REAL OPTIONS VALUATION OF INVESTMENT IN SOLAR PARABOLIC TROUGH TECHNOLOGY

Arjun P. Gupta

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Background

- Oil and Gas companies are interested in Solar Parabolic Trough Technology
- It is currently not cost effective but…
- Future evolution of uncertain parameters may make it desirable

Fixed System

- 400 MW Combined-Cycle (CC) Power Plant
- Produces 2,102 GWh/year; all using natural gas

CC Plant	Value	Unit
Capital Cost	718	$/kW
O&M Fixed	18	$/kW/yr
O&M Variable	0.00063	$/kWh
Fuel Cost	4.50	$/MMBtu
Heat Rate	6800	Btu/kWh
Capacity Factor	60%	%
CO_2 emission intensity	0.4	Kg/kWh

Source: *EIA, 2009 and **Tester et al., 2005

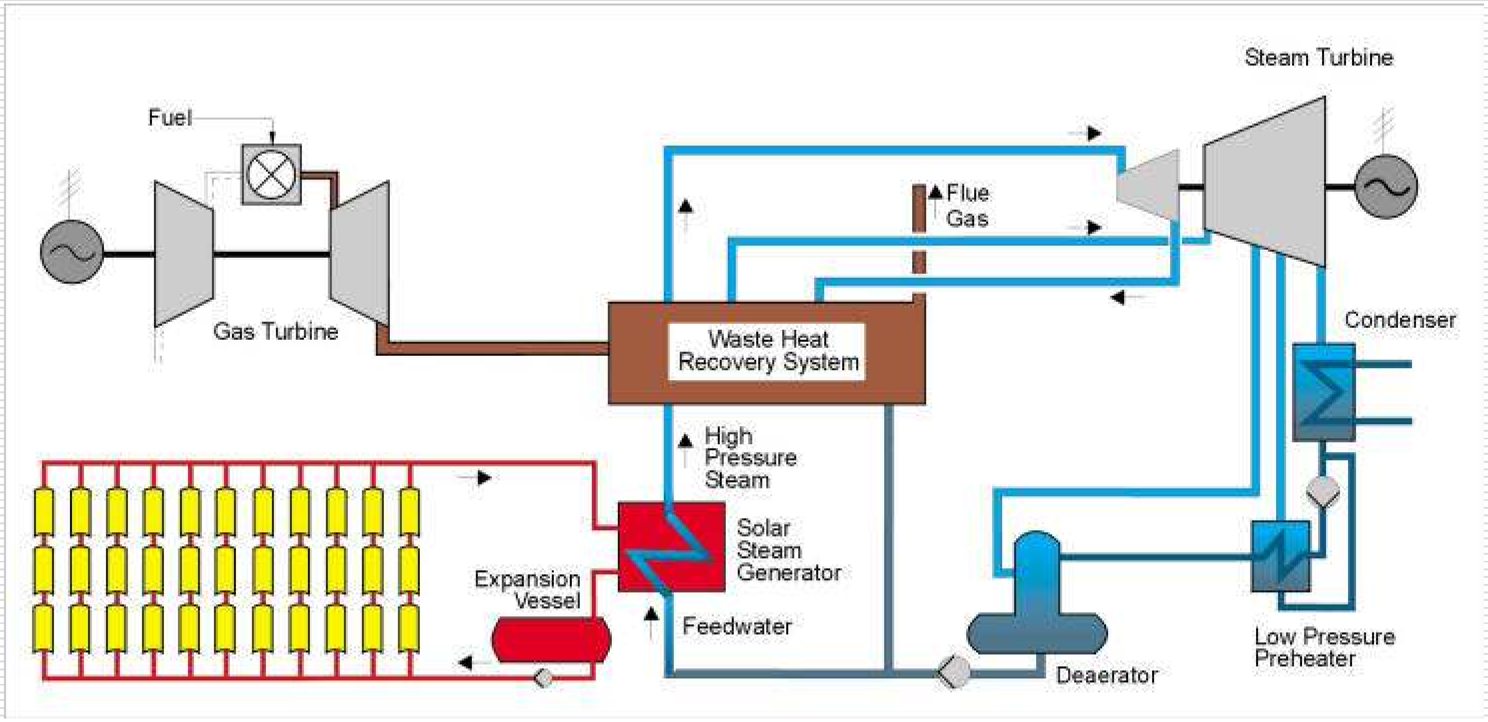
*Energy Information Administration (EIA) 2002, *Derivatives and Risk Management in the Petroleum, Natural Gas, and Electricity Industries*, Available at http://www.eia.doe.gov/oiaf/servicerpt/derivative/pdf/appb_tbls.pdf.

**Tester, J. W. et al. Sustainable Energy: Choosing Among Options. Cambridge: MIT Press, 2005.

Option

- Investment in Parabolic Trough Technology
- Gives the company the ‘ability but not the obligation’ to transform a modified CC plant into an Integrated Solar Combined Cycle Plant (ISCC)
- ISCC produces 25% of electricity (526 GWh/year) from Solar component

Integrated Solar Combined Cycle



Source: http://www.flagsol.com/ISCCS_tech.htm

Integrated Solar Combined Cycle

Solar Plant (100 MWe)	Value	Units
Direct Capital Costs		
Site Improvements	20	$\$/m^2$
Solar Field	350	$\$/m^2$
Heat Transfer Fluid System	50	$\$/m^2$
Indirect Capital Costs		
Engineer, Procure, Construct	15%	
Project, Land, Management	3.5%	
O&M Costs		
Fixed Cost by Capacity	80	$/kW-yr
Variable Cost by Generation	3	$/MWh

Source*: NREL, 2009

*National Renewable Energy Laboratory (NREL) 2009, 'Solar Advisor Model (SAM) Version 2009.10.13', Available at https://www.nrel.gov/analysis/sam/, accessed October 15, 2009.

Base Case Analysis – Choose CC

Plant Life = 30 years

Interest Rate = 10%

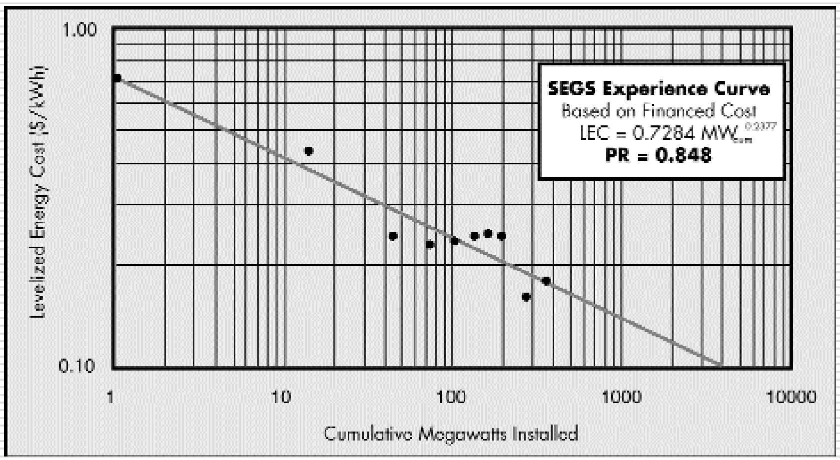
in $ million	CC Plant	ISCC Plant	Which is Better?
Initial Capital Cost	287	944	CC
Annual Fuel Costs	64	48	
Annual Non-Fuel Operational Costs	8.4	21	
Annual Carbon Costs	0	0	
Total Annual O&M Costs	73	69	~
Net Present Cost	1,041	1,659	CC

Uncertainties

- Capital Cost of Solar Component
- Natural Gas Costs
- Regulations (Carbon Costs)

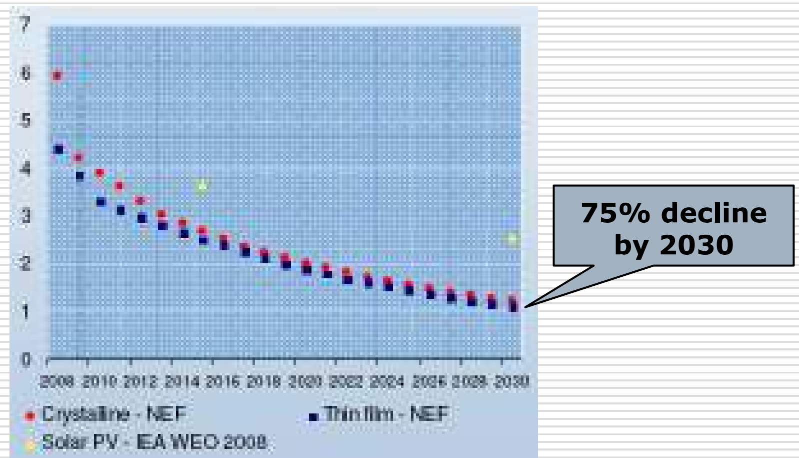
Capital Cost of Solar Component

- Can Decline because of:
  - Technological Innovation
  - Learning-by-doing
  - Economies of Scale



Experience Curve for SEGS Plants

(Mariyappan and Anderson, 2001)



Projected Solar PV System Cost Decline 2008-30 ($/W)

(Liebreich, 2009)

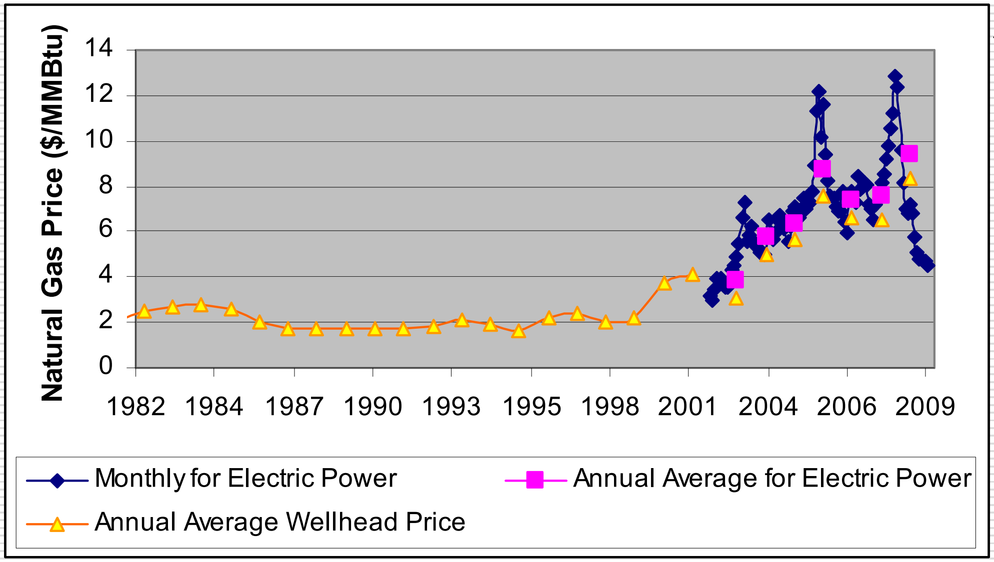
Mariyappan, J. and Dennis Anderson 2001, ‘Thematic Review of GEF-Financed Solar Thermal Projects’, *Global Environment Facility*.

Liebreich, M. 2009, ‘Global Futures 2009: Clean Energy Investment Not On Track To Prevent Climate Change’, *New Energy Finance*, Barcelona, Spain, 21st April 2009.

Natural Gas Costs

- Highly Variable
  - 6-year high: $12.50/MMBtu
  - 6-year low: $2.86/MMBtu
  - July 2009: $4.50/MMBtu

$15/MMBtu not unrealistic



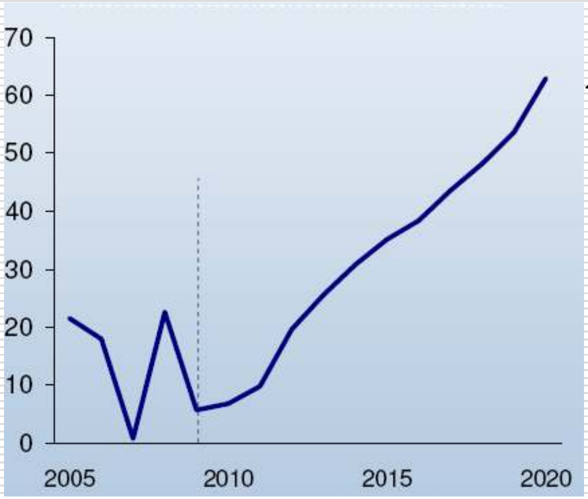
Natural Gas Prices in the US ($/MMBtu)

(EIA, 2009)

Energy Information Administration (EIA) 2009, *Gas Prices in the US*, Available at http://tonto.eia.doe.gov/dnav/ng/hist/n3045us3A.htm, accessed October 13, 2009.

Regulations (Carbon Costs)

- Currently in the US = $0/tonne
- Likely to change
- Europe ETS



$100/tonne in future not unrealistic

EUA Allowance Price Forecast under the EU ETS (Euro/tCO2)
Source: Liebreich, 2009

Liebreich, M. 2009, 'Global Futures 2009: Clean Energy Investment Not On Track To Prevent Climate Change', *New Energy Finance*, Barcelona, Spain, 21st April 2009.

Decision Analysis: 2-Stage

Decisions

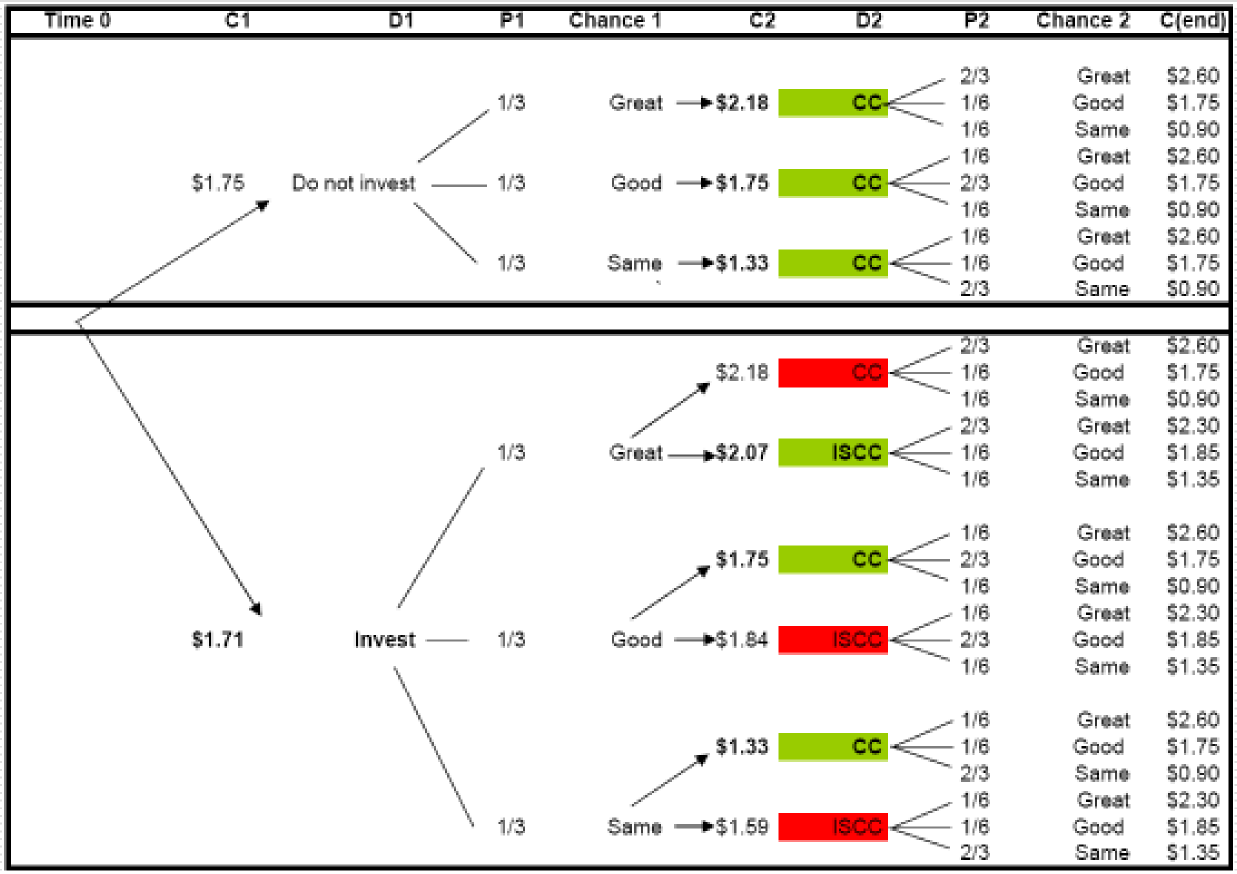
- Stage 1: Invest in Solar Parabolic Troughs or Do Not Invest
- Stage 2:
  - If Invested - Build CC Plant or Build ISCC Plant depending on uncertainty
  - If Not Invested - Build CC Plant regardless of uncertainty

Chance Outcomes

- Stage 1: Same, Good or Great with 1/3 probability each
- Stage 2: Same, Good or Great with modified probabilities.
  - If outcome in stage 1 is "good," probability of "good" in stage 2 is higher (=2/3). Same for the other two scenarios.

Uncertainty/Outcome	Great	Good	Same
Solar Cost (% reduction over base-case)	75%	50%	25%
Gas Price ($/MMBtu)	15	10	5
CO_2 Price ($/tonne)	100	50	0

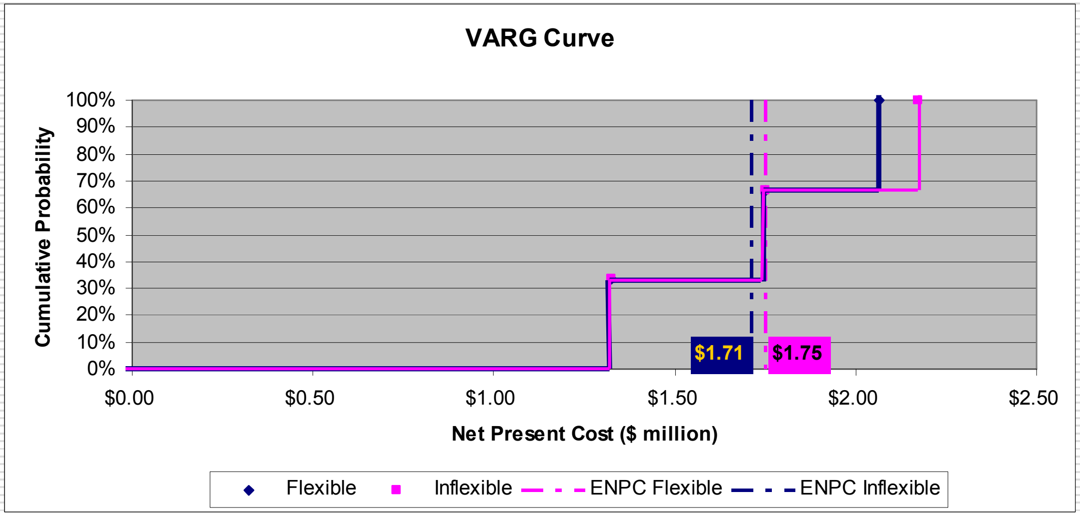
Decision Analysis: 2-Stage



Best Decision in Stage 2 highlighted in green

Best Decision in Stage 1 is to **Invest!**
Value of Flexibility
= $1.75B - $1.71B
=$40 million

Decision Analysis: 2-Stage



VARG Curve from Decision Analysis

In $ Billion	Fixed Option	Flexible Option	Which is Better?
Expected Value NPC	1.75	1.71	**Flexible**
Maximum NPC	2.6	2.3	**Flexible**
Minimum NPC	0.9	1.35	Fixed

Multi-Dimensional Comparison of Fixed and Flexible Systems

Lattice Analysis

- Fixed System: Traditional CC Plant
- Flexible System: Modified CC Plant with capability of transformation into ISCC plant in year 5
  - Design-in Costs: Enabling the transformation (over-sizing turbine, land etc.)
    - ~$46 million
  - Decision Costs: Implementing the Option (buying mirrors etc.)
    - ~$306 million under following assumption:
- Assume Capital Cost and Carbon Prices Correspond to "Good" Scenario from Decision Analysis
  - Capital Cost of Solar Component: 50% lower than current
  - Carbon Costs: $50/tonne
- Modeled Uncertainty: Natural Gas Prices
  - Brownian Motion Approach: Produces unrealistic estimates of gas prices towards the end of the plant's life
  - Prescriptive Approach: Better!

Maximum ($/MMBtu) in Year 11	30	u	1.188
Average ($/MMBtu) in Year 10	10	d	0.842
Starting ($/MMBtu)	4.5	p	0.697

Lattice Analysis

CC Lattice

Year 0	1	2	3	4	5
2,366,489,556	2.3E+09	2.6E+09	2.9E+09	3.3E+09	3.7E+09
	1.8E+09	2.0E+09	2.2E+09	2.5E+09	2.8E+09
		1.6E+09	1.7E+09	1.9E+09	2.1E+09
			1.4E+09	1.5E+09	1.6E+09
				1.2E+09	1.3E+09
					1.1E+09

Lattice for Flexible Case (v)

Year 0	1	2	3	4	5
2,298,014,945	2.2E+09	2.4E+09	2.6E+09	2.9E+09	
	1.71E+09	1.9E+09	2.1E+09	2.3E+09	
		1.5E+09	1.7E+09	1.9E+09	
			1.4E+09	1.5E+09	
				1.2E+09	

Decision Lattice

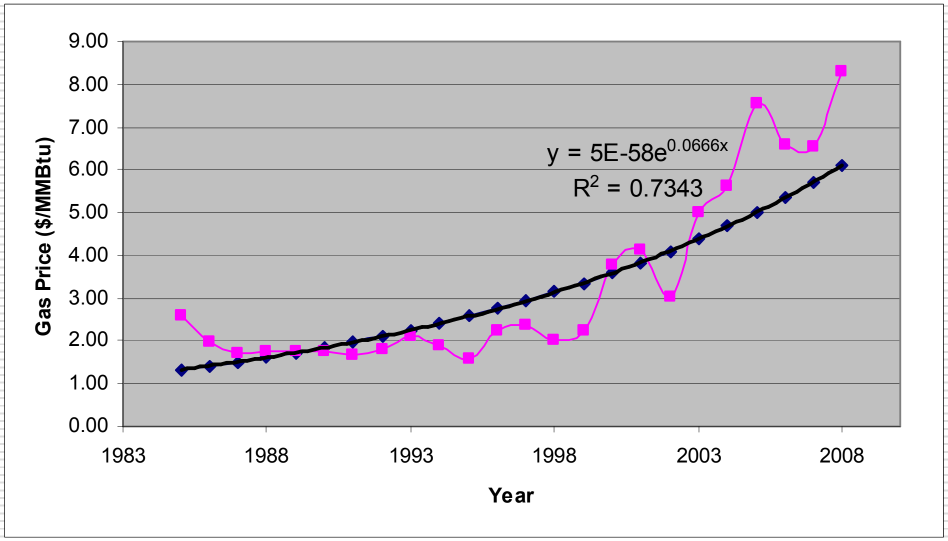
Year 0	1	2	3	4
				yes
				yes
				yes
				no
				no

Value of Flexibility
= $2,366M - $2,298M
=$68 million!

ISCC is preferred in case of high gas prices

Monte-Carlo Simulation

- Fixed System: ISCC Plant for year 0
- Flexible System: Modified CC plant which can be converted into ISCC in any of the first 10 years of the plant's life ("Good" Scenario)
- Uncertain Variable: Natural Gas Prices (modeled as a random variable)



Natural Gas Well-Head Price History (EIA, 2009)

Annual Growth Rate (mean)
= 6.66%
Volatility (standard deviation)
= 29%

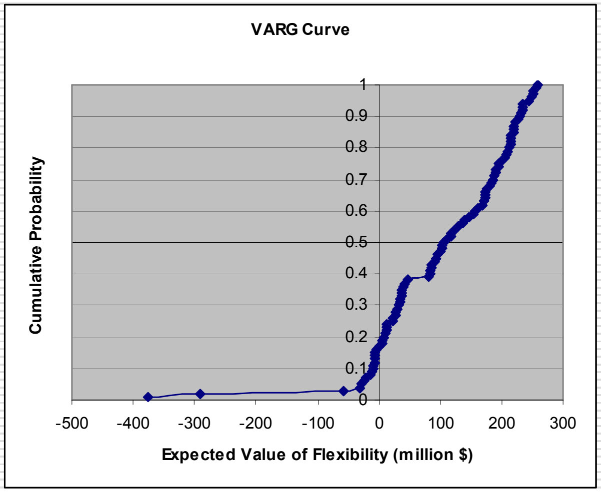
Energy Information Administration (EIA) 2009, *Gas Prices in the US*, Available at http://tonto.eia.doe.gov/dnav/ng/hist/n3045us3A.htm, accessed October 13, 2009.

Monte-Carlo Simulation

Decision Rule: *Implement the option if gas prices for the previous two years have been observed to be higher than $8/MMBtu*

	Fixed System	Flexible System	Which is Better?
Expected NPC ($ million)	2,158	2,074	**Flexible**
Maximum NPC ($ million)	14,663	14,695	Fixed
Minimum NPC ($ million)	1,280	985	**Flexible**
Initial Capital Ex ($ million)	638	333	**Flexible**

Net Present Costs of the Option (Fixed and Flexible Cases)



Flexible System Performs Better 80% of the time

Value of Flexibility
=$2,158M – $2,074M
=$84 million!

Conclusions

- Different Approaches are suitable for different types of analysis
  - Decision Analysis is better for step changes and multiple decisions
  - Lattice Analysis is better for constant changes and a single decision
  - Monte-Carlo Analysis allows for less restricted decision rule
- Solar Parabolic Trough Technology may be valuable in future!
- A flexible approach to the design of power plants will increase expected value!

Course Reflections

- Several criteria (NPV, B/C ratio, IRR etc.) should be used to compare investment alternatives
- Uncertainty in inevitable and forecasts are always wrong
- Uncertainties imply risks as well as opportunities
- A (very good) way to deal with uncertainties in engineering systems is to design flexibility into the system
- There are advantages and limitations of different methods of valuing flexibility. The choice of method depends upon the nature of the system, the goals of the analysis, and the available data
- It is not enough to have a good idea; good implementation plans are necessary to keep options ‘alive’
  - Integrated Project Delivery
  - Game Plan Development
  - Anticipating Developments
  - Operational Actions