# THE CONSUMER ECONOMICS OF NUCLEAR REACTORS:

# Renaissance or Rip Off?

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# Outline

- **Findings**
- **Basic Cost Concepts**
- **Sources**
- **Consumer Cost**
- **Risk**
- **Environmental Externalities**
- **Potential Low Carbon Electricity Futures**
- **The Bottom Line**

# Findings:

**Even in a world where carbon is constrained, nuclear reactors would not enter the supply mix under a least cost approach for decades, if ever.**

**Nuclear reactors are more expensive than a host of alternatives available today like efficiency, cogeneration, geothermal, biomass, landfill, onshore wind and natural gas that would also dramatically reduce carbon emissions.**

**In the long-term, other renewable and low carbon alternatives are likely to be less costly than nuclear reactors.**

**Nuclear reactors have environmental, safety and security issues of their own that the alternatives do not.**

# The Consumer Stakes in Making the Right Choices are Huge

**Each 1000 MW of nuclear power that is forced into the supply mix would cost between $16 billion $41 billion more than a mix of efficiency and renewables.**

**If the 100 aging nuclear reactors currently on line in the U.S. are replaced with these high cost nuclear reactors, the excess costs could be well in in the range of $1.6 trillion to$4.1 trillion.**

# Basic Cost Concepts:

**Overnight Cost**
**(a virtual barn raising – assemble all the pieceparts and build it overnight)**

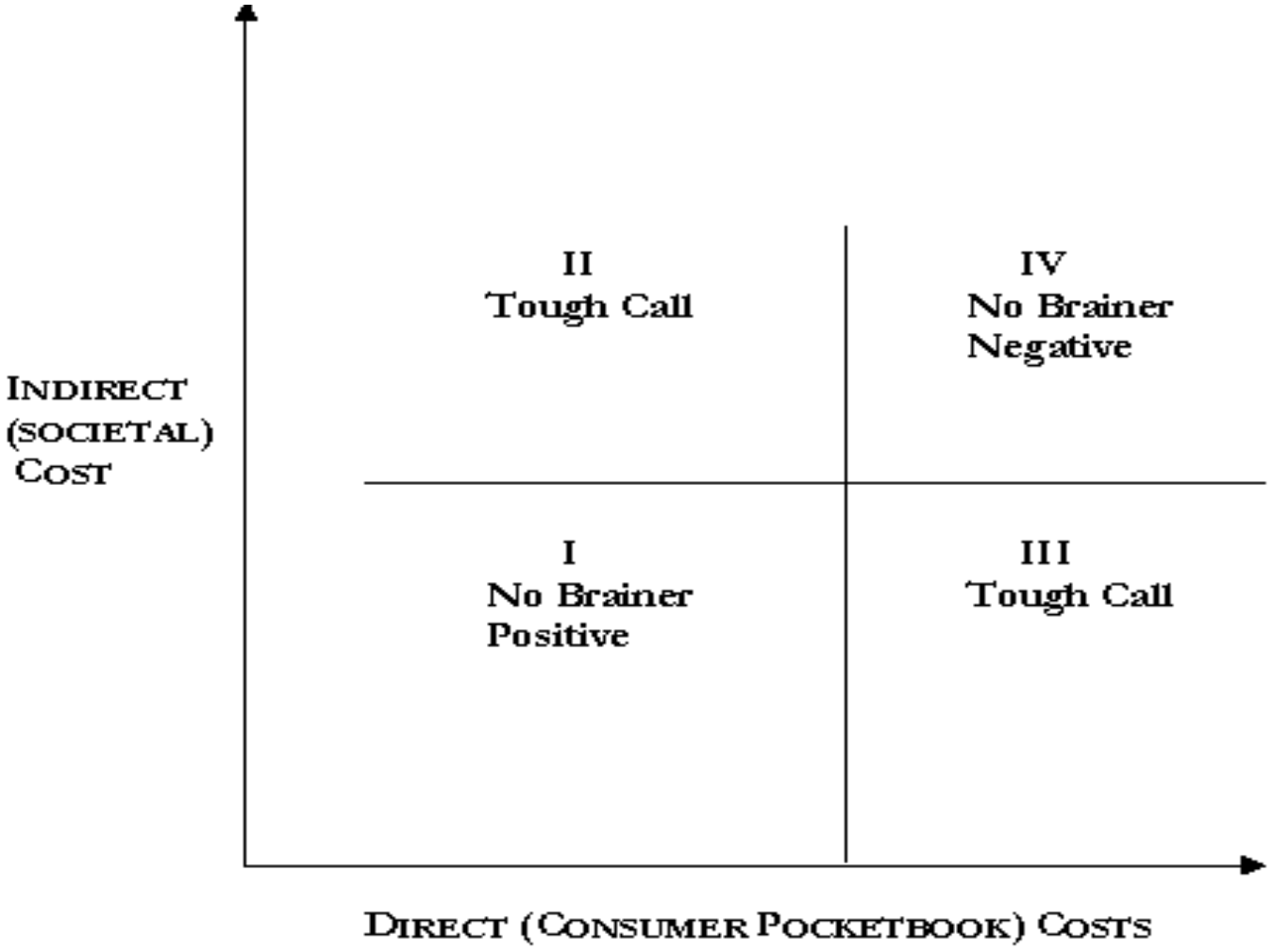
+ Finance and Ownership Costs

= **All-in Costs**

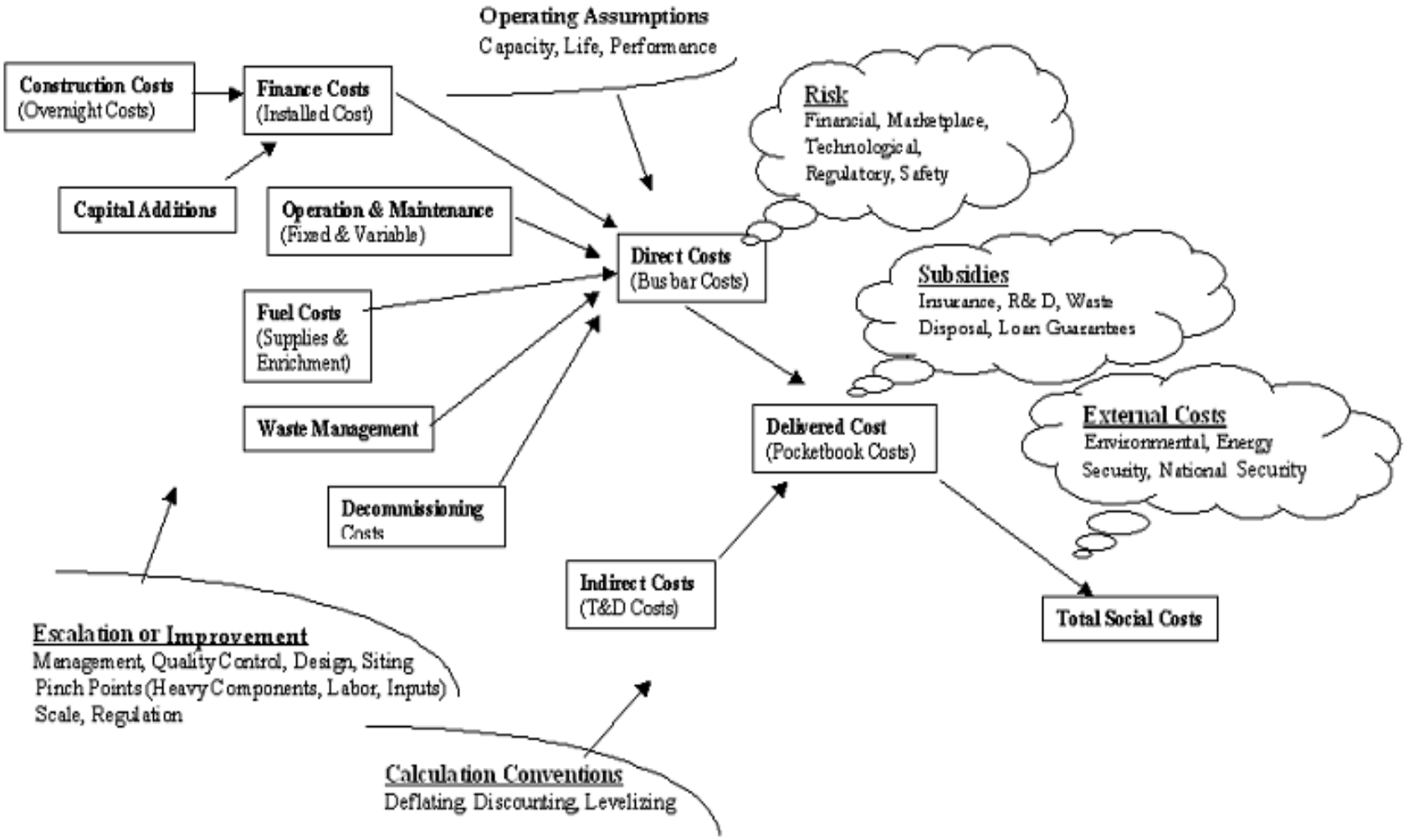
+ Operation and Maintenance, Fuel, Waste Disposal, Decommissioning Costs, etc.

= **Busbar Costs**

# A Simple Policy Framework to Analyze Consumer and Societal Costs



# THE COMPLEX REALITY OF NUCLEAR REACTOR COSTS



## INPUTS

### Plant Characteristics
- Capacity (MW)
- Capacity Factor
- Forced Outage Rate
- Scheduled Outage Rate
- Heat Rate (if applicable)
- Heat Rate & Capacity Degradation

Deflator Series

- Fuel Prices ($/MMBtu)

- Instant Cost ($/kW)
- Installed Cost ($/kW)

Fixed O&M ($/kW-Yr)

Variable O&M ($/MWh)

### General Assumptions
(Merchant, Muni & IOU)
- Insurance
- Ad Valorem
- State & Federal Taxes
- O&M Escalation
- Labor Escalation

### Financial Assumptions
(Merchant, Muni & IOU)
- % Debt
- Cost of Debt (%)
- Cost of Equity (%)
- Loan/Debt Term (Years)
- Book Life (Years)
- Federal Tax Life (Years)
- State Tax Life (Years)

## COST OF GENERATION MODEL

### Wholesale Electricity Prices
($/MWh)
- Fixed Cost
- Variable Cost - Marketsym
- Total Cost

## OUTPUTS

### Levelized Fixed Costs
($/kW-Yr & $/MWh)
- Capital & Financing
- Insurance
- Ad Valorem
- Fixed O&M
- Corporate Taxes

### Levelized Variable Costs
($/kW-Yr & $/MWh)
- Fuel
- Variable O&M

### Total Levelized Costs
($/kW-Yr & $/MWh)
- Levelized Fixed Costs
- Levelized Variable Costs

### Annual Costs
($/MWh)
- Fixed Cost
- Variable Cost
- Total Cost

### Screening Curves
($/kW-Yr & $/MWh)
- Fixed Cost
- Variable Cost
- Total Cost

### Sensitivity Curves
(%)
- Fuel Price
- Capacity Factor
- Installed Cost
- Discount Rate
- Cost of Equity
- Cost of Dept

# Sources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**Michael Tomin, James Griffin and Robert J. Lempert, *Impacts on U.S. Energy Expenditures and Greenhouse Gas Emission of Increasing Renewable Energy Use,* Rand 2008.**

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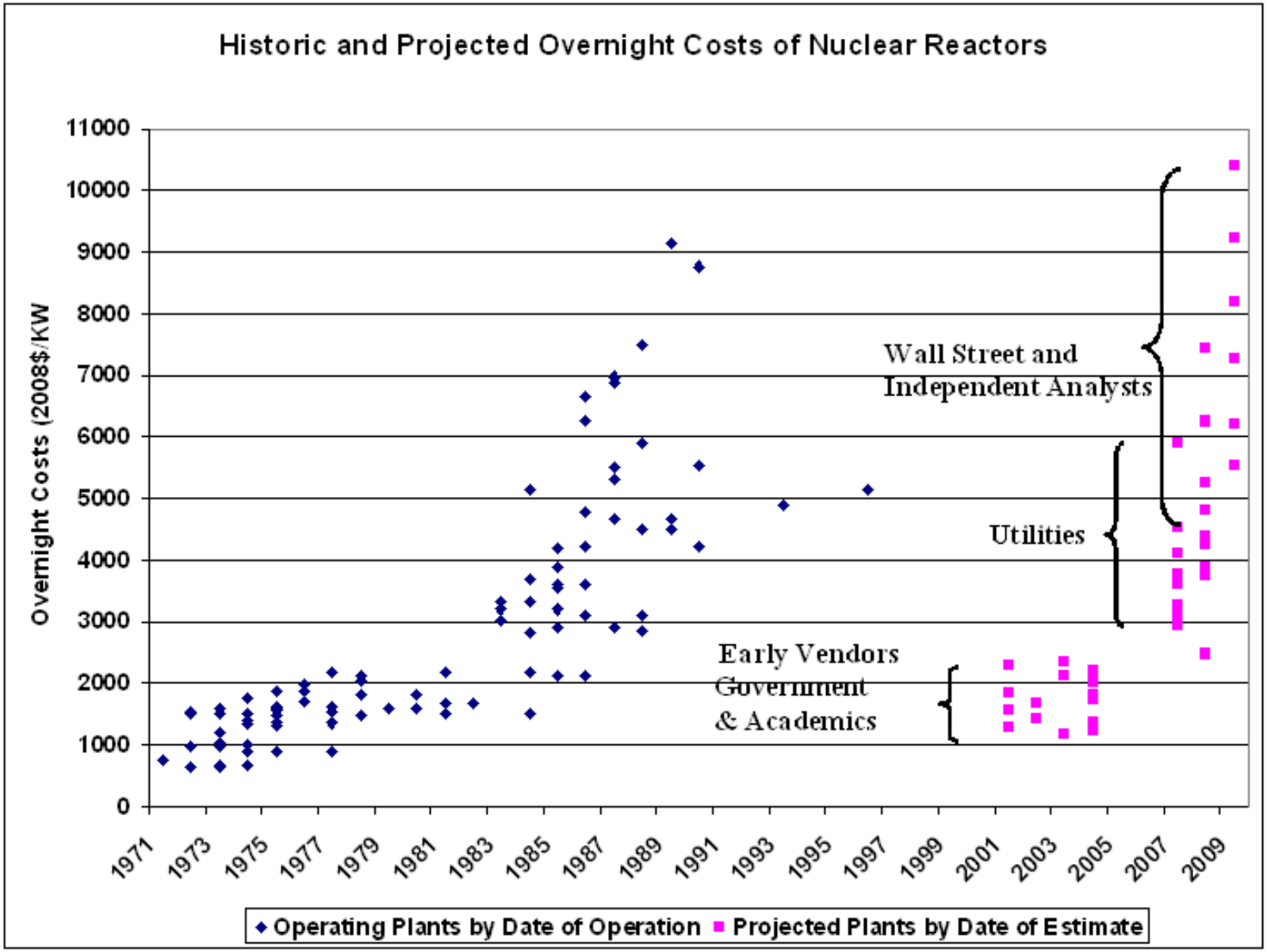
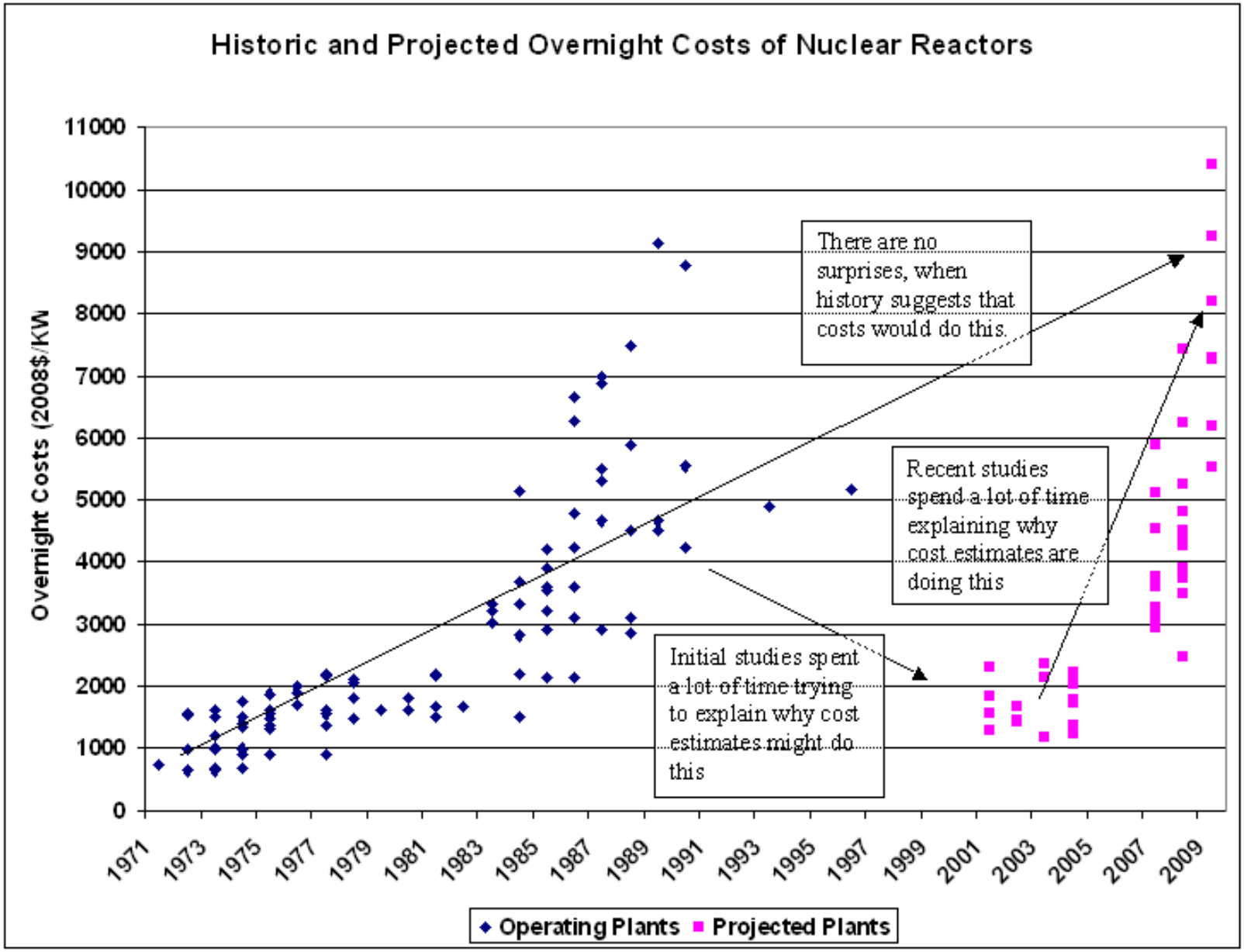
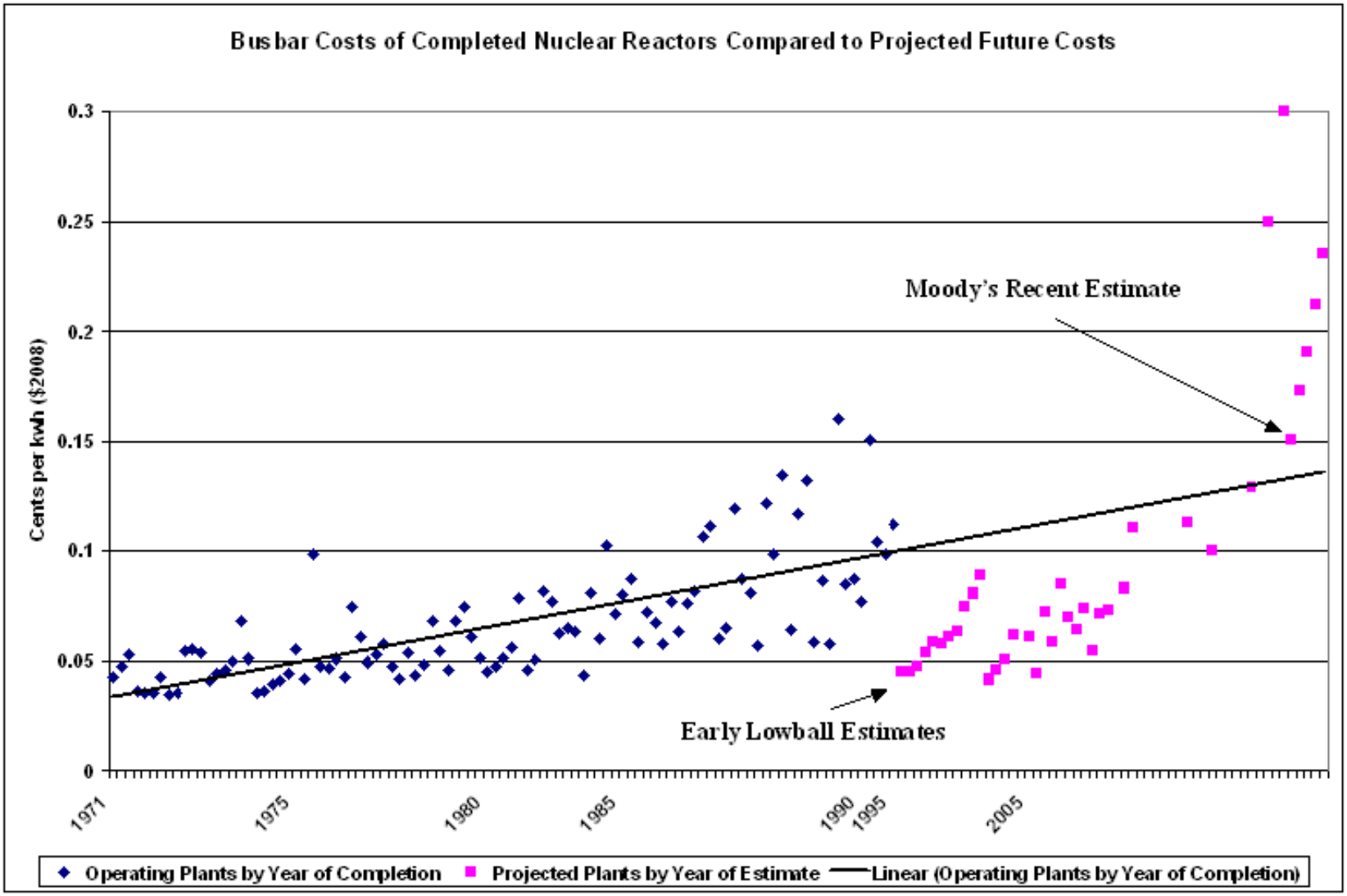
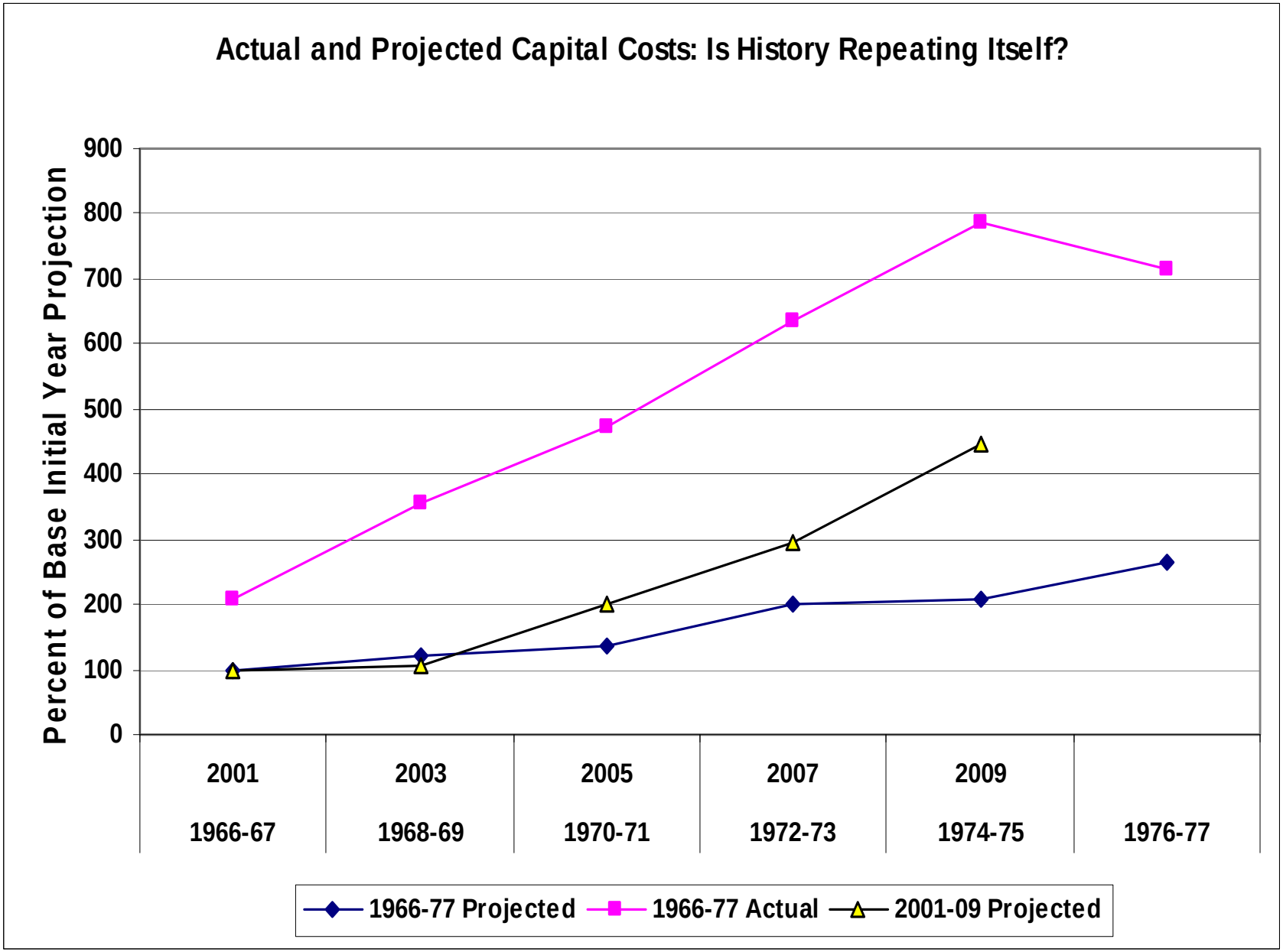
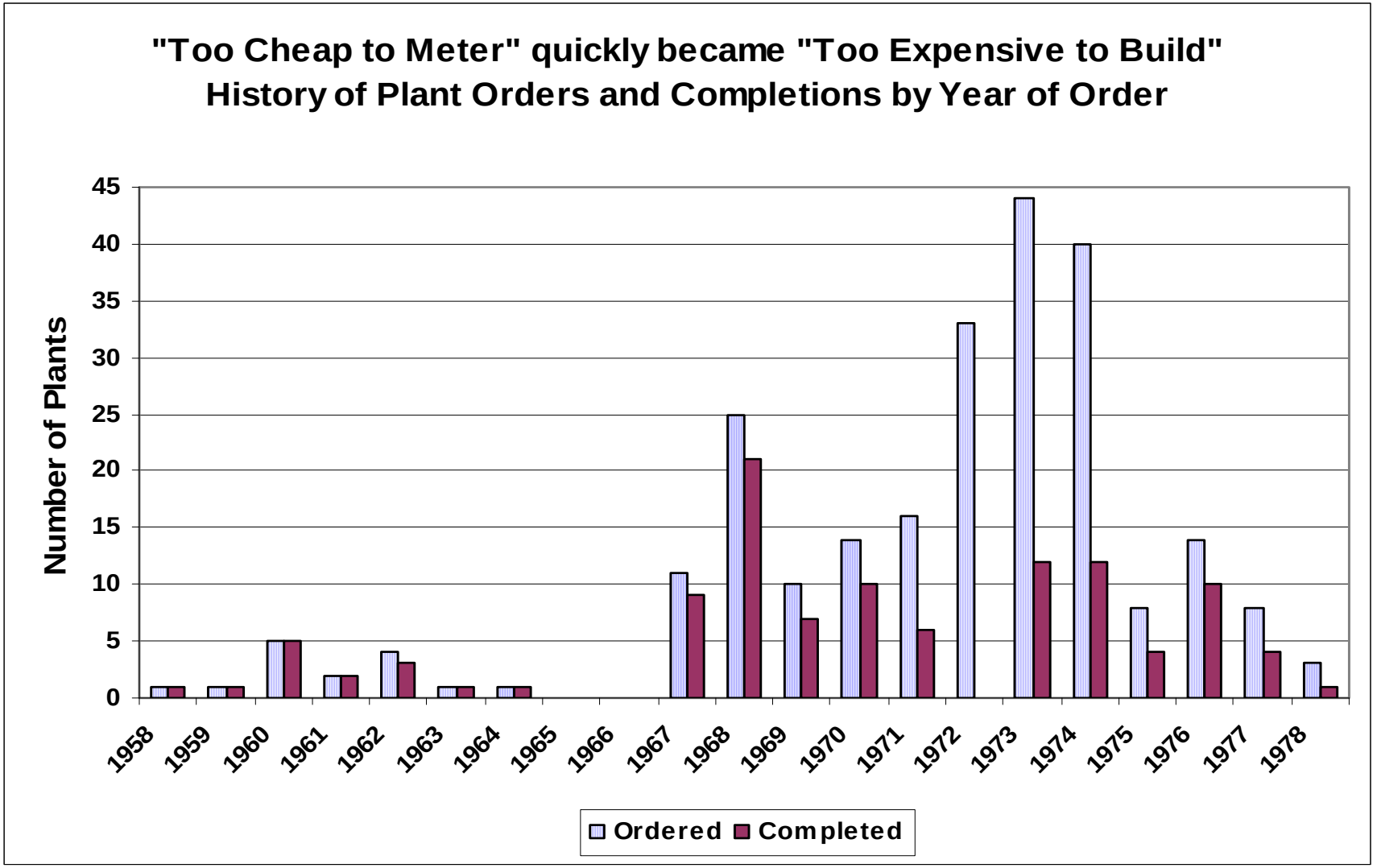
# Consumer Cost


Historic and Projected Overnight Costs of Nuclear Reactors
Overnight Costs (2008$/KW
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
Wall Street and
Independent Analysts
Utilities
Early Vendors
Government
& Academics
Operating Plants by Date of Operation
Projected Plants by Date of Estimate


Historic and Projected Overnight Costs of Nuclear Reactors
Overnight Costs (2008$/KW
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
There are no surprises, when history suggests that costs would do this.
Recent studies spend a lot of time explaining why cost estimates are doing this
Initial studies spent a lot of time trying to explain why cost estimates might do this
Operating Plants
Projected Plants


Busbar Costs of Completed Nuclear Reactors Compared to Projected Future Costs
Cents per kwh ($2008)
0.3
0.25
0.2
0.15
0.1
0.05
0
1971
1975
1980
1985
1990
1995
2005
Moody's Recent Estimate
Early Lowball Estimates
Operating Plants by Year of Completion
Projected Plants by Year of Estimate
Linear (Operating Plants by Year of Completion)


Actual and Projected Capital Costs: Is History Repeating Itself?
Percent of Base Initial Year Projection
900
800
700
600
500
400
300
200
100
0
2001
1966-67
2003
1968-69
2005
1970-71
2007
1972-73
2009
1974-75
1976-77
1966-77 Projected
1966-77 Actual
2001-09 Projected


"Too Cheap to Meter" quickly became "Too Expensive to Build"
History of Plant Orders and Completions by Year of Order
Number of Plants
0
5
10
15
20
25
30
35
40
45
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
Ordered
Completed

# Why does this happen?

## *Endemic Long-term Issues*

**Reactor design is complex, site-specific and non-standardized.**

**Specialized supply chain has trouble ramping up, causing costs to rise.**

**Mega projects where extremely large, complex undertakings are dependent on sequential and complementary activities are prone to delays that cascade into interruptions.**

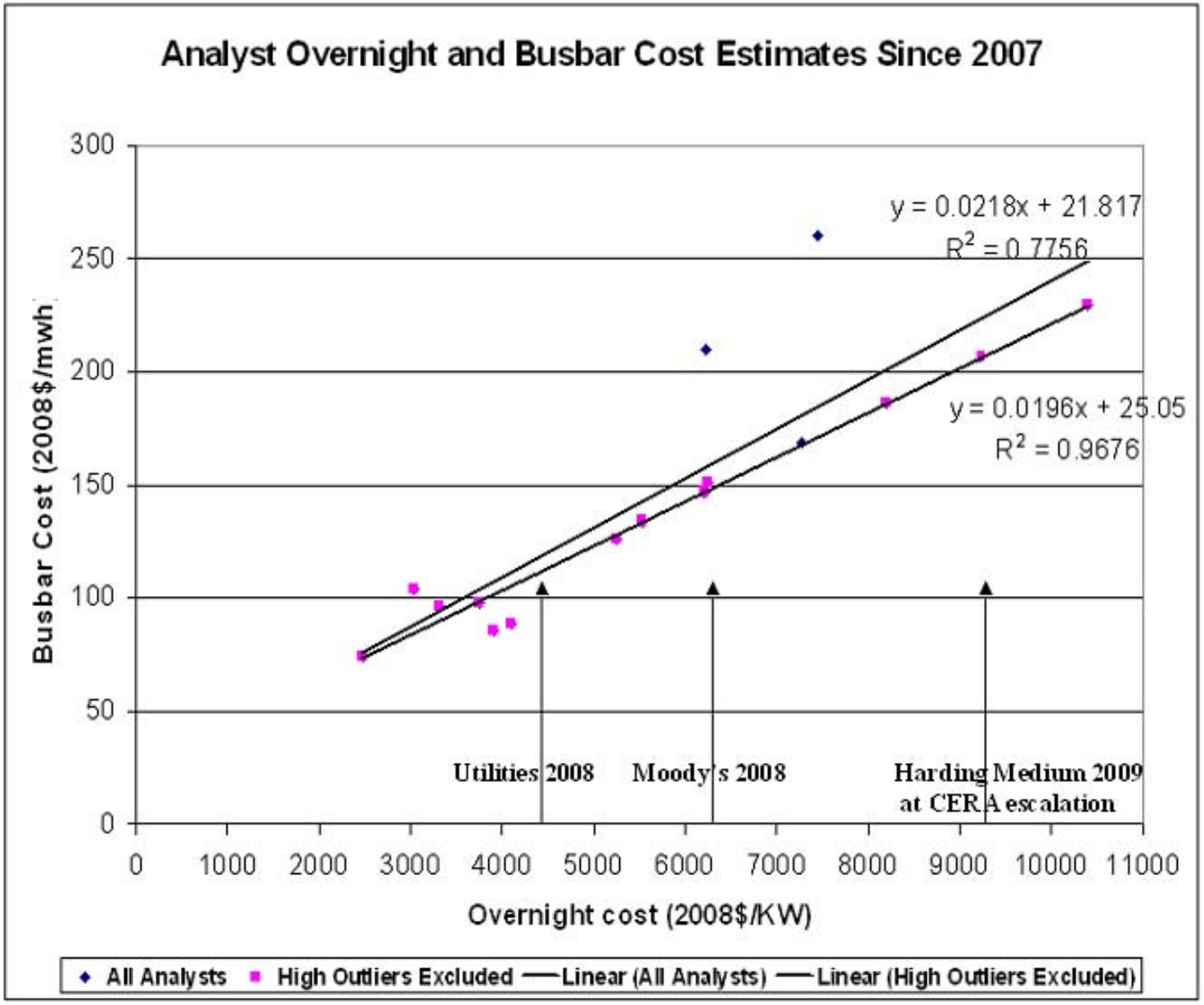
## *Short and Mid-Term Issues Compound Problems*

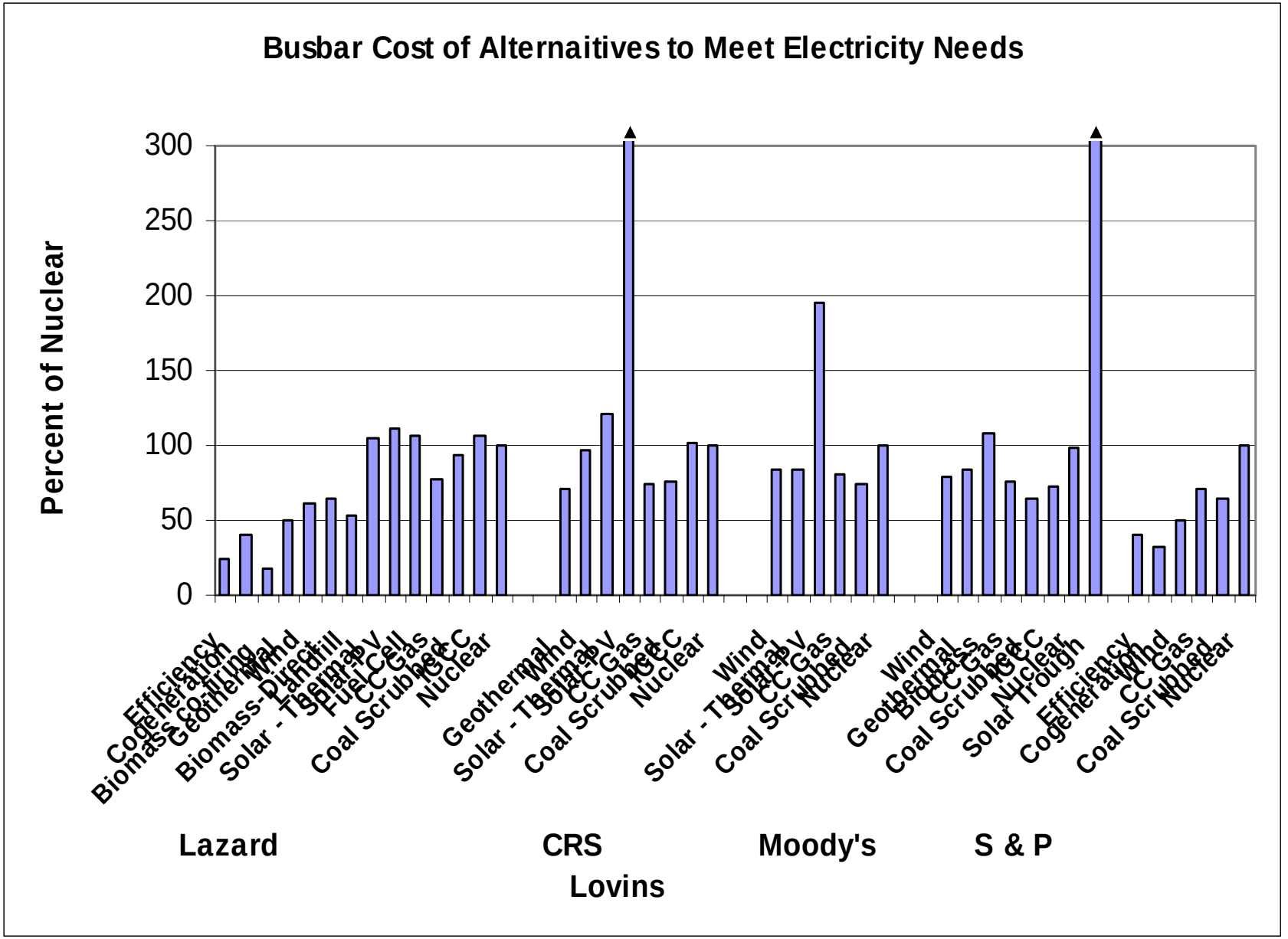
**Material costs have been rising**

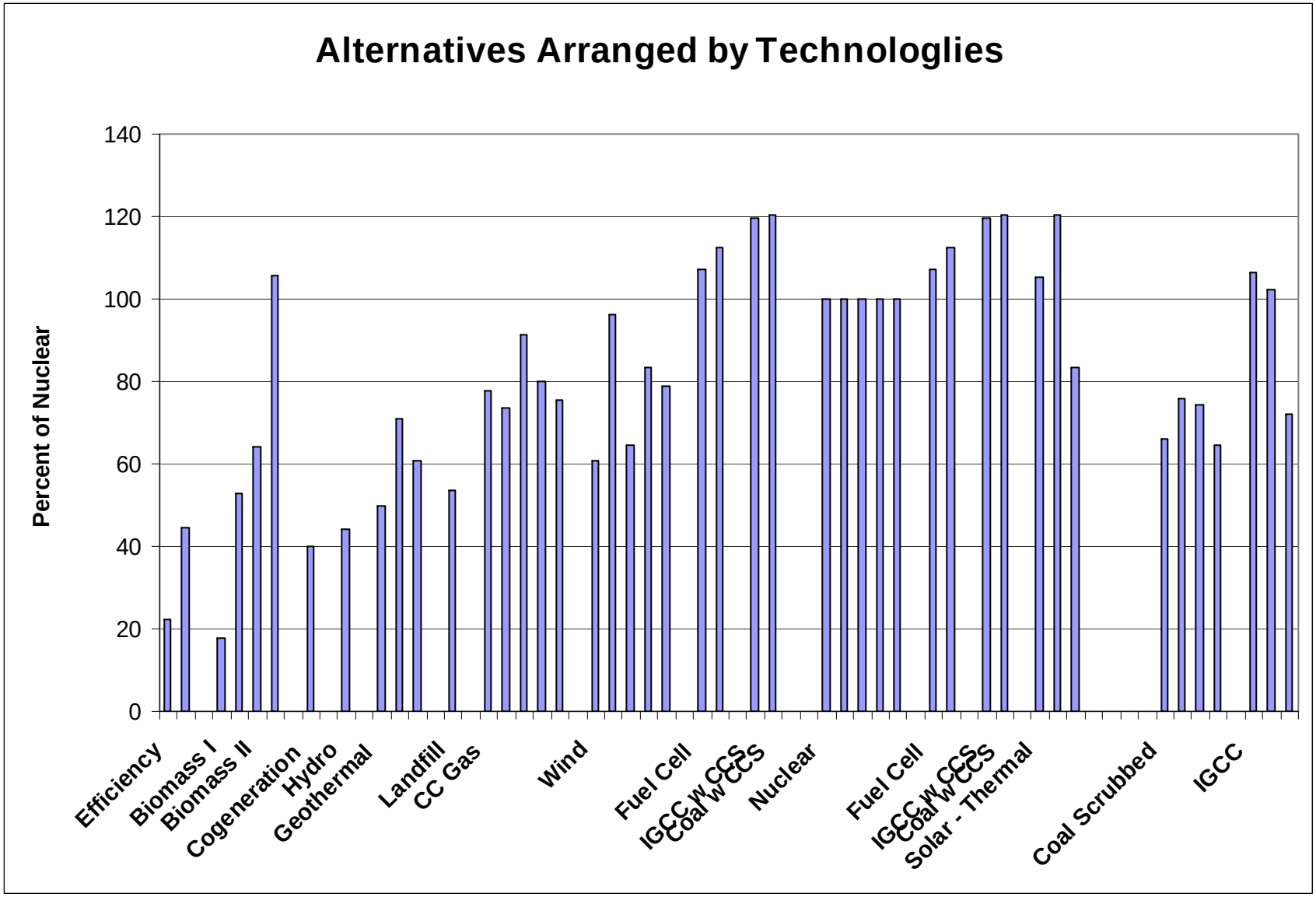
**Skilled labor is in short supply.**

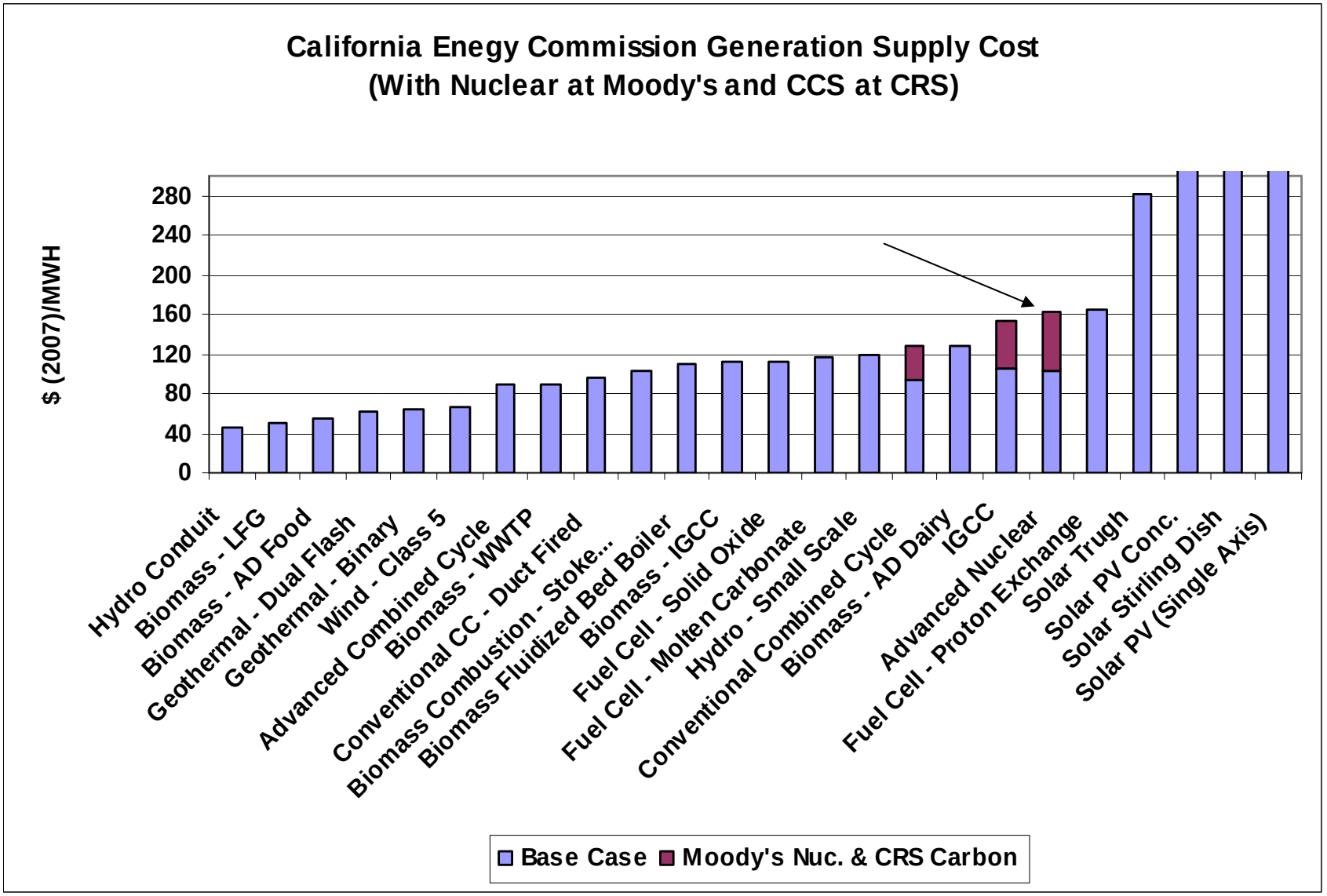
**Supply train is stretched thin.**

> **The one-of-a-kind, specialized products have few suppliers,so interruption or delay in delivery cannot be accommodated and ripple through the implementation of the project.**


Analyst Overnight and Busbar Cost Estimates Since 2007
Busbar Cost (2008$/mwh)
Overnight cost (2008$/KW)
y = 0.0218x + 21.817
R² = 0.7756
y = 0.0196x + 25.05
R² = 0.9676
Utilities 2008
Moody's 2008
Harding Medium 2009 at CERA escalation
All Analysts
High Outliers Excluded
Linear (All Analysts)
Linear (High Outliers Excluded)


Busbar Cost of Alternaitives to Meet Electricity Needs
Percent of Nuclear
300
250
200
150
100
50
0
Efficiency
Cogeneration
Biomass Co-firing
Geothermal
Wind
Biomass-Direct
Landfill
Solar - Thermal
Solar PV
Fuel Cell
CC Gas
Coal Scrubbed
IGCC
Nuclear
Geothermal
Wind
Solar - Thermal
Solar PV
CC Gas
Coal Scrubbed
IGCC
Nuclear
Wind
Solar - Thermal
Solar PV
CC Gas
Coal Scrubbed
Nuclear
Wind
Geothermal
Biomass
CC Gas
Coal Scrubbed
IGCC
Nuclear
Solar Trough
Efficiency
Cogeneration
Wind
CC Gas
Coal Scrubbed
Nuclear
Lazard
CRS
Moody's
S & P
Lovins

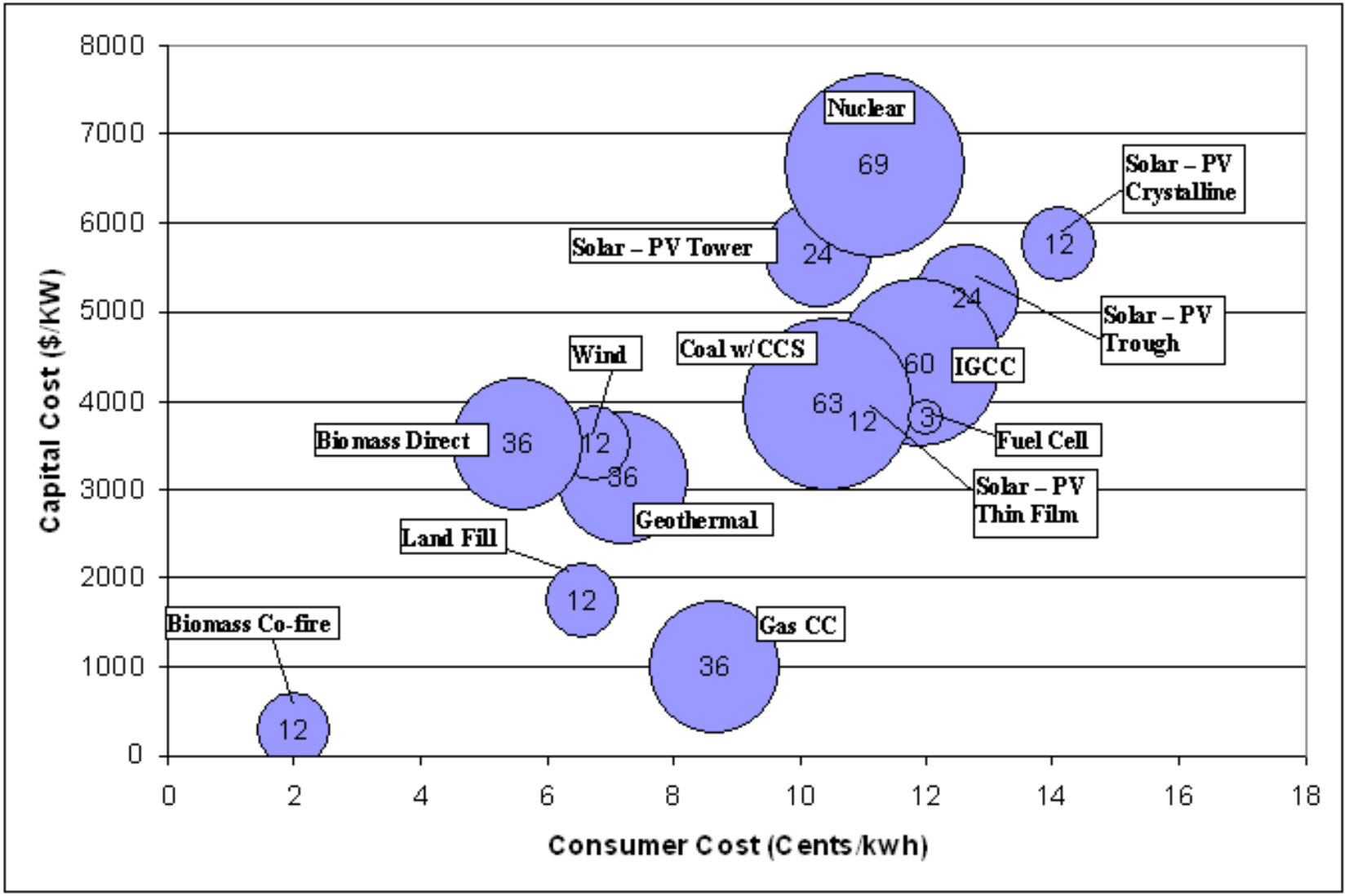

Alternatives Arranged by Technologlies
Percent of Nuclear
140
120
100
80
60
40
20
0
Efficiency
Biomass I
Biomass II
Cogeneration
Hydro
Geothermal
Landfill
CC Gas
Wind
Fuel Cell
IGCC w CCS
Coal w CCS
Nuclear
Fuel Cell
IGCC w CCS
Coal w CCS
Solar - Thermal
Coal Scrubbed
IGCC


California Enegy Commission Generation Supply Cost
(With Nuclear at Moody's and CCS at CRS)
$ (2007)/MWH
0
40
80
120
160
200
240
280
Hydro Conduit
Biomass - LFG
Biomass - AD Food
Geothermal - Dual Flash
Geothermal - Binary
Wind - Class 5
Advanced Combined Cycle
Biomass - WWTP
Conventional CC - Duct Fired
Biomass Combustion - Stoke...
Biomass Fluidized Bed Boiler
Biomass - IGCC
Fuel Cell - Solid Oxide
Fuel Cell - Molten Carbonate
Hydro - Small Scale
Conventional Combined Cycle
Biomass - AD Dairy
IGCC
Advanced Nuclear
Fuel Cell - Proton Exchange
Solar Trugh
Solar PV Conc.
Solar Stirling Dish
Solar PV (Single Axis)
Base Case
Moody's Nuc. & CRS Carbon

# RISK:

**Large, Sunk Costs (Inflexible Assets)**
**Long Lead Times (Technological & Economic Change)**
**Big Ratepayer Impacts (Demand Destruction)**

*Figure V-1: Consumer Cost, Capital Cost and Construction Times, Various Supply-Side Alternatives*
*(Circle Size Indicates Construction Time)*



# ENVIRONMENTAL EXTERNALITIES

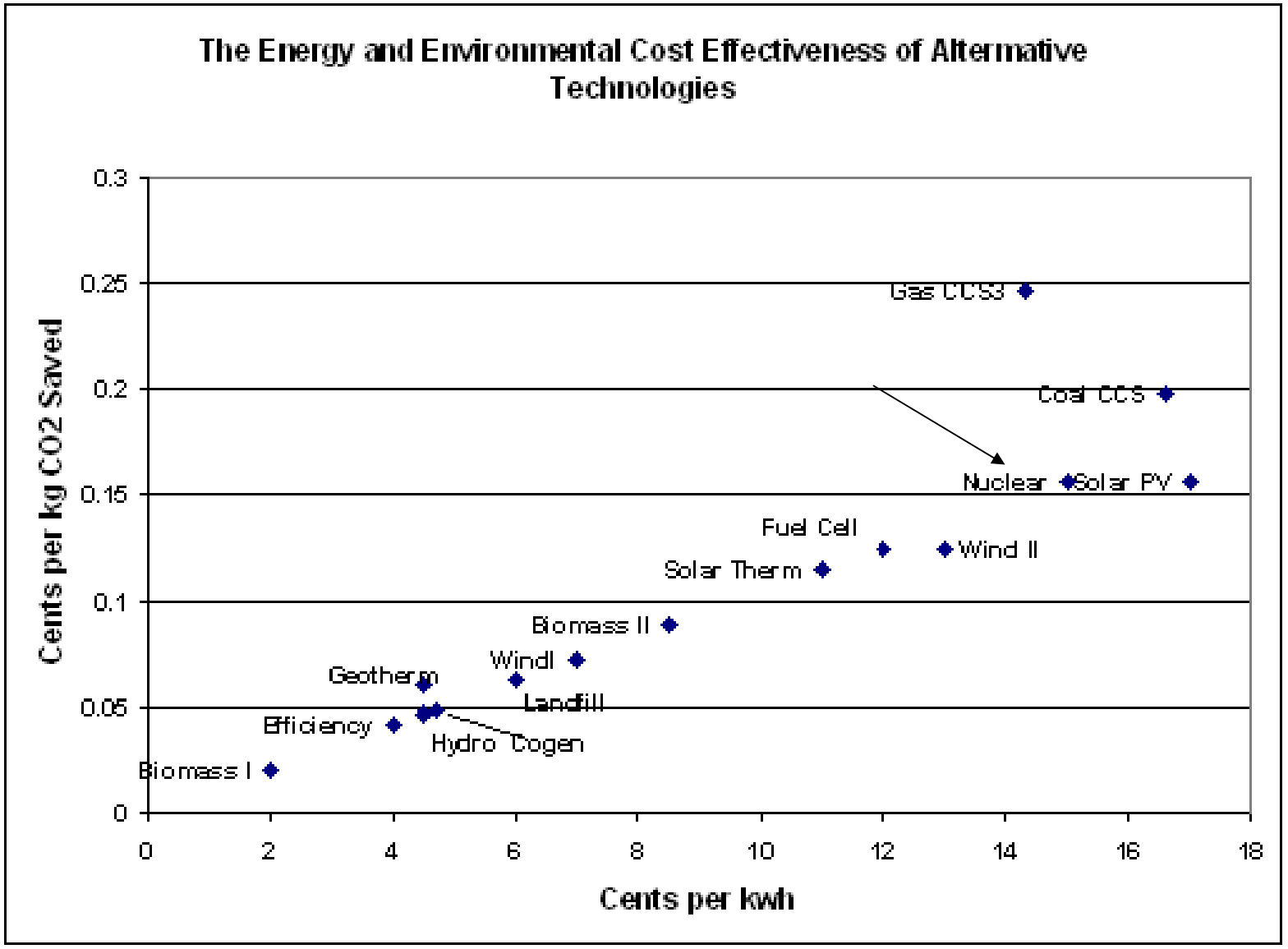
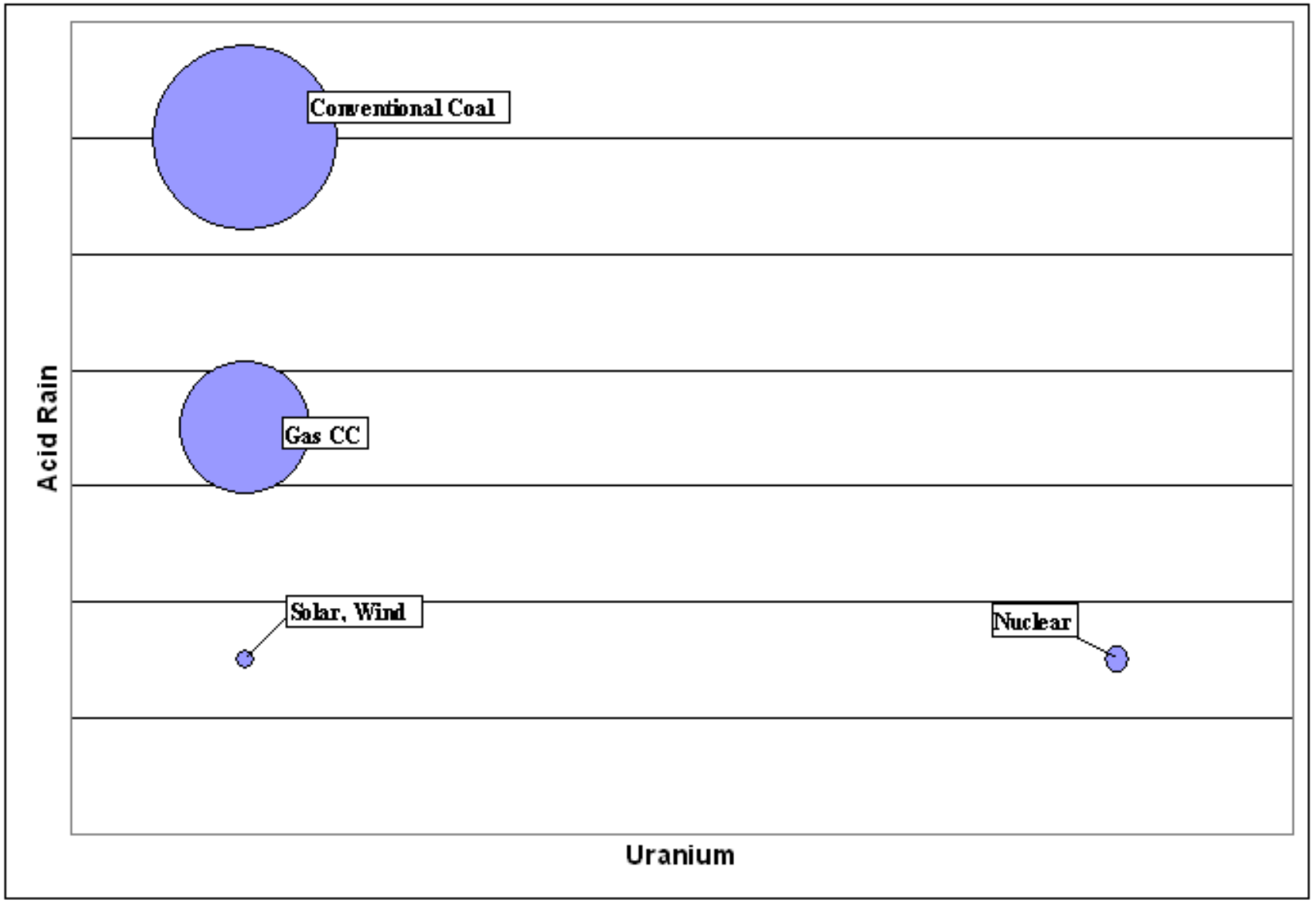
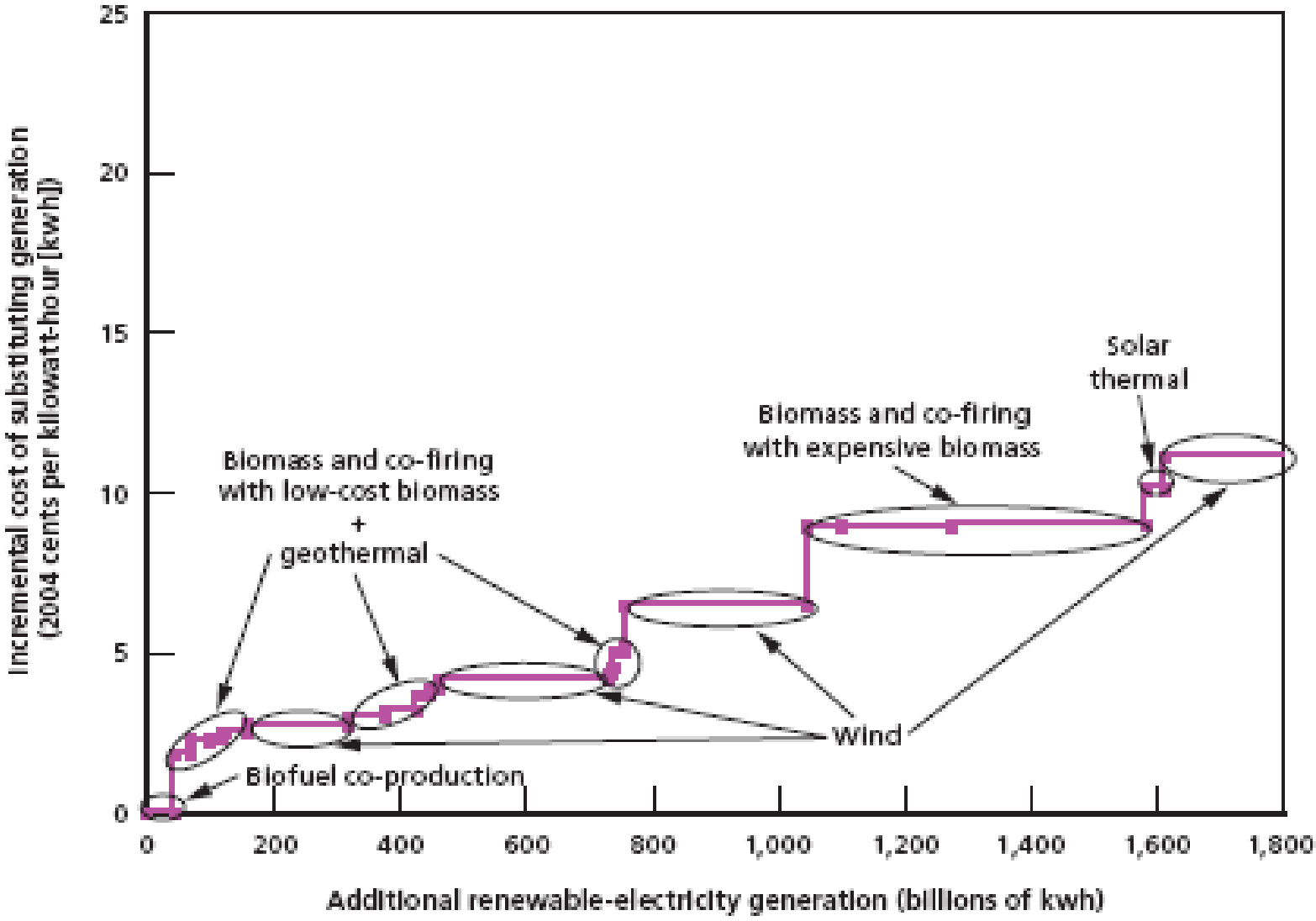

The Energy and Environmental Cost Effectiveness of Alternative Technologies
Cents per kg CO2 Saved
0.3
0.25
0.2
0.15
0.1
0.05
0
Gas CCS3
Coal CCS
Nuclear
Solar PV
Fuel Cell
Wind II
Solar Therm
Biomass II
WindI
Geotherm
Landfill
Efficiency
Hydro
Cogen
Biomass I
0
2
4
6
8
10
12
14
16
18
Cents per kwh

*Figure V-2: Major Environmental Impacts of Alternative Generation Technologies*
*(Circles Represent CO2 Emissions)*

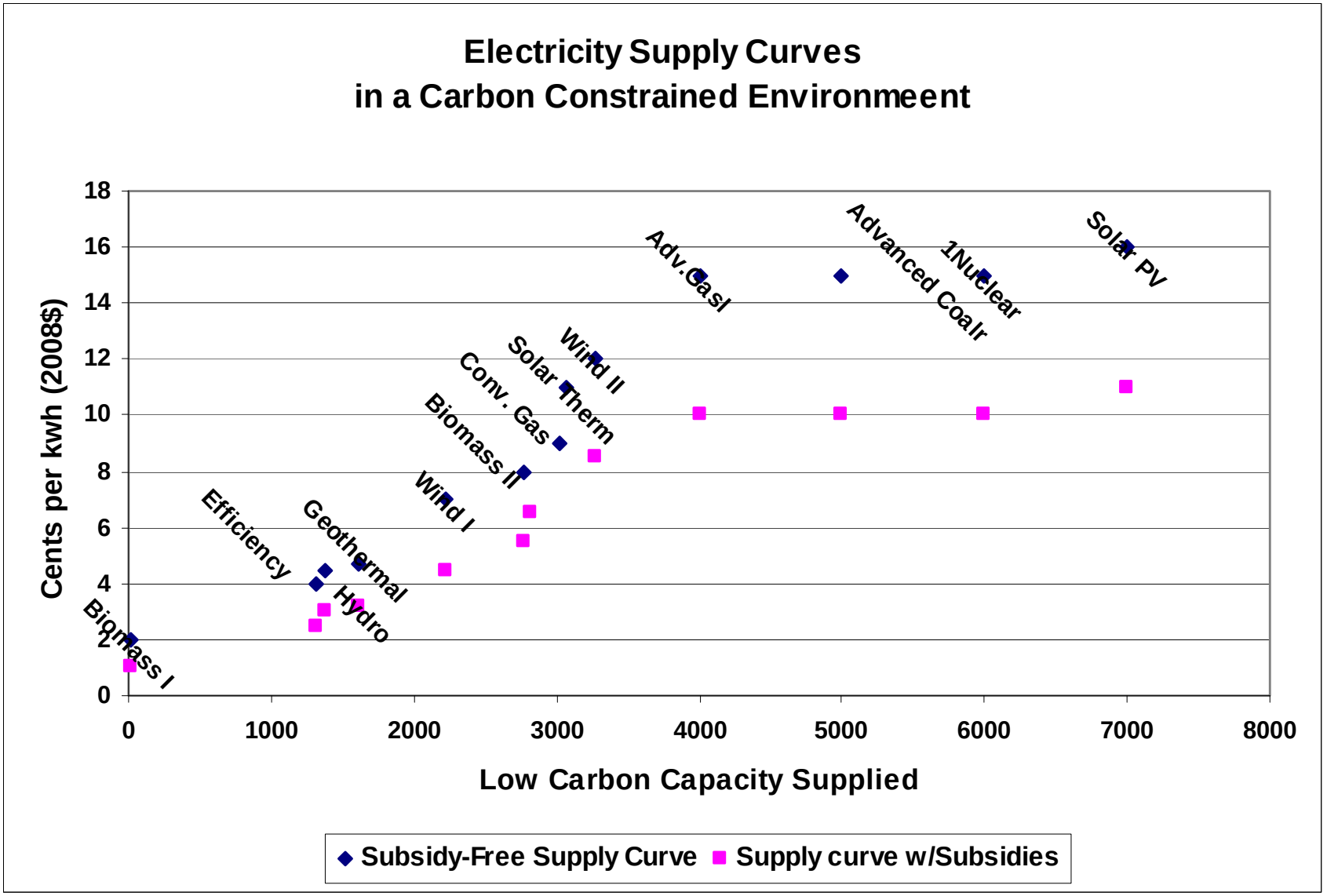


# POTENTIAL

Figure 2.3
Sample Incremental Cost of Renewables Substitution Curve Under One Set of Parameter Assumptions




RAND TR384-2.3


Electricity Supply Curves
in a Carbon Constrained Environmeent
Cents per kwh (2008$)
0
2
4
6
8
10
12
14
16
18
0
1000
2000
3000
4000
5000
6000
7000
8000
Low Carbon Capacity Supplied
Biomass I
Efficiency
Geothermal
Hydro
Biomass II
Wind I
Conv. Gas
Solar Therm
Wind II
Adv.Gasl
Advanced Coalr
1Nuclear
Solar PV
Subsidy-Free Supply Curve
Supply curve w/Subsidies

# THE BOTTOM LINE

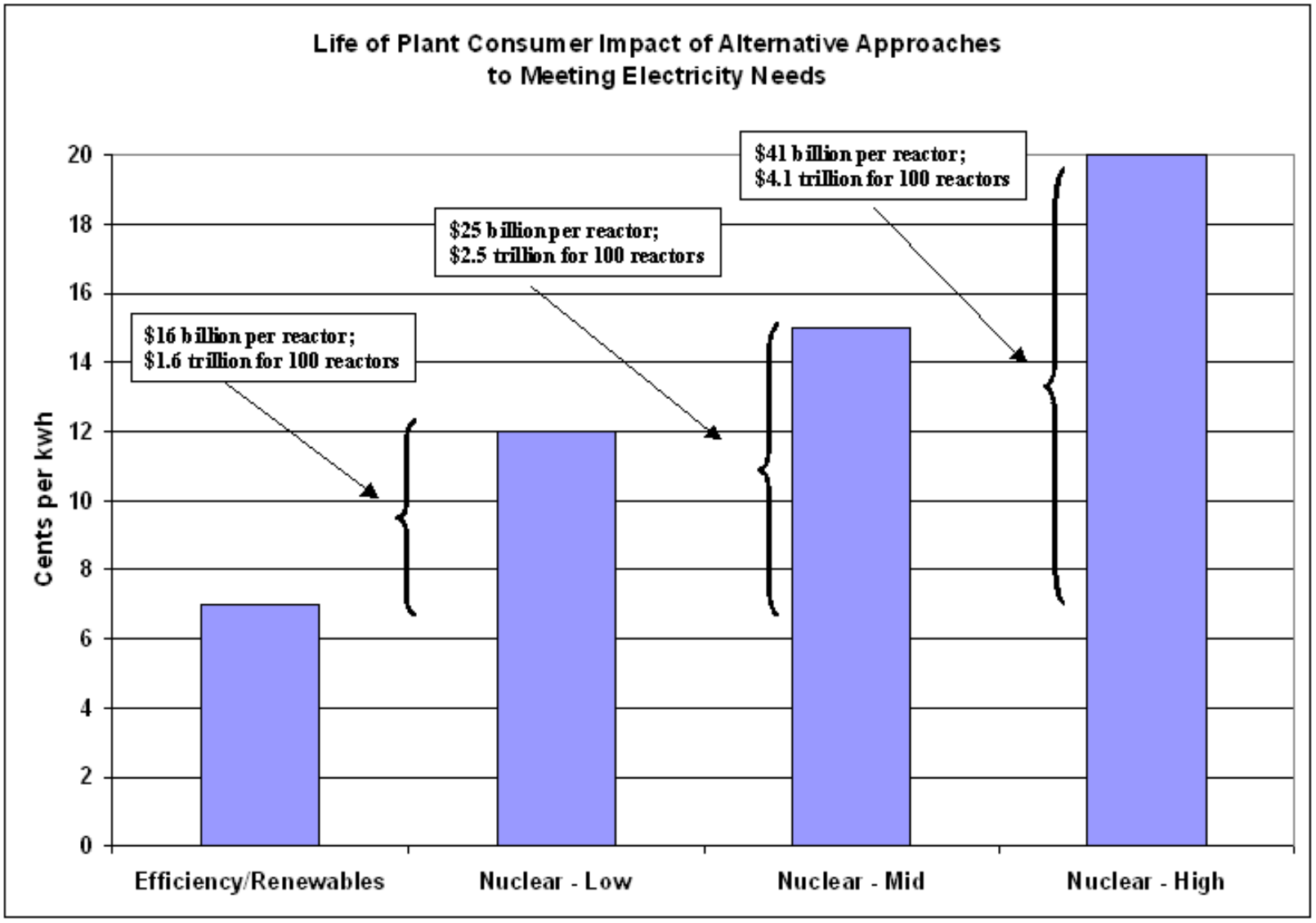

Life of Plant Consumer Impact of Alternative Approaches to Meeting Electricity Needs
Cents per kwh
0
2
4
6
8
10
12
14
16
18
20
$16 billion per reactor; $1.6 trillion for 100 reactors
$25 billion per reactor; $2.5 trillion for 100 reactors
$41 billion per reactor; $4.1 trillion for 100 reactors
Efficiency/Renewables
Nuclear - Low
Nuclear - Mid
Nuclear - High

*Figure VI-6: Multidimensional Evaluation of Alternatives*
*(Size of Circles Represents Risk)*