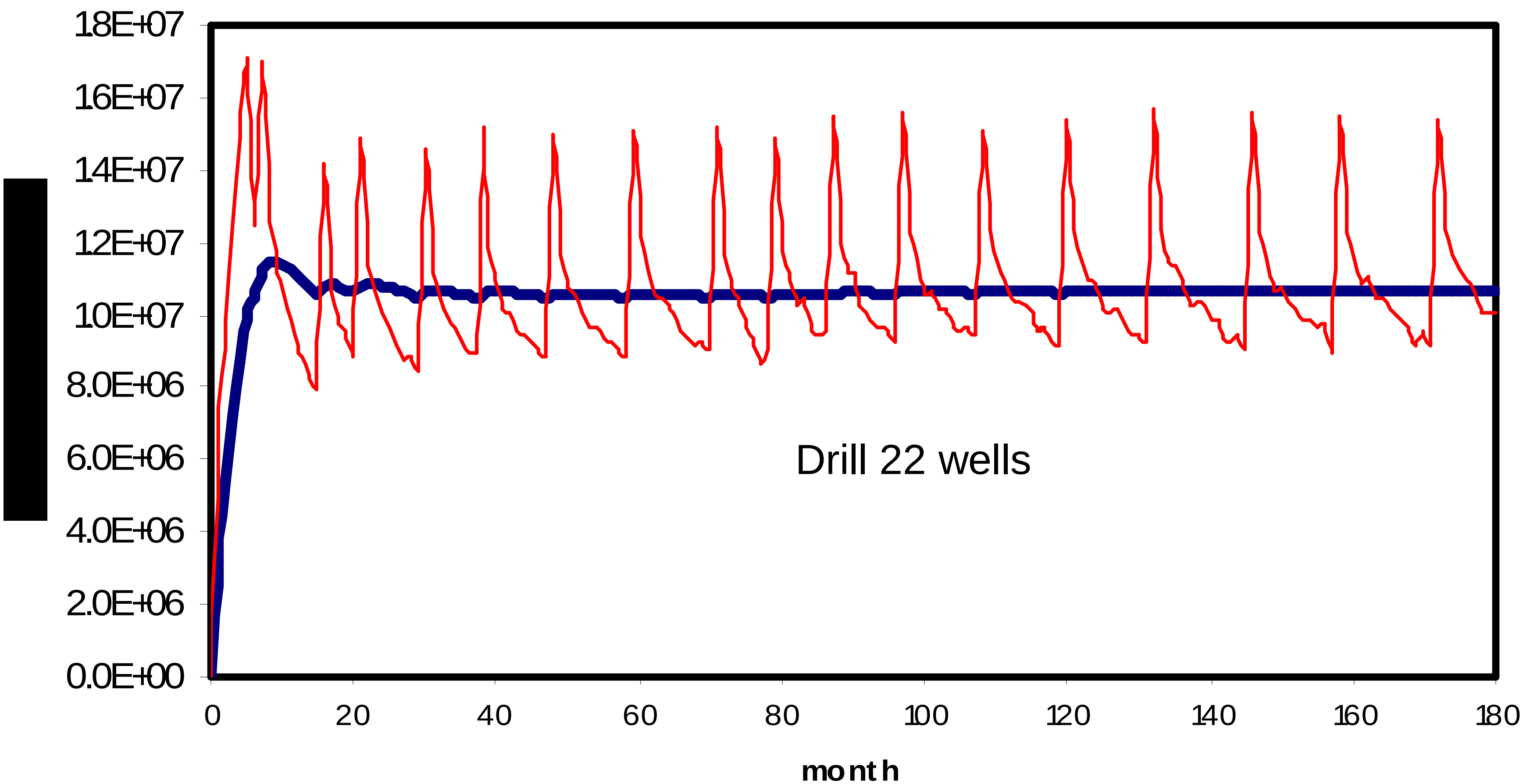
Production cont’



Production


2.50E+08
2.00E+08
150E+08
100E+08
5.00E+07
0.00E+00
[redacted]
Power law model
y = 1E+08x-0.4895
R2 = 0.9586
0
10
20
30
40
50
60
70
80
month

Production



1.8E+07
1.6E+07
1.4E+07
1.2E+07
1.0E+07
8.0E+06
6.0E+06
4.0E+06
2.0E+06
0.0E+00
0
20
40
60
80
100
120
140
160
180
month
Drill 22 wells

Production - conclusions

- Control gas production initially at 10.5 MM scm/day
- Rate drops off to about 2.25 MM scm/day after the first month
- Expected production for the first month is 1,770,000 scm per foot of formation
- Expect to continue significant gas production for entire project.

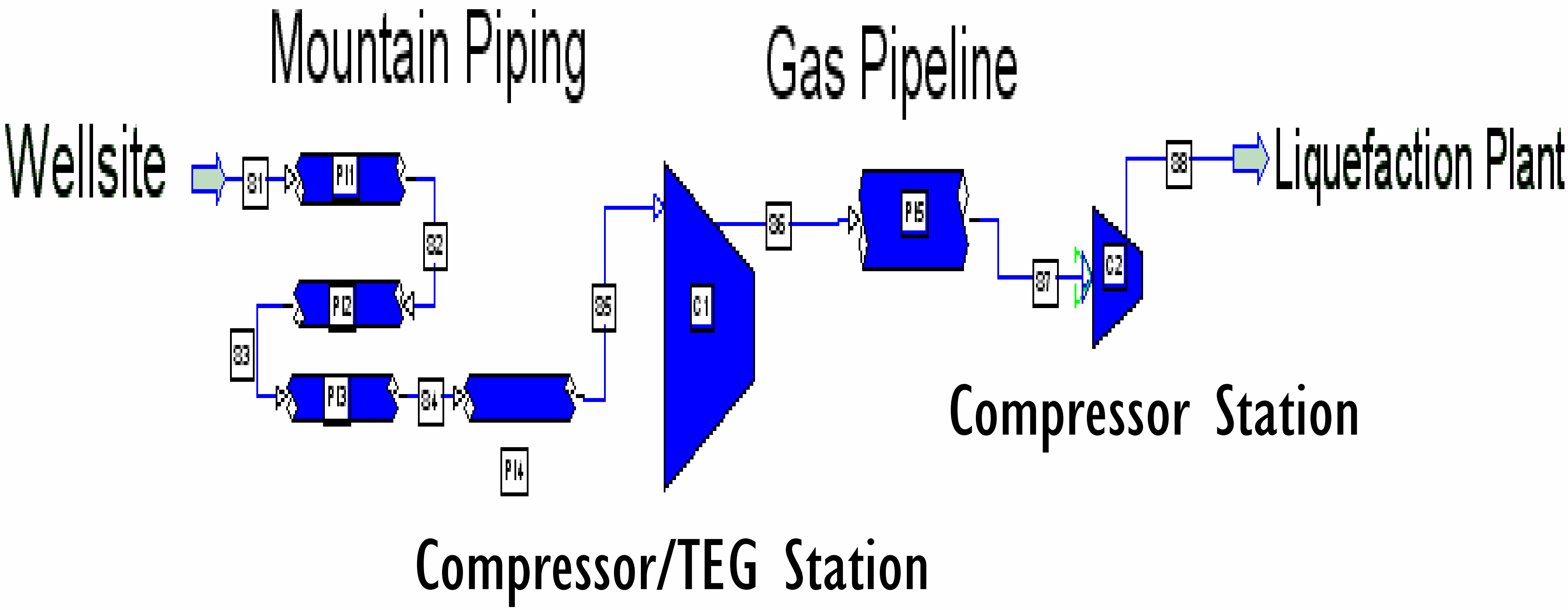
Production - conclusions

- 22% of gas from hydrates is left down hole
- Exposing as much hydrate surface as possible is best way to produce gas
- Wells produce significant gas over an extended period
- The monthly rate is fairly accurately modeled by a power regression, this was used after the first 70 months

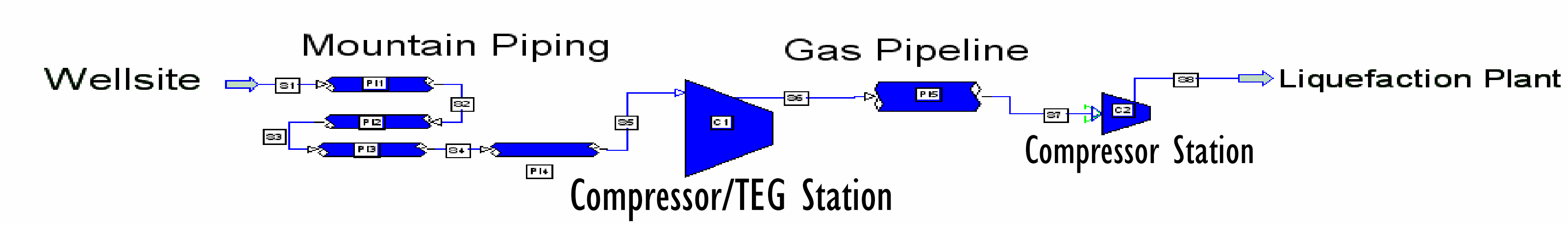
Piping

- Challenges
  - Provide a force to push the gas through the pipe
  - Preventing methane and water from reforming into a hydrate in the pipe
  - Excess water causing erosion damage to pipeline
- Solutions
  - Use Bernoulli's formula to solve for minimal compressor power required to move gas, simulated in ProII
  - Remove water from gas via a dehydration station
  - Maintain gas above 4C to prevent refreezing

Piping

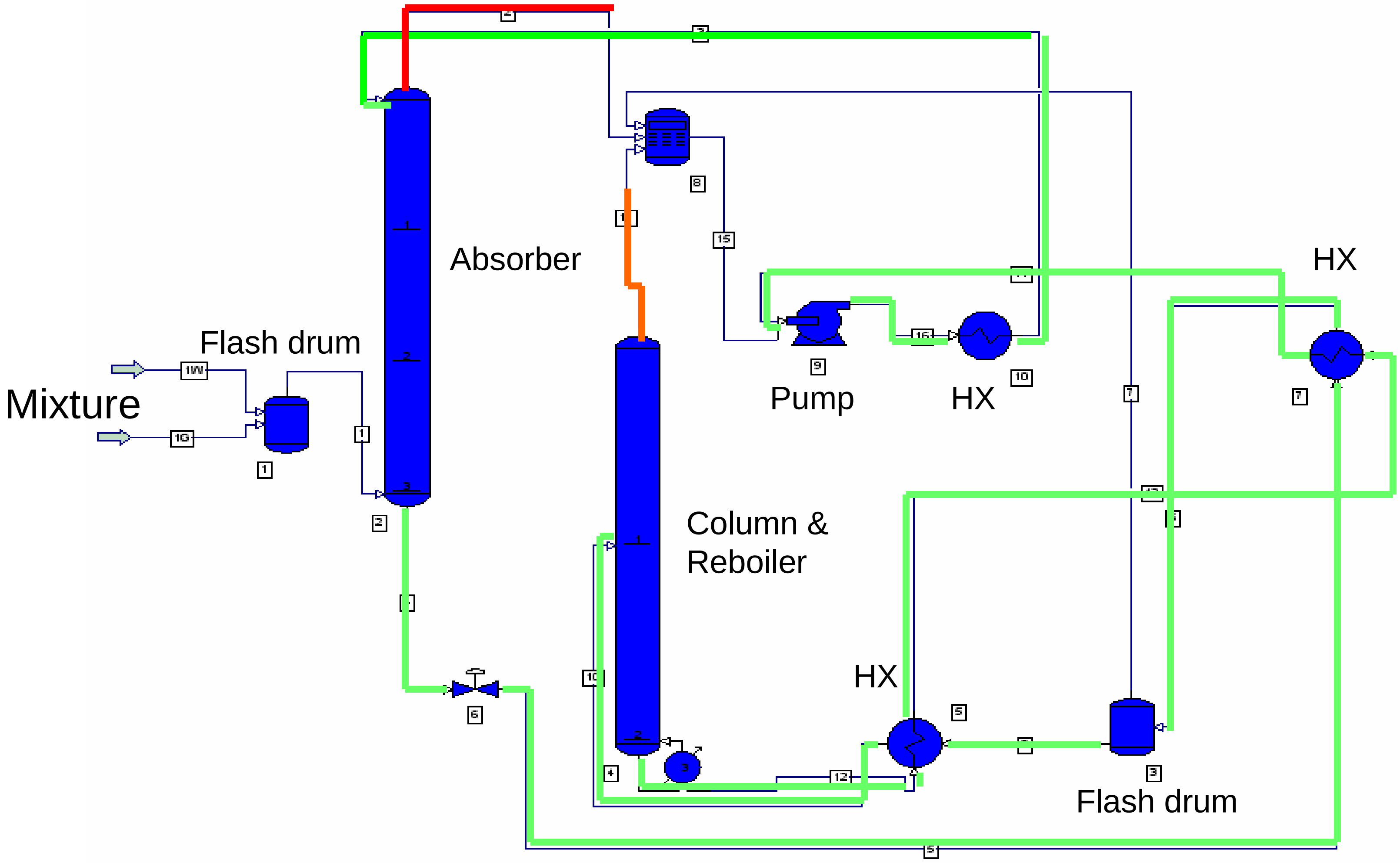

Mountain Piping
Gas Pipeline
Wellsite
Liquefaction Plant
S1
P11
S2
P12
S3
P13
S4
P14
S5
C1
S6
P15
S7
C2
S8
Compressor Station
Compressor/TEG Station

Piping cont’



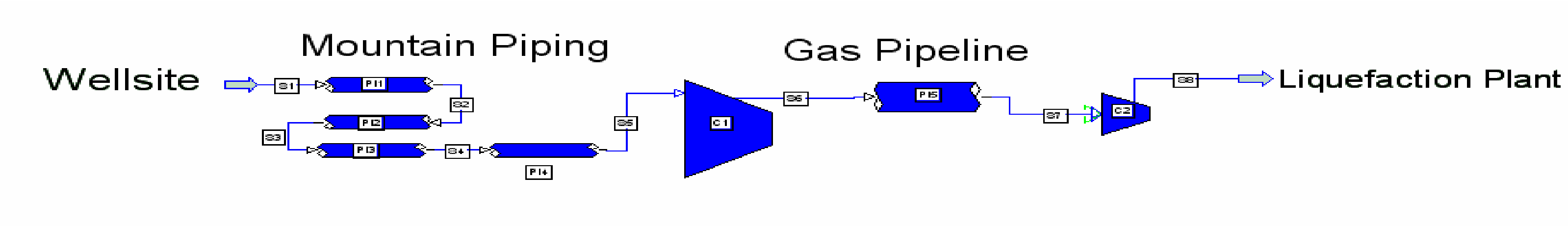
- Local Mountain Pipeline Assumptions for Calculations
  - 4 miles of pipe required to reach bottom of mountain
  - 8” pipe from well site
  - 12” pipe header into compressor station
- Compressor/TEG Assumptions for Calculations
  - Producing an average 10.5 million cubic feet of gas per day
  - Use Centrifugal pumps rated 6000kw and 75kWfor commercial industry
- Pipeline Assumptions for Calculations
  - Roughly 50 miles from the first compressor station to LNG Plant
  - Temperature above 4C and pressure above 1000kPa
  - 36” main pipeline to the LNG Plant

Piping cont'



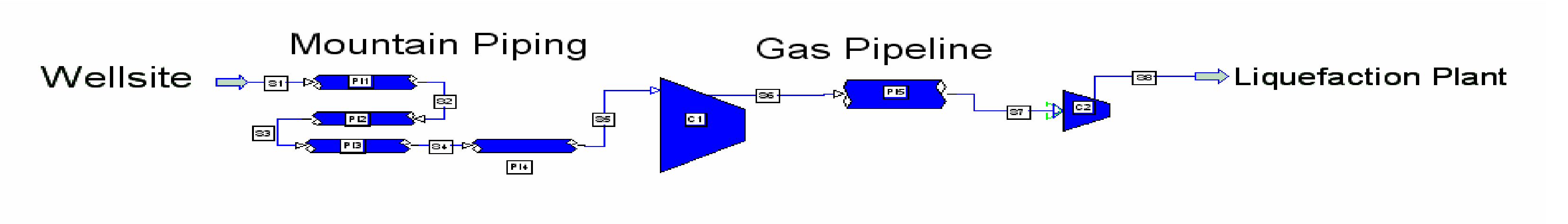
Absorber
Flash drum
Mixture
Column &
Reboiler
Pump
HX
HX
HX
Flash drum

Piping cont’



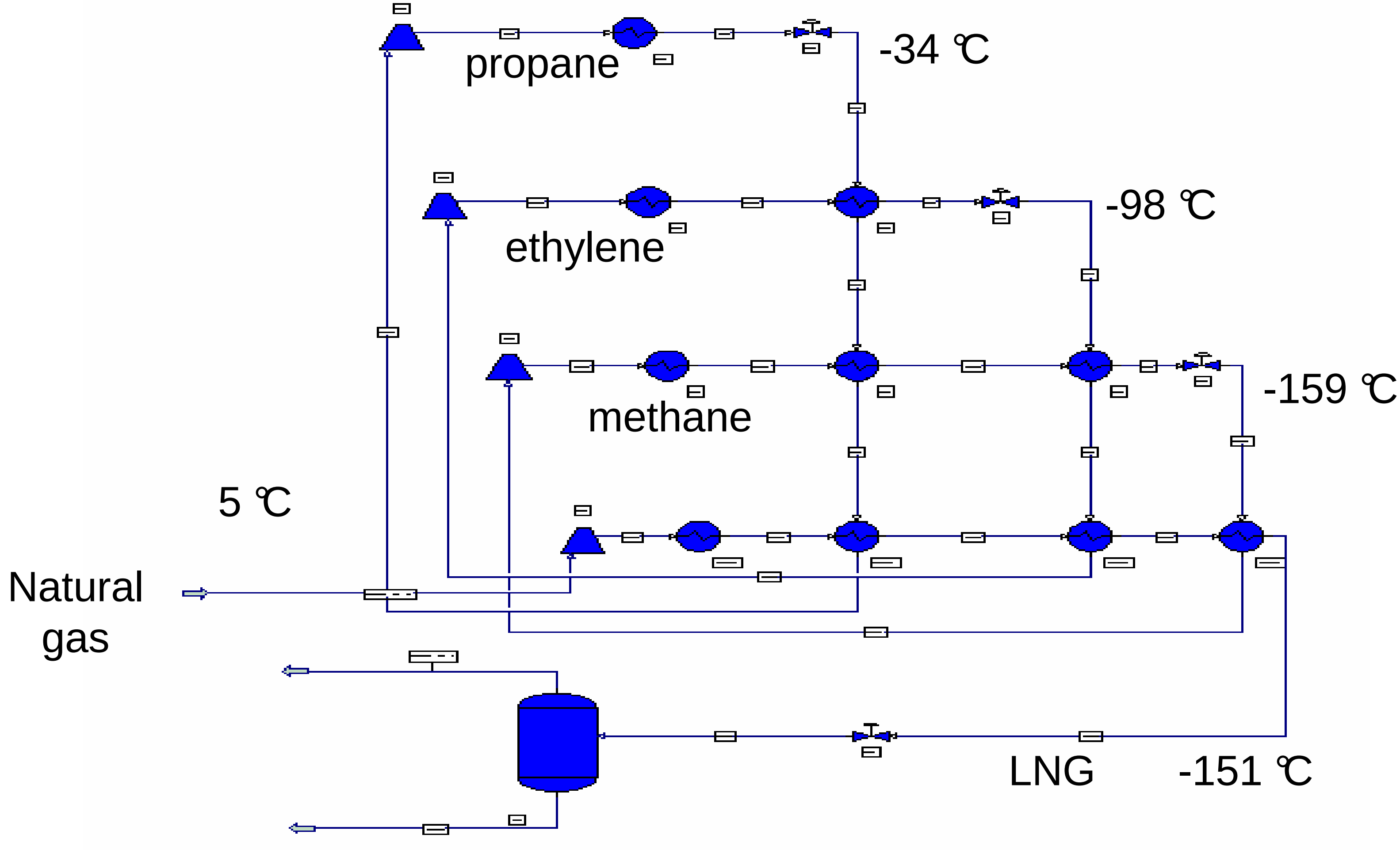
- TEG Dehydration Station
  - $450,000
- Compressor Costs
  - $3.6 million for a 6000kW compressor (9 total)
  - $0.3 million for a 560kW compressor (6 total)
  - Total compressor cost = $11.5 million
- Piping Costs
  - $60 million for 36” pipe going 50 miles

Piping cont’



- Equipment Costs
  - $94 million
- Initial investment
  - $270 million
- Yearly operating cost
  - $87 million

Liquefaction cascade



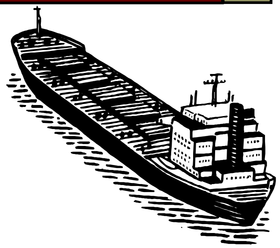
Liquefaction

- Heat exchangers
  - 266 at 200 m^2 each (52,200 m^2 required)
  - $14.8 million
- 4 compressors –
  - 53 at 6000 kW each (309 MW required)
  - $68.4 million
- Flash drum – $250,000
- Storage tank – $12,200

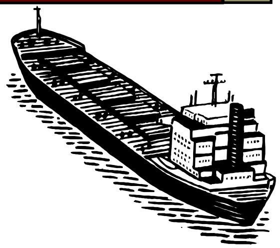
Liquefaction

- 1.25 billion kg/year capacity
- $500 million investment
- $270 million yearly operating costs
  - $140 million per year for electricity
  - $60 million for depreciation
  - Taxes, insurance, repairs personnel, etc…

Shipping



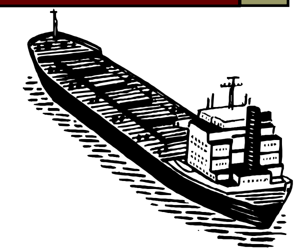
- LNG will be transported from Kamchatka to Japan via one LNG ship
- Assumptions
  - 8 day sea voyage one way trip
  - 6 days for loading, unloading and in port maintenance operations
  - 22 day round trip voyage
  - 15 nm average speed of LNG ship



Shipping cont’

- Costs
  - Round trip - $1.5 million
  - Daily operational cost is a function of building costs, financing and operating the ship
  - One LNG ships in operation will cost $65,000 per day

Shipping cont’

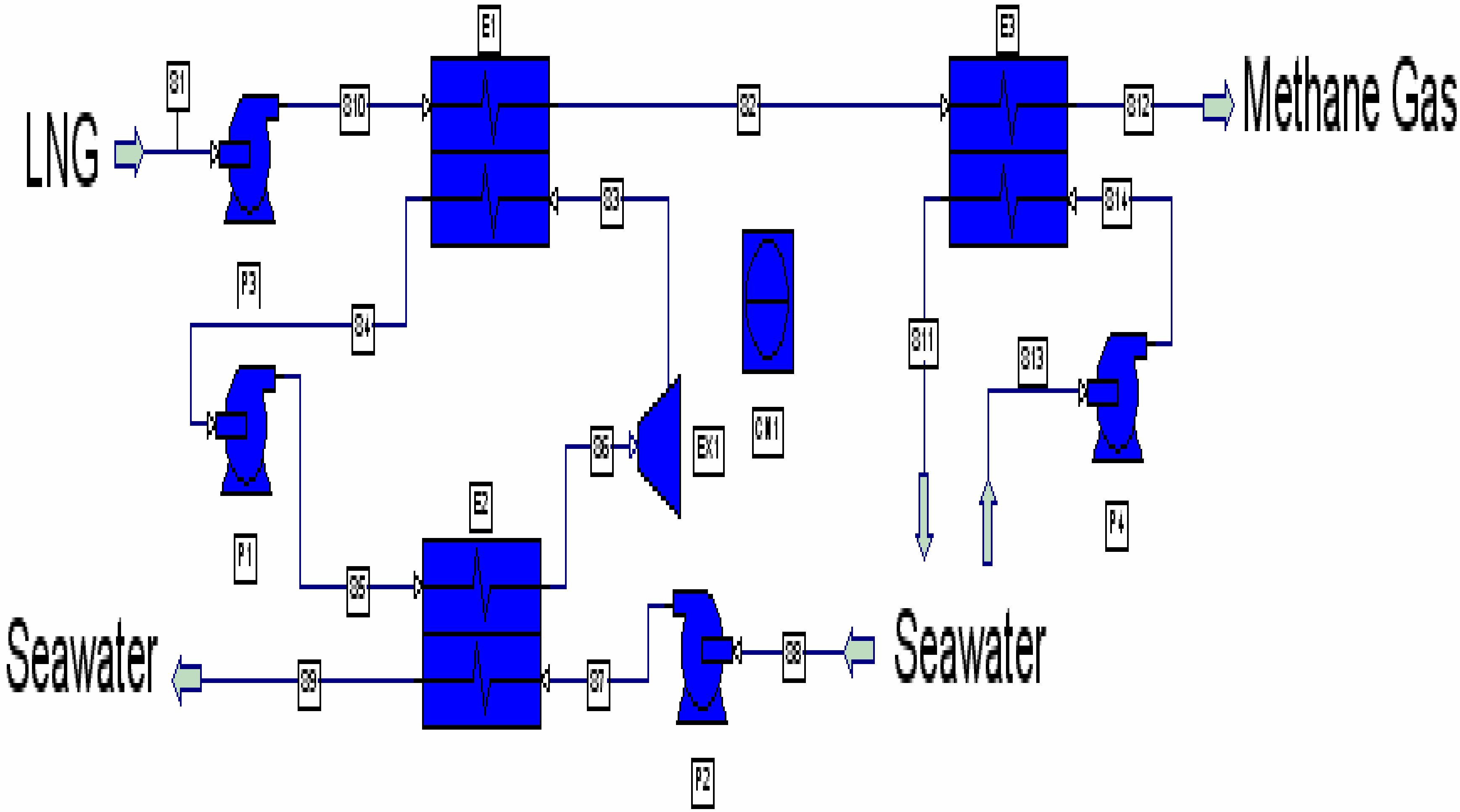


- 3 Ships Costs
  - $150 million each
- Initial investment
  - $58.1 million
- Yearly Operating Costs
  - $71.2 million

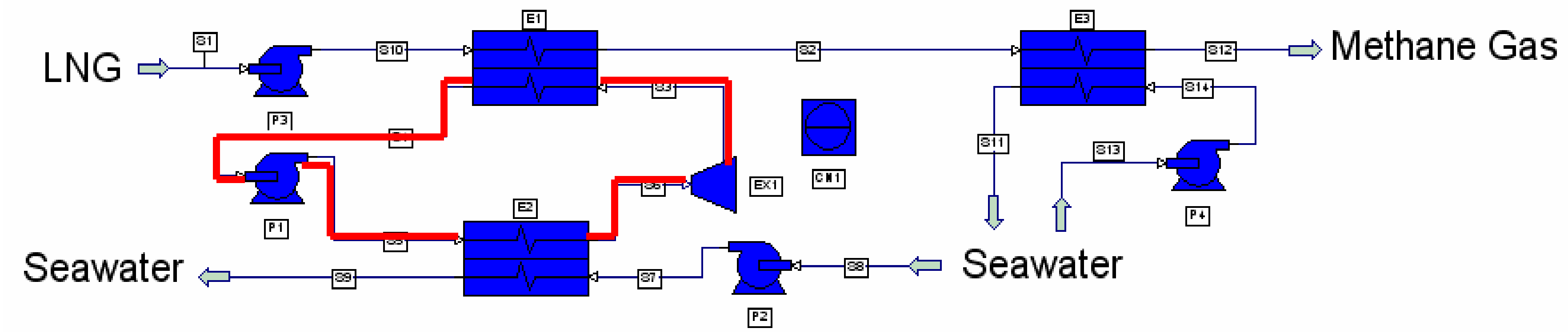
Regasification

- Challenges
  - Phase change of LNG to gas methane
  - Achieve regasification with minimal power requirements
- Solutions
  - Use seawater as heat source
  - Use propane as a medium b/w seawater and LNG to harness expansion power of a gas and generate power

Regasification



Regasification cont’



Expander (propane, gas)				
Q =	-3155.863	HP		
h =	58.4	ft		
P =	14.70003641	psi		
volumetric flowrate * discharge pressure =	353.5716666	kPa-m^3/s		
Power in kW =	-2353.327039	kW		
cost of expander (max value at 1000kW) =	$157,862			
Number of Expanders needed =	1	approximately =		3
cost (horizontal pump @ 174 kPa-m^3/s) =	$473,586.00			
Selling price of Expanders energy in kW =	-$188.27	per hour		
	-$4,518.39	per day		
	-$1,649,211.59	per year		

Regasification cont’

- Equipment Costs
  - $14 million
- Initial Investment
  - $84 million
- Yearly Operating Costs
  - $17 million

Decisions

- 1 LNG Ship
  - 3.5 scm/day
  - TCI $690 million
  - Expected ROI 7% per year
  - Final Cash Position of $1.74 billion
- 2 LNG Ship
  - 7.0 scm/day
  - TCI $1.25 billion
  - Expected ROI 12% per year
  - Final Cash Position of $4.17 billion
- 3 LNG Ship
  - 10.5 scm/day
  - TCI $1.9 billion
  - Expected ROI 12% per year
  - Final Cash Position of $5.8 billion

Regret

- Regret analysis is the analysis of unrealized profit associated with production choices

Regret

	lowest	low	expected	high	highest	Average
1 Ship	$ (1,189.42)	$ (479.07)	$ 732.96	$ 2,597.31	$ 3,220.50	$ 976.46
2 Ship	$ (1,605.89)	$ (186.40)	$ 2,237.76	$ 5,952.30	$ 6,704.74	$ 2,620.50
3 Ship	$ (2,311.69)	$ (193.75)	$ 3,401.06	$ 9,113.69	$ 11,154.77	$ 4,232.82
highest	$ (1,189.42)	$ (186.40)	$ 3,401.06	$ 9,113.69	$ 11,154.77	$ 4,232.82

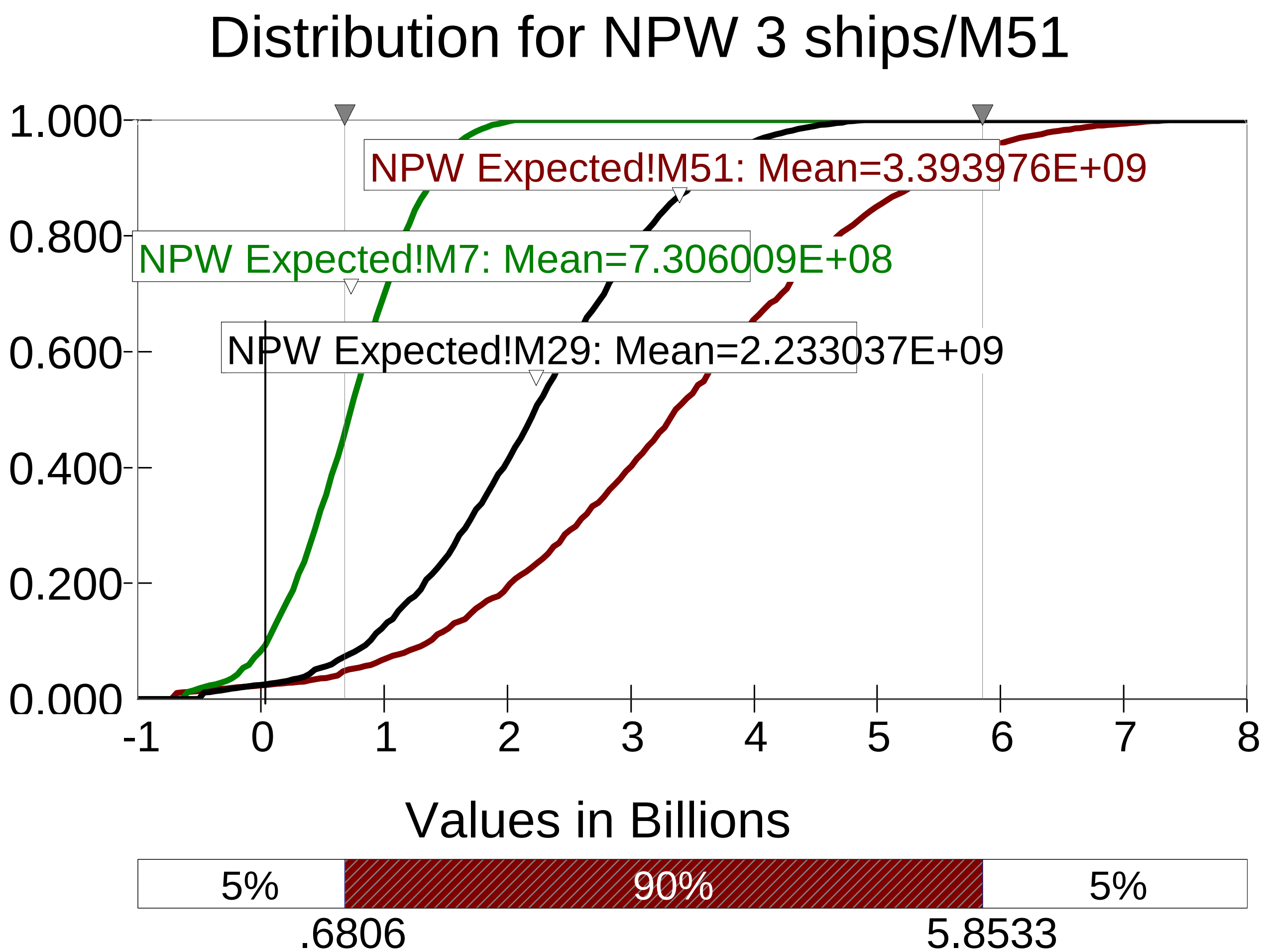
Regret

	lowest	low	expected	high	highest	Maximum regret
1 Ship	$ -	$ 292.67	$ 2,668.10	$ 6,516.38	$ 7,934.27	$ 7,934.27
2 Ship	$ 416.47	$ -	$ 1,163.30	$ 3,161.39	$ 4,450.02	$ 4,450.02
3 Ship	$ 1,122.27	$ 7.35	$ -	$ -	$ -	$ 1,122.27

minimax regret $ 1,122.27

3 ship

Risk


Distribution for NPW 3 ships/M51
1.000
0.800
0.600
0.400
0.200
0.000
NPW Expected!M51: Mean=3.393976E+09
NPW Expected!M7: Mean=7.306009E+08
NPW Expected!M29: Mean=2.233037E+09
-1
0
1
2
3
4
5
6
7
8
Values in Billions
5%
90%
5%
.6806
5.8533


RUSSIA
CHINA

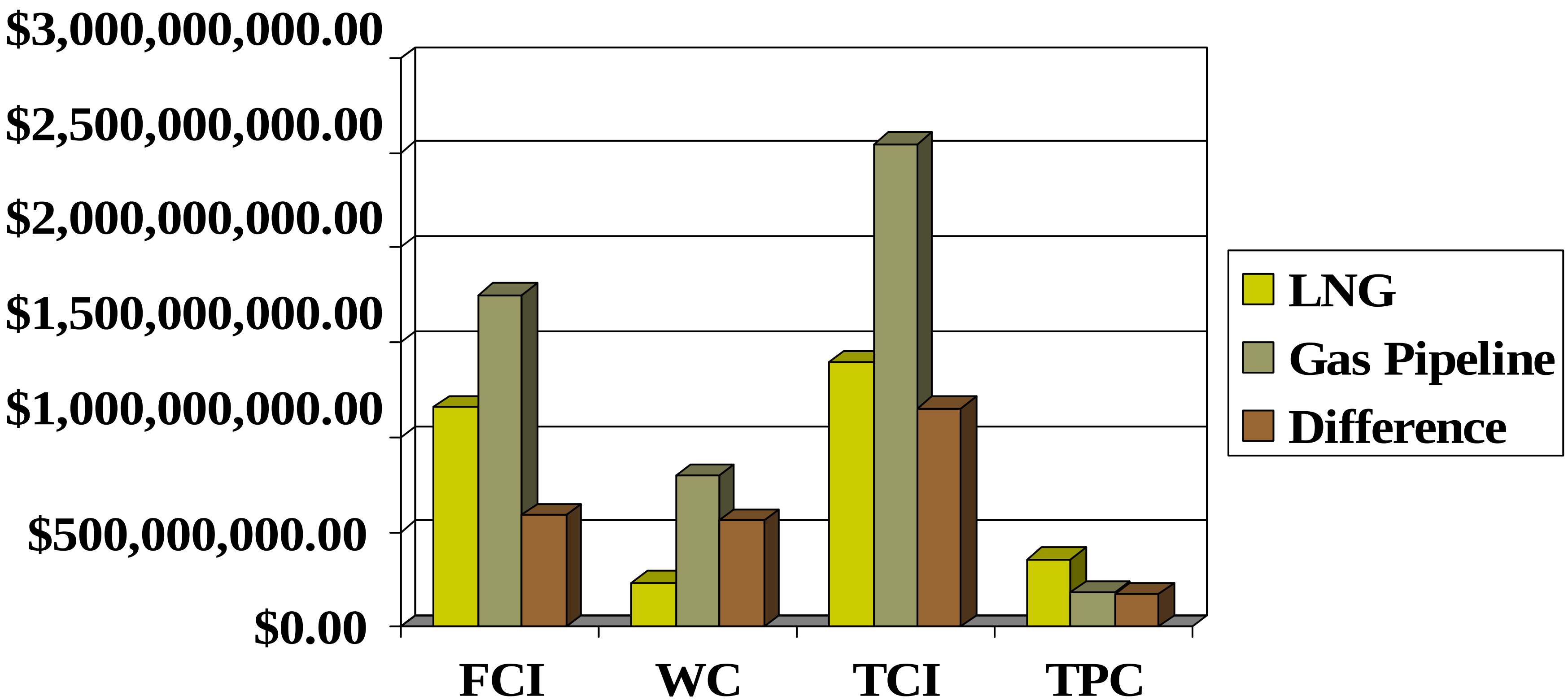
Pipeline to China vs. LNG Conversion

- LNG Costs

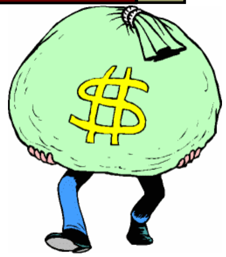
  (Using 3 ships)
  - FCI $1.3 billion
  - WC $318 million
  - TCI $1.7 billion
- Gas Costs

  (Using 32” pipe)
  - FCI $1.8 billion
  - WC $798 million
  - TCI $2.6 billion
- Difference in Gas vs. LNG
  - FCI $404 million
  - WC $480 million
  - TCI $883 million
  - TPC $260 million

Pipeline to China vs. LNG Conversion

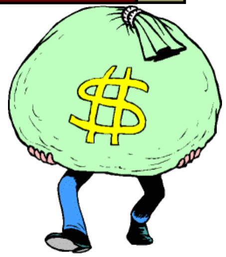


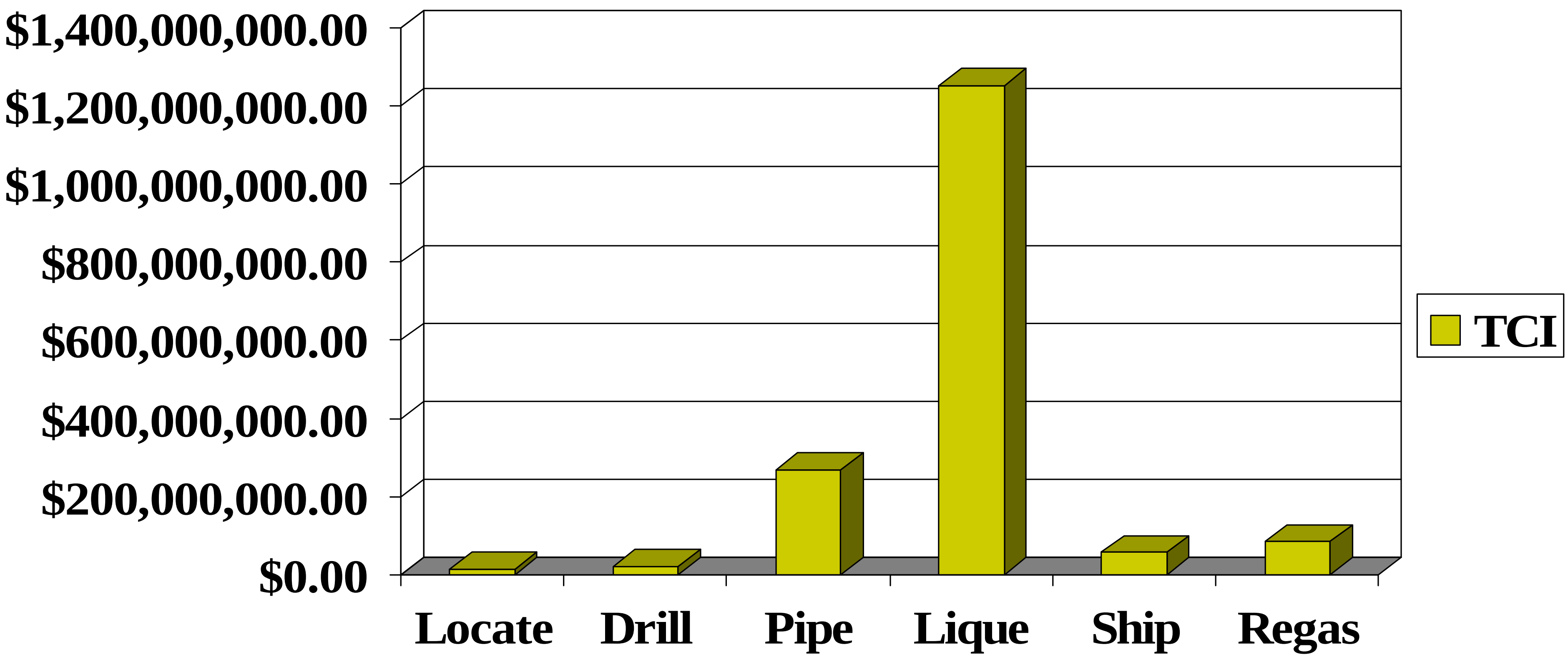
Total Capital Investment ($Million)



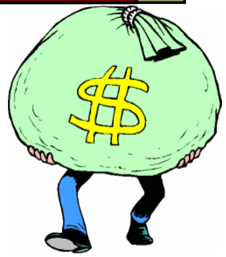
TCI	$1,700	% of TCI
Locating	$15	0.88%
Drilling	$21	1.80%
Piping	$270	19.11%
Liquefaction	$1,252	59.59%
Delivery	$58	15.70%
Regasification	$84	3.79%

Total Capital Investment ($Million)



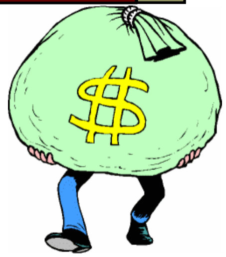


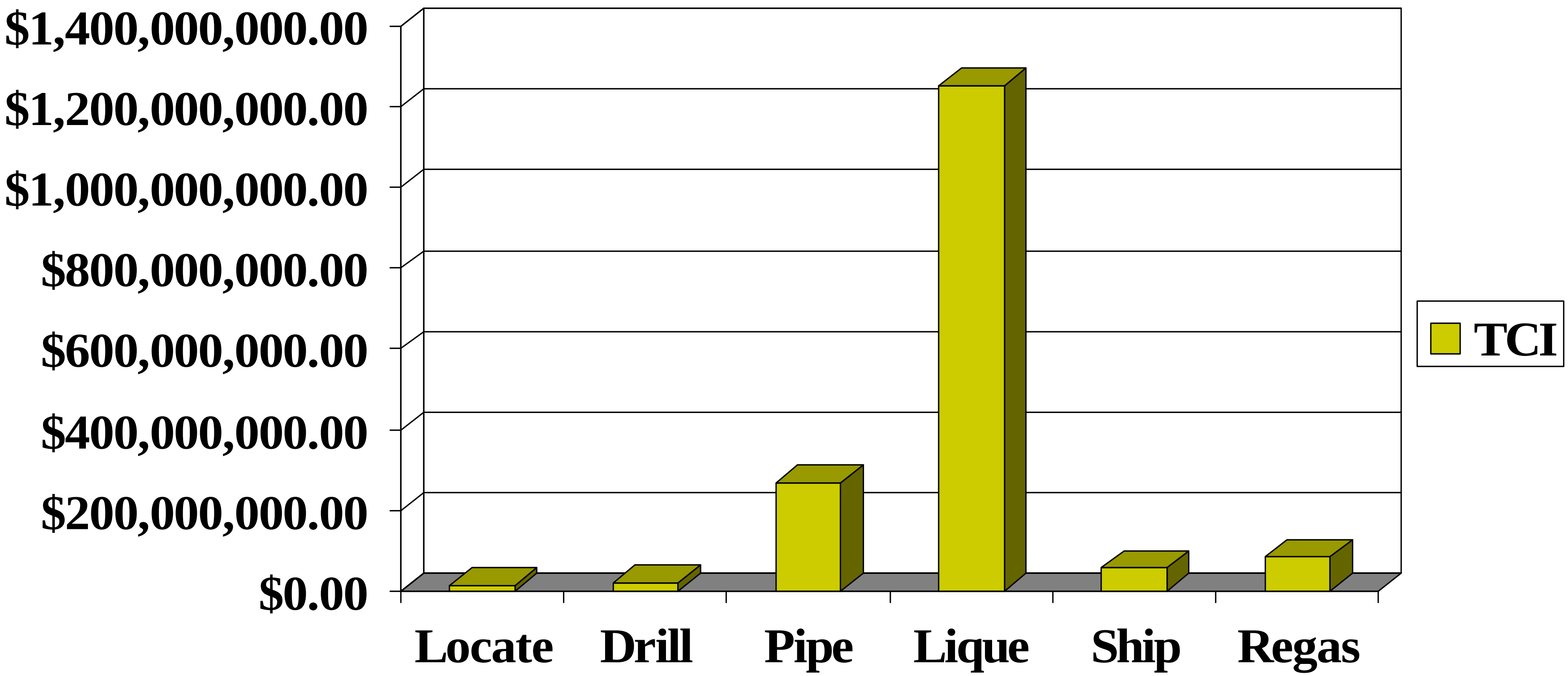
Total Production Cost ($Million)



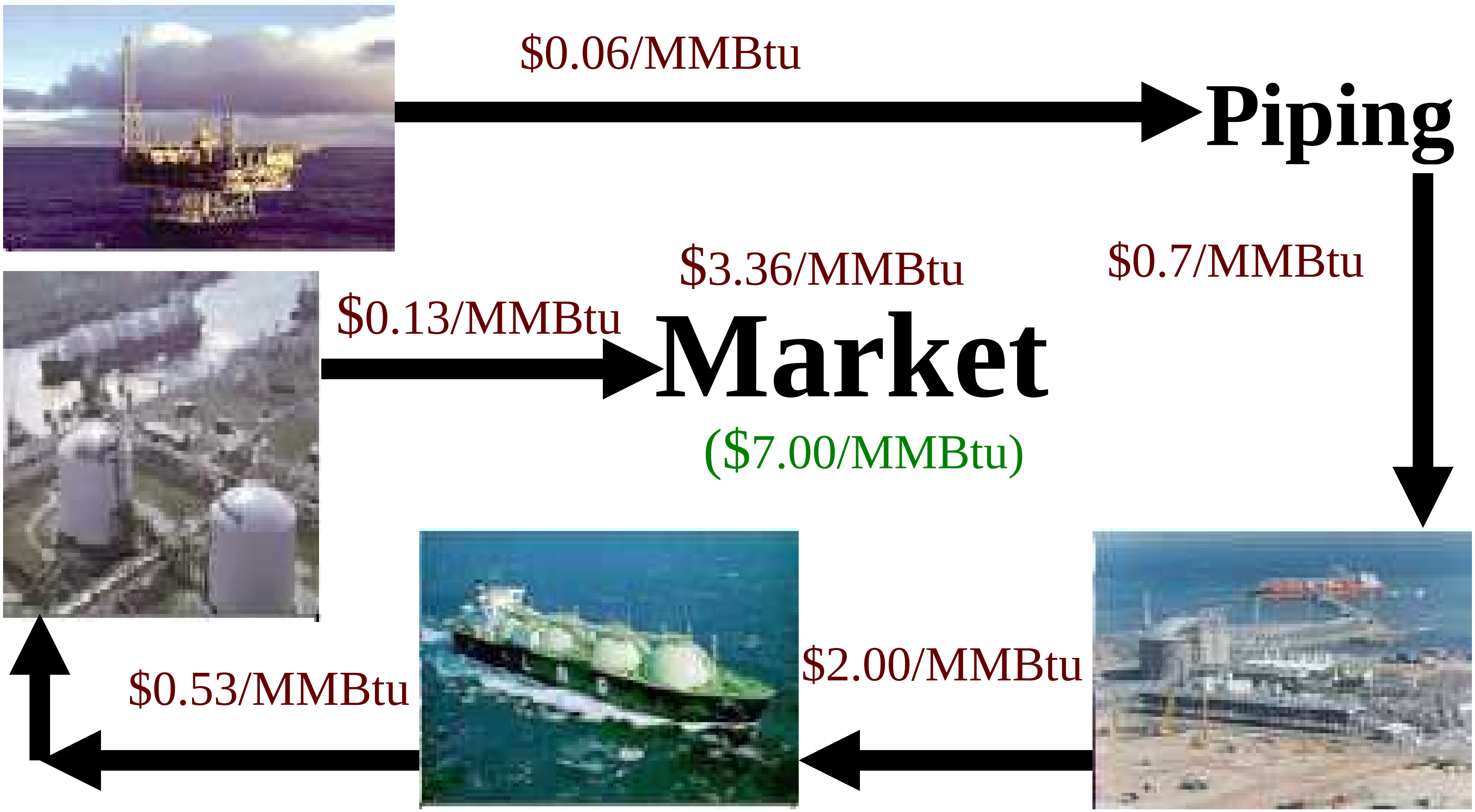
TPC	$453	% of TPC
Drilling	$8.2	1.80%
Piping	$87	19.11%
Liquefaction	$270	59.59%
Delivery	$71	15.70%
Regasification	$17	3.79%

Total Production Cost ($Million)





Value Chain

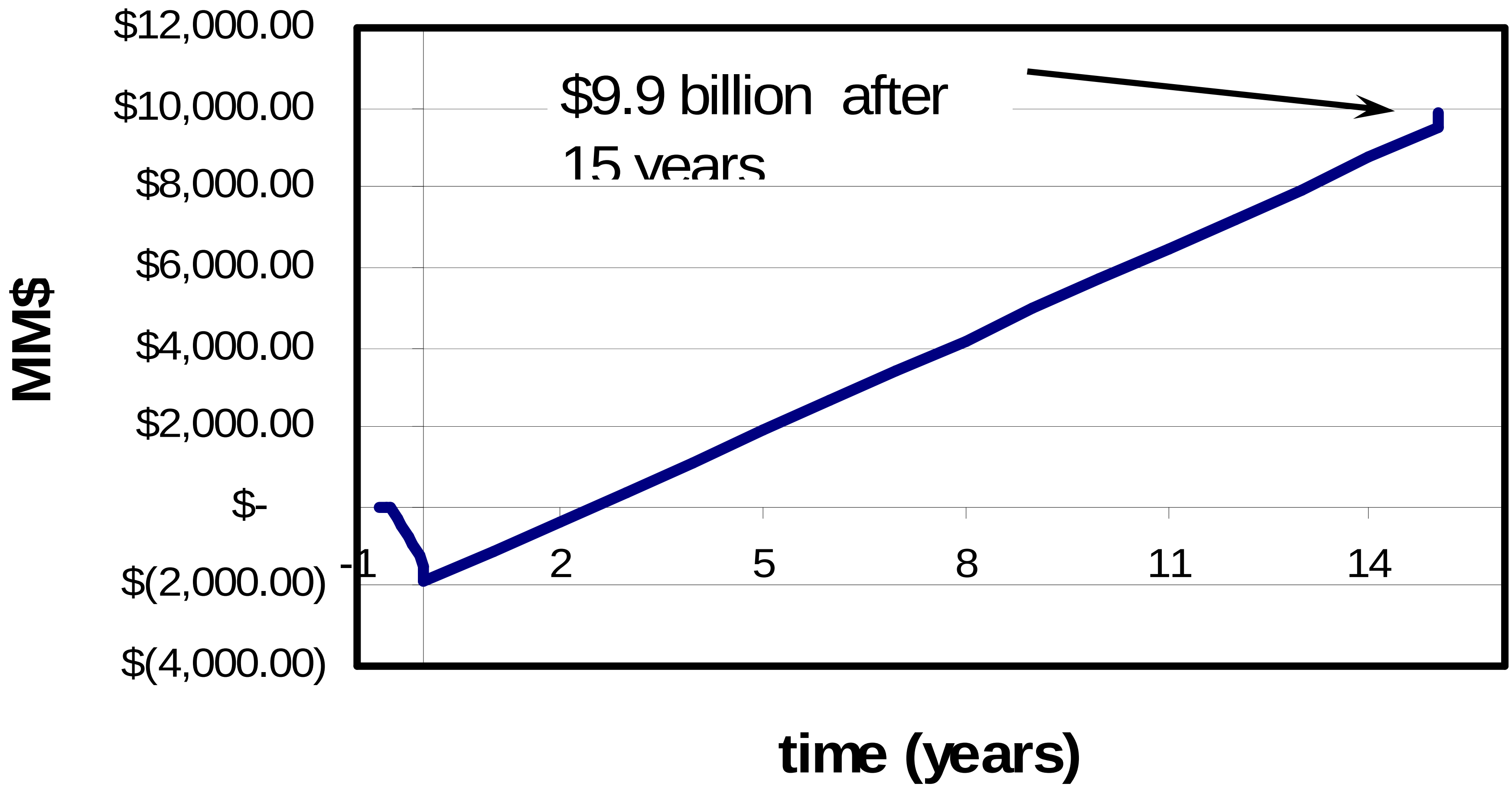

$0.06/MMBtu
Piping
$0.7/MMBtu
$3.36/MMBtu
$0.13/MMBtu
Market
($7.00/MMBtu)
$2.00/MMBtu
$0.53/MMBtu

Value Chain

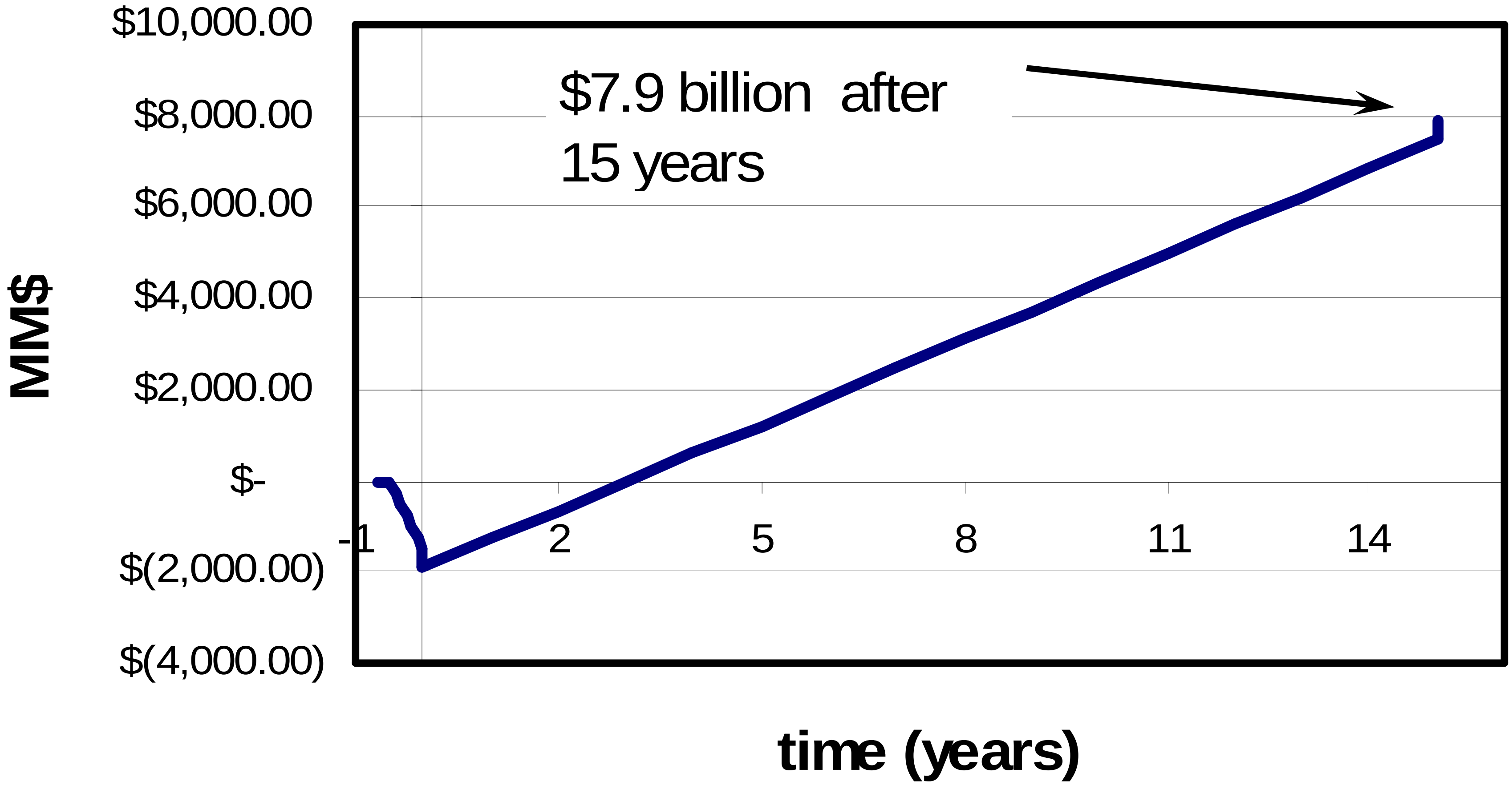
Profit

($3.64/MMBtu)

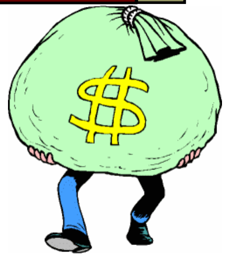
Cumulative Cash Position $9 gas

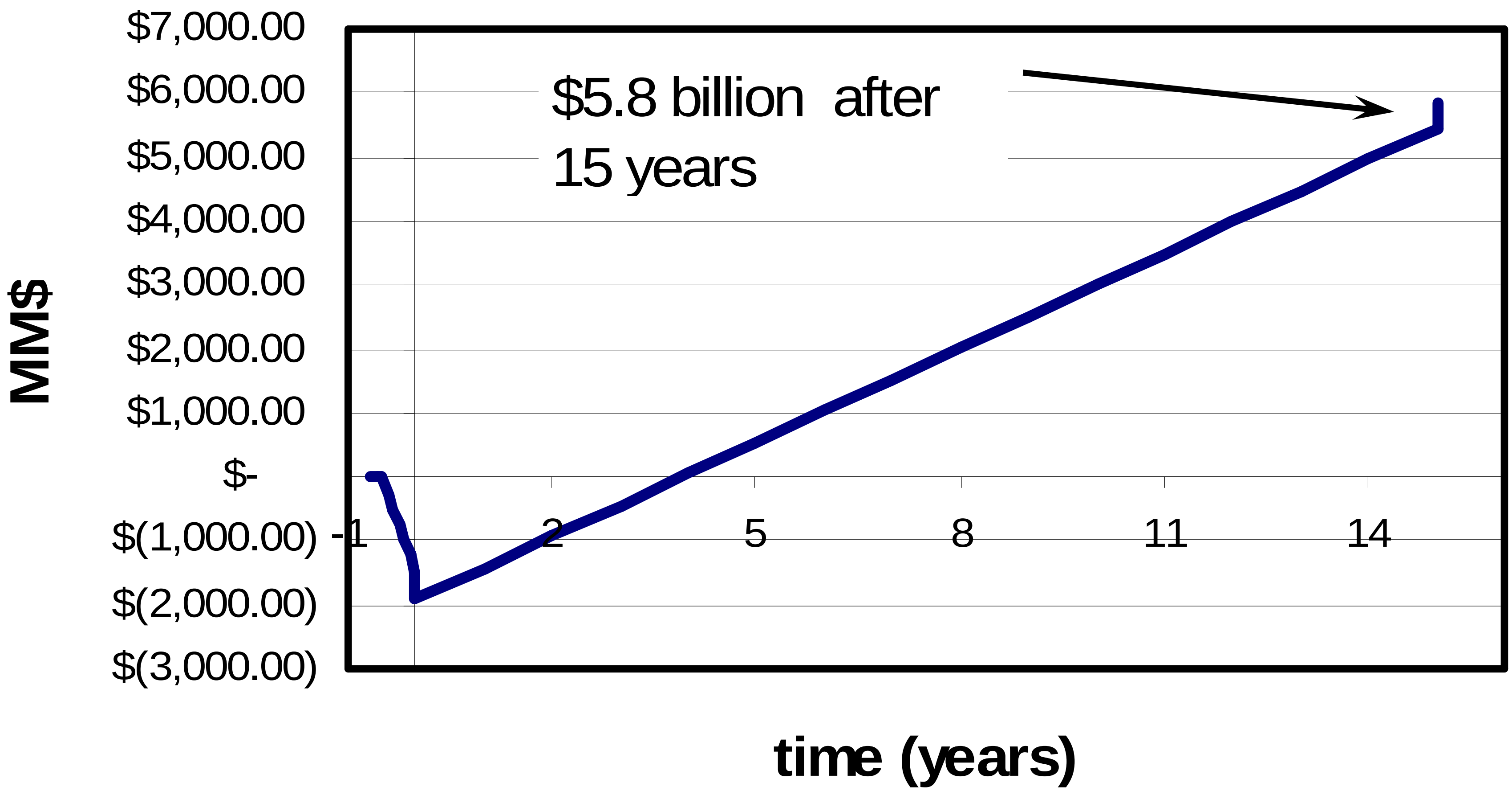


Cumulative Cash Position $8 gas

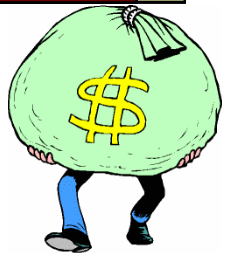


Cumulative Cash Position $7 gas





Net Present Worth



- $7 gas
  - Expected NPW of $3.4 billion
  - 12% ROI per year
  - 180% ROI over all
- $8 gas
  - Expected NPW of $4.5 billion
  - 16% ROI per year
  - 240% ROI over all
- $9 gas
  - Expected NPW of $3.4 billion
  - 20% ROI per year
  - 300% ROI over all

Questions?

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- Mandil, Claude, The Global Outlook for LNG, 2004