ORD, US EPA
Research Triangle Park, NC
December 10, 2007

Power Industry R&D and Decisions on Innovative Technology

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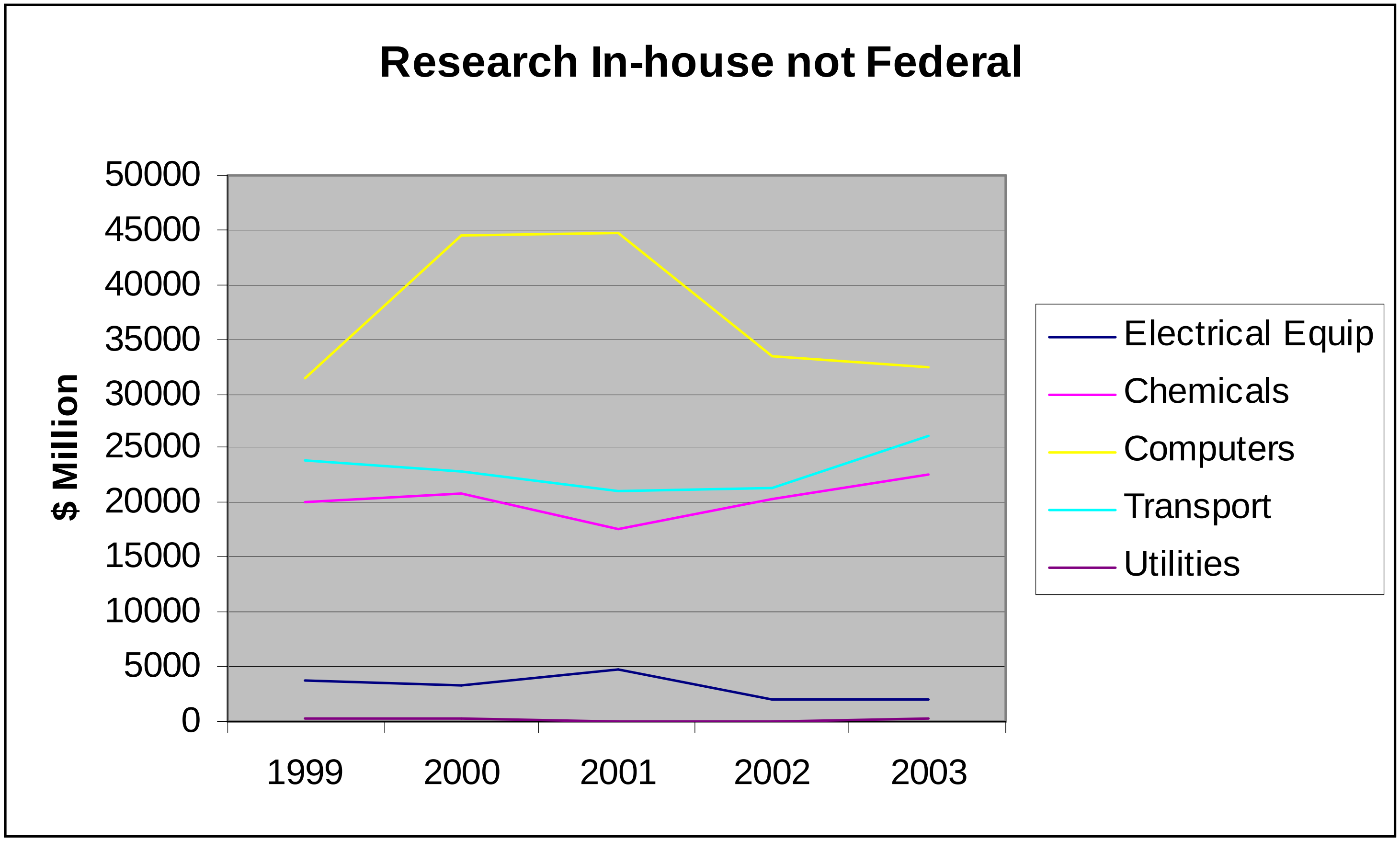
Topics

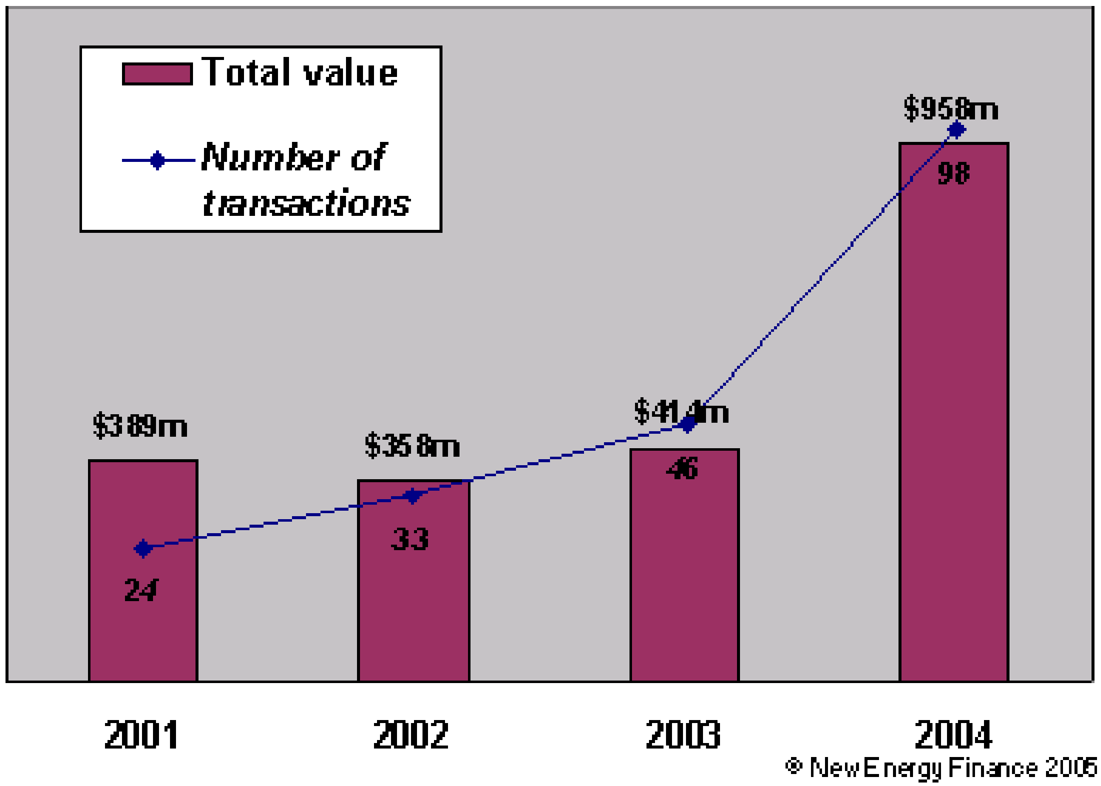
ELECTRIC POWER INDUSTRY R&D

R&D investment in current dollars US



Source: NSF

Venture capital investment in clean energy



In 2006 in North America, $866 million was invested in solar, wind, geothermal and hydro marine, representing a 3.4X increase over 2005 activity. Source Clean Tech Venture Network

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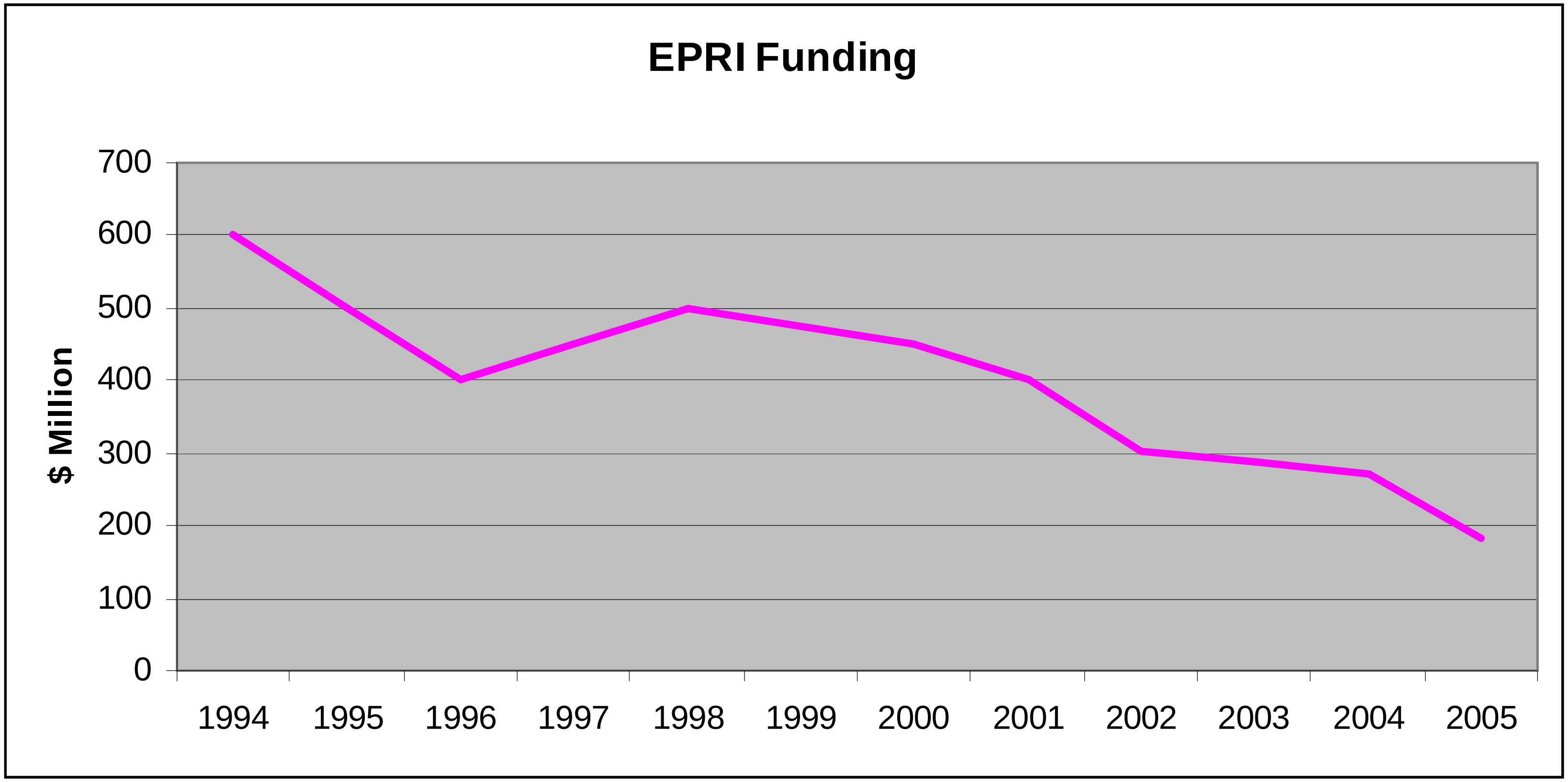
EPRI



Estimates of funding are approximate. Various sources.

Negative R&D drivers

- **Utilities remain regulated entities. Their ability to profit from innovation is limited.**
- **Utilities are technology users rather than technology developers. They are more akin to airlines or computer centers, than they are to Boeing or Intel.**
- **Most of the industries' basic technologies: boilers, gas turbines and reciprocal engines are very mature.**
- **Current industry pricing structures may hurt renewables**
  - The first projects in an area may have to bear very high transmission interconnection costs, unless a strong showing can be made. E.g., the Tehachapi area in California.

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Positive R&D drivers

- **The new markets for renewables and for clean power have created exciting new areas for technology.**
- **Merchant generation may provide a spur to innovation, but conservative lending practices pose problems.**
- **States are getting into the energy research business through programs such as PIER in California. A utility fee is directed to renewables research of about $70 million/year.**

EPRI story the beginning

- **EPRI started in 1972-73 as an industry response to a proposed Federal energy research tax on utilities**
- **At one time 90% of US generation participated in EPRI. The budget peaked at about $600 Million/year**
- **Research planning was initially top down**
  - All members participated in all programs
  - Board and Senior Advisory group allocated funds to research areas
  - Staff developed projects
  - Projects were matched to budgets by staff

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EPRI story recent history

- **In the late 90's, deregulation brought a new, more competitive mind set to industry. Utilities cutting costs left EPRI.**
- **EPRI tried to increase value by allowing utilities to pick and choose – shorter time horizon.**
- **Research planning is bottom up**
  - Staff and utility allies develop projects.
  - Staff market the projects to utilities.
  - If there is enough buy-in, the project goes forward.
  - Formal project analyses are prepared, but the market rules.
- **12% of budget is still committed top down.**

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How can clean power innovation be fostered?

- **Increase efficiency – by getting prices right**
  - Time and location pricing
  - Costs of emissions
- **Increase the upside**
  - Subsidies and tax credits.
  - Deregulation
- **Decrease the risks**
  - Government funding of R&D

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Summary

- **Electric power has been a low R&D, low innovation industry. Regulation does not foster innovation.**
- **This capital intensive industry requires large investments to conduct R&D, in addition to satisfying ongoing needs.**
- **The utility industry has supported research sometimes due to government threat or mandate.**
- **Equipment providers have been and are likely to continue to be the key innovators, not utilities.**
- **Merchant generation, both traditional and green, creates new players who may be able to profit more from innovation, but conservative lending practices pose problems.**

POWER INDUSTRY & RESOURCE SELECTION

Two kinds of firms build power plants

- **Regulated electric utilities**
  - Chief concern is that regulators approve construction and investment expenses, which must be deemed "used and useful."
  - Are very risk averse and view penalties for failure as much more likely than rewards for better performance.
  - Pass through expenses such as fuels, subject to prudence review.
- **Independent power producers**
  - Have more opportunities to profit from innovation,
  - But, project financing makes them conservative.
    - Lenders have recourse just to the project revenues
    - Lenders, therefore, want power purchase agreements, fuel purchase agreements, and equipment performance guarantees.
  - Technology development firms building first of kind plants or even demonstration plants are special cases.

Several barriers to clean power seem to be understated

- **Transmission. In the west, transmission is widely regarded as the biggest barrier to clean power. Wind, geothermal, and central solar all exist in relatively remote locations.**
- **Intermittance. On the west coast, wind currently gets about 5%-25% capacity credit. Solar, without storage, is likely to get less than 60%.[1]**
- **Permitting. Stories of 5 to 10 years to permit a 10MW plant are heard frequently. It seems to take the same amount of time to permit 250+ MW.**

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[1] Resource Adequacy factors for SDG&E are 95% for Biomass, 95% for Landfill Gas, 95% for Geothermal, 60% for Solar Thermal, 30% for Solar Photovoltaic and 24% for Wind.

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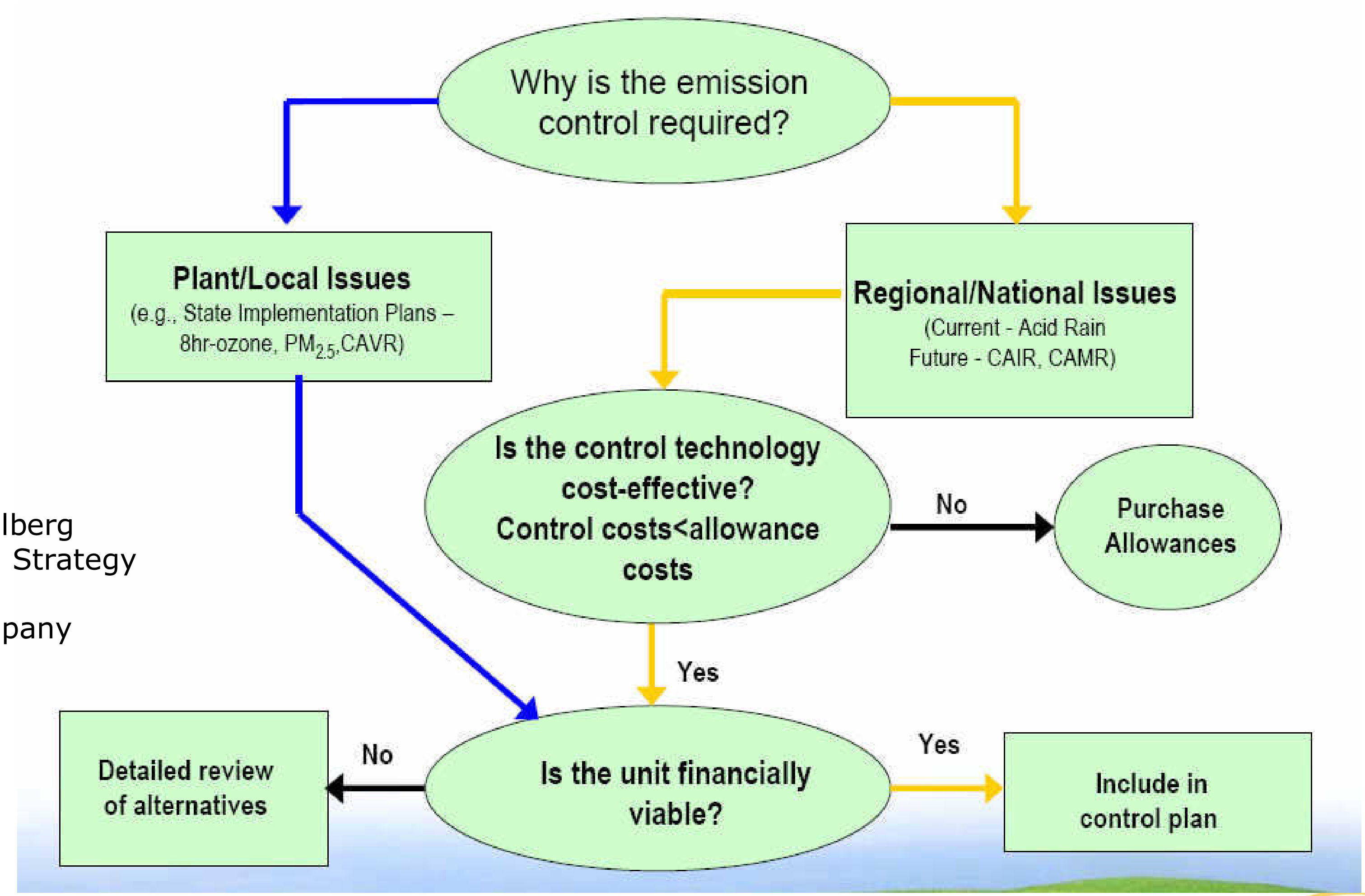
Utility Procurement Decisions

- **Evaluate different types of technologies and their operations,**
- **Apply different methods for comparing:**
  - Supply versus demand-side bids,
  - Peaking, dispatchable, non-dispatchable & baseload resources, and
  - Differences in start-date and in contract terms.
- **Examine portfolio characteristics**
  - Determine portfolio cost
  - Determine portfolio loss-of-load risk
  - Determine value-at-risk for trades both in electricity and fuels markets

Southern Company Emission Control Decision Making



Source:
Kim Malm Adelberg
Environmental Strategy Manager,
Southern Company Generation

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Real options approaches are the cutting edge in analysis

- **Recognize uncertainty and downstream flexibility to make different decisions**
- **Use market information when available**

We illustrate with a hypothetical example. The analysis is based on an actual project. Results have been modified and are reasonable, but not real.

A four-step analytic process is used to improve resource strategy and valuation.

- **<u>Uncertainty Analysis.</u> Identify and analyze the uncertainties that affect value.**
- **<u>Learning Analysis.</u> Identify and analyze learning associated with these uncertainties.**
- **<u>Decision Analysis.</u> Identify and analyze options for acting on this learning.**
- **<u>Recommendations.</u> Use this analysis to develop the best strategy.**

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Big Muddy 3, a typical “dirty, old” coal plant.

- **Built during the 1960s, maintained adequately.**
- **Multiple units with a total rated capacity > 1000 MW.**
- **Last year, produced more than 8,000,000 GWh of electricity burning > 3 million tons of low-sulfur coal.**
- **Has neither SO_2 scrubbers nor NOx SCRs. Relies on low-sulfur coal for SO_2 control and low-NOx burners for NOx control. Produces 50,000 tons of SO_2 and 20,000 tons of NOx per year, along with 200 pounds of mercury.**
- **Emits roughly 9,000,000 tons of CO_2 per year.**

What should we do with this plant?

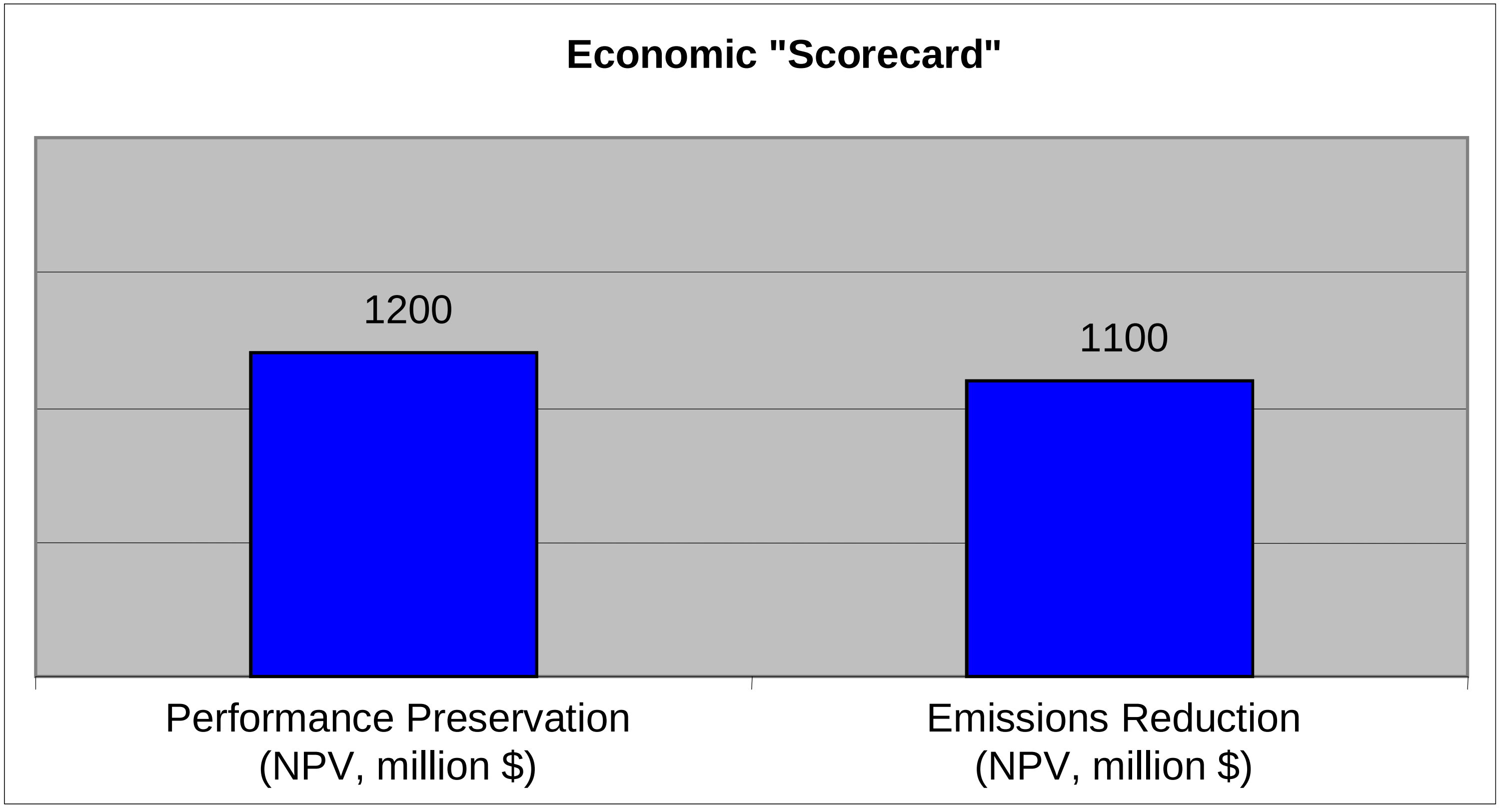
Performance Preservation Alternative

PERFORMANCE PRESERVATION	NPV	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Revenue ($1,000)		271,150	285,563	341,779	423,928	604,000	762,632	637,248	568,359	590,332	561,226
Generation (1000 GWh)		6,875	6,911	6,998	7,205	8,995	8,993	8,967	9,011	9,011	9,022
Electricity Price ($/MWh)		39.44	41.32	48.84	58.84	67.15	84.80	71.07	63.07	65.51	62.21
Fixed Costs ($1,000)		53,545	62,191	45,470	50,824	54,093	54,545	63,622	64,890	67,264	70,130
Capital		21,170	28,926	12,701	14,894	17,292	17,079	20,826	21,106	21,666	22,116
Fixed O&M		32,375	33,265	32,769	35,930	36,801	37,466	42,795	43,784	45,598	48,014
Operating Costs ($1,000)		206,629	224,823	252,550	283,119	344,150	364,898	384,380	357,091	328,639	326,615
Fuel Price ($/MWh)		22.55	22.47	24.05	23.61	24.84	25.32	26.64	24.92	23.76	24.72
Fuel Cost ($1000)		155,045	155,290	168,327	170,126	223,440	227,745	238,850	224,573	214,089	223,005
Variable O&M ($/MWh)		2.12	2.16	2.19	2.22	2.25	2.28	2.32	2.35	2.39	2.42
Variable Cost ($1000)		14,597	14,936	15,337	16,004	20,220	20,515	20,760	21,183	21,510	21,870
Environmental Price ($/MWh)		5.38	7.90	9.84	13.46	11.17	12.97	13.91	12.35	10.32	9.06
Environmental Cost ($1000)		36,988	54,597	68,887	96,990	100,491	116,637	124,771	111,335	93,040	81,740
Cash Flow ($1,000)	$1,249,323	10,976	-1,451	43,759	89,984	205,757	343,189	189,246	146,379	194,429	164,481
Emissions	**AVERAGE**										
SO2 Emissions (KTon)	52.73	41.20	41.84	42.28	43.69	53.83	53.83	54.42	54.69	54.69	54.75
Nox Emissions (kTon)	35.02	24.95	25.02	25.63	32.01	36.40	36.34	36.30	36.48	36.48	36.58
Hg Emissions (lbs)	178.85	135.30	132.40	131.64	140.71	186.39	186.15	186.40	186.58	186.58	187.53
CO2 Emissions (KTon)	9,528	7,670	7,702	7,725	7,963	9,834	9,831	9,803	9,852	9,852	9,863

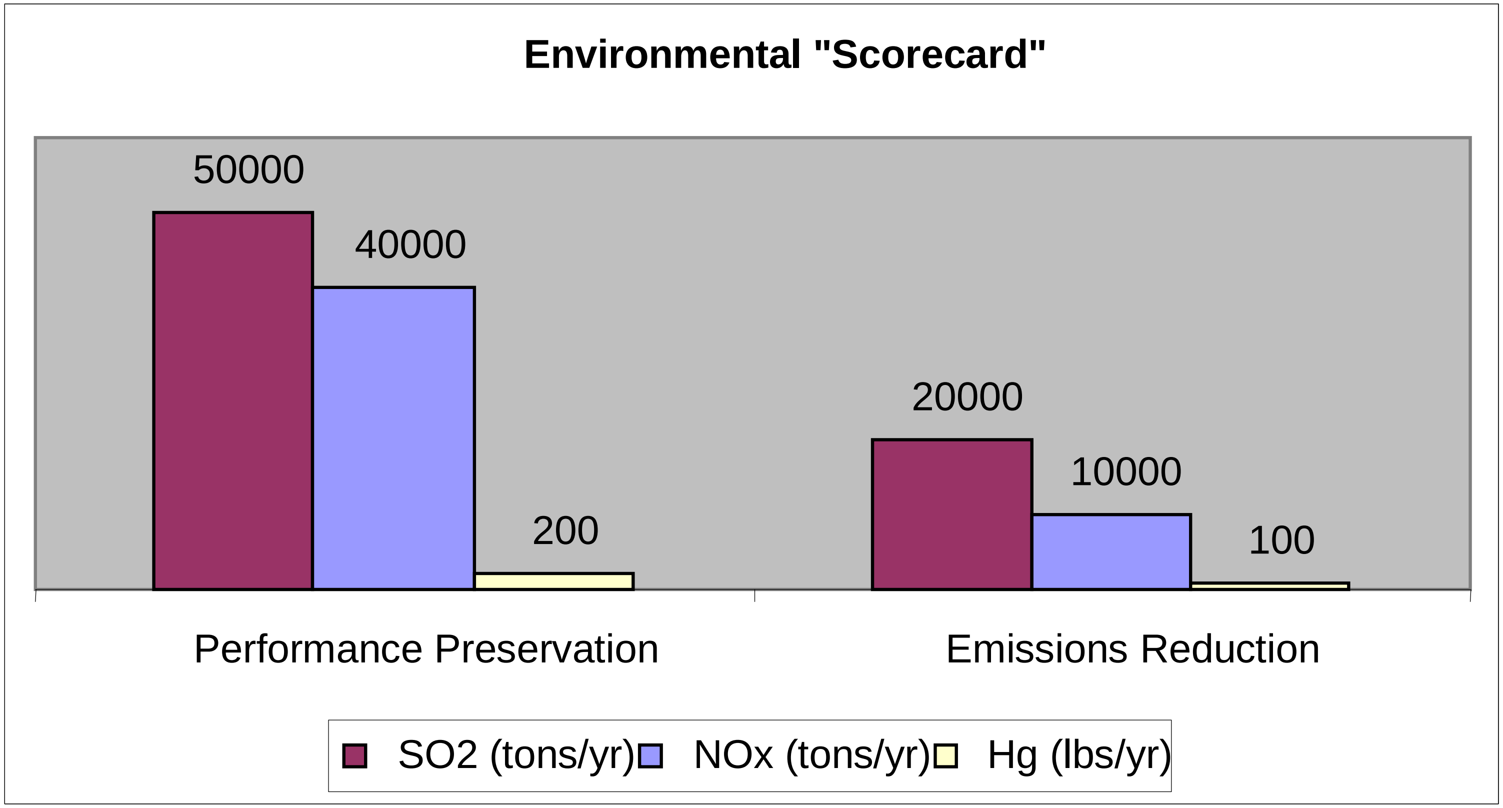
Emissions Reduction Alternative

EMISSIONS REDUCTION	NPV	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Revenue ($1,000)		241,383	259,187	342,900	398,559	591,658	747,871	625,025	555,454	577,385	551,332
Generation (1000 GWh)		7,004	7,185	7,228	6,747	8,810	8,823	8,810	8,810	8,810	8,866
Electricity Price ($/MWh)		34.46	36.07	47.44	59.07	67.16	84.76	70.95	63.05	65.54	62.18
Fixed Costs ($1,000)		92,059	150,700	242,819	322,521	196,941	64,002	73,336	74,875	77,537	80,710
Capital ($1000)		52,194	110,773	201,218	277,578	150,919	17,079	20,826	21,106	21,666	22,116
Fixed O&M ($1000)		39,866	39,927	41,602	44,943	46,022	46,923	52,509	53,769	55,870	58,594
Operating Costs ($1,000)		233,896	223,874	236,985	239,788	240,911	249,660	266,563	239,642	222,225	231,077
Fuel Price ($/MWh)		22.08	20.02	22.28	22.03	23.38	23.87	25.52	22.83	21.35	22.42
Fuel Cost ($1000)		154,681	143,833	161,017	148,619	206,007	210,572	224,847	201,125	188,058	198,740
Variable O&M ($/MWh)		1.18	1.20	1.20	1.23	1.25	1.28	1.31	1.35	1.39	1.42
Variable Cost ($1000)		8,265	8,622	8,670	8,306	10,991	11,299	11,583	11,896	12,216	12,627
Environmental Price ($/MWh)		10.13	9.94	9.31	12.28	2.71	3.15	3.42	3.02	2.49	2.22
Environmental Cost ($1000)		70,951	71,419	67,298	82,863	23,913	27,788	30,133	26,621	21,951	19,711
Cash Flow ($1,000)	$1,138,189	-84,572	-115,386	-136,905	-163,751	153,807	434,209	285,126	240,937	277,623	239,545
Emissions	**AVERAGE**										
SO2 Emissions (KTon)	19.54	40.48	43.39	44.18	41.41	15.98	16.00	15.98	15.98	15.98	16.08
Nox Emissions (kTon)	11.53	19.05	20.34	20.58	19.27	10.22	10.24	10.22	10.22	10.22	10.30
Hg Emissions (lbs)	82.28	133.88	117.20	137.94	123.54	74.61	75.00	74.61	74.61	74.61	75.67
CO2 Emissions (KTon)	9,487	6,933	7,297	7,964	7,450	9,774	9,788	9,774	9,774	9,774	9,835

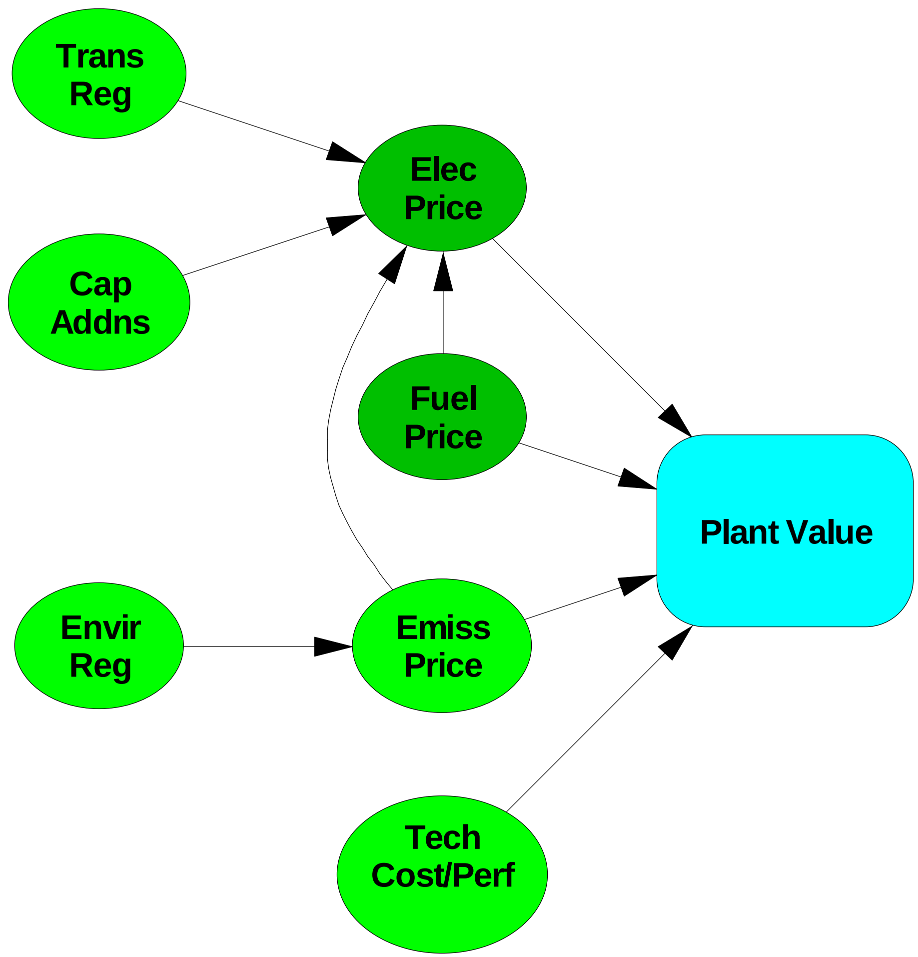
Initial Economic Analysis



Initial Environmental Analysis



Uncertainty analysis influence diagram



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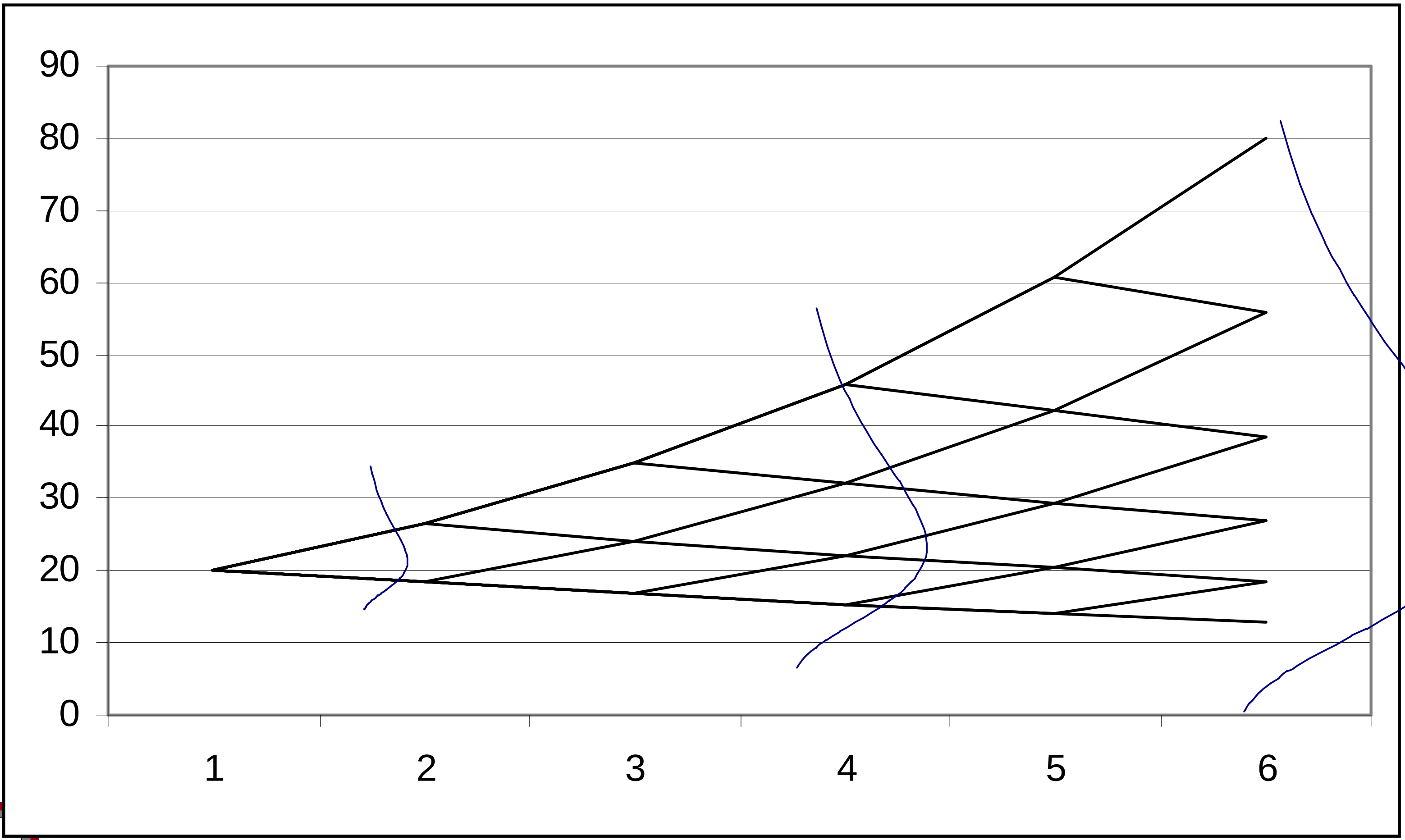
Geometric Brownian Motion (GBM): The "default" market uncertainty model



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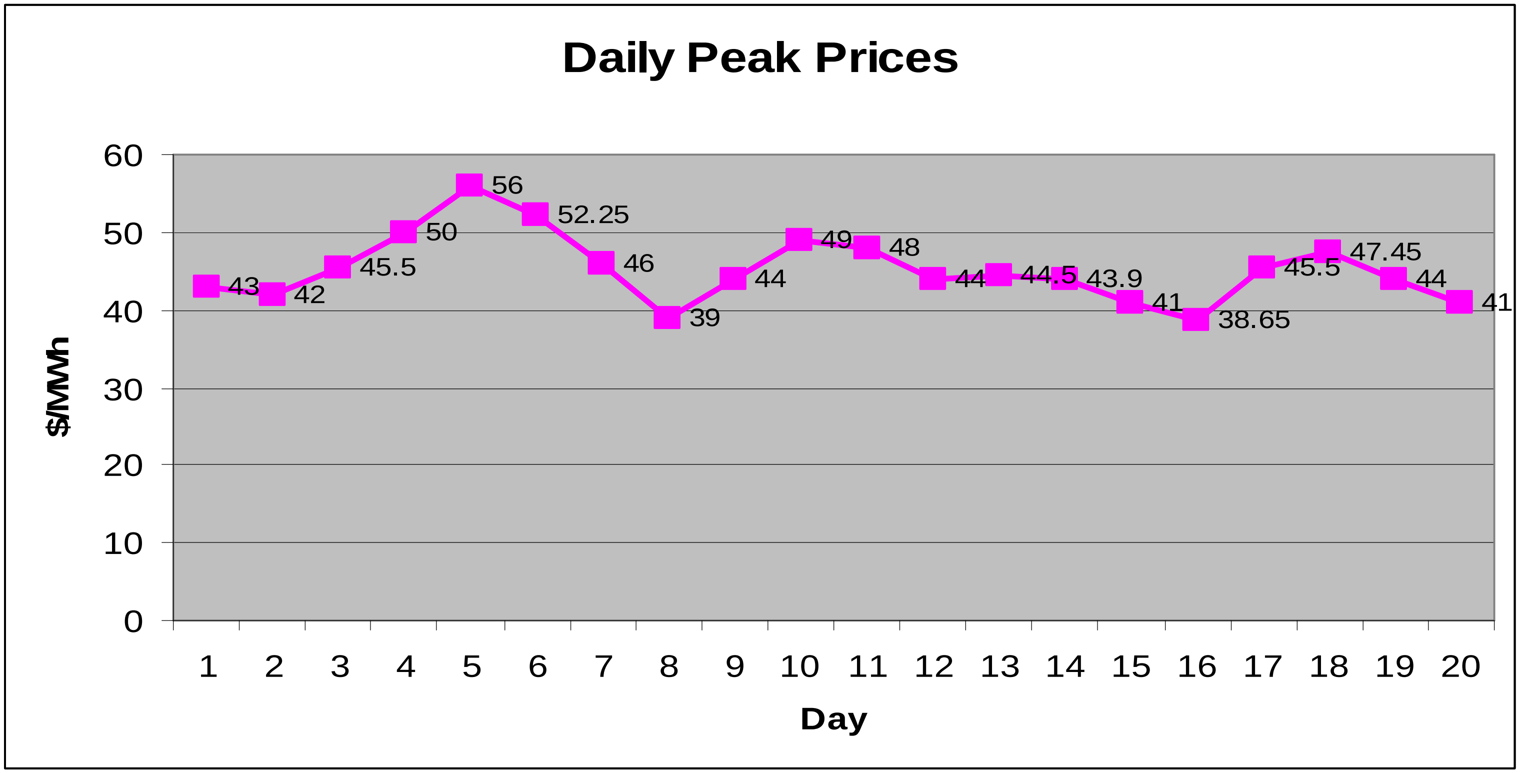
Market uncertainty example: gather historical data



Market uncertainty example: fit parameters of suitable distribution

- **GBM is defined by two parameters**
  - μ (drift)
  - σ (std deviation)
  - $\ln(P_T)$ is distributed normally with mean **[$\ln(P_0) + (\mu-\sigma^2/2)T$]** and standard deviation
    [$\sigma T^{0.5}$]
  - The expected value of P_T is $P_0\exp(\mu T)$
- **Determine $D_t = \ln(P_t/P_{t-1})$ from historical data**
- **Estimate GBM parameters:**
  - σ = standard deviation of D_t
  - μ = (mean of D_t) + $0.5^* \sigma^2$

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Price	43	42	45.5	50	56	52.25	46	39	44	49	48	44	44.5	43.9	41	38.65	45.5	47.45	44	41
D		-0.024	0.08	0.0943	0.1133	-0.069	-0.127	-0.165	0.1206	0.1076	-0.021	-0.087	0.0113	-0.014	-0.068	-0.059	0.1632	0.042	-0.075	-0.071
μ	**0.0019**																			
σ	**0.0938**																			

On a yearly basis, μ =.0019*250= .475 and σ =.00938*250$^{.5}$ = 1.4831

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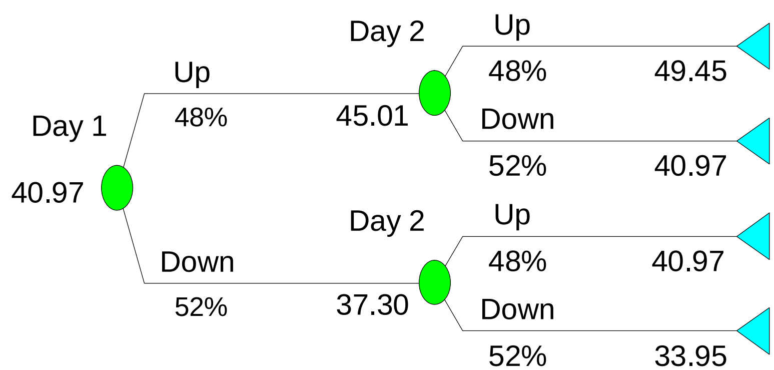
Market uncertainty example: develop discrete approximation

- **Binomial approximation of GBM is defined by two parameters**
  - Multiplicative size of up movement (u); size of down movement d is 1/u
  - Probability of up movement (p); probability of down movement is (1-p)
- **For a binomial process of period length N (for example, N=1 day or 0.0040 years)**
  - $u = \exp(\sigma * \text{sqrt}(N))$
  - $d = 1/u$
  - $p = [\exp(\mu N)-d]/[u-d]$
- **u = 1.0986, d = 0.9103, p = 0.4870**

Market uncertainty example: risk adjust the discrete approximation

- **Electric futures reveal the risk-free rate of electric price increases**
- **Determine the rate of futures price increase (say f=0.05)**
- **Determine the length of the period in years (say N=1/250 or 0.004 for 1 trading day)**
- **Calculate the "risk-adjusted" probability of up (q) and down (1-q) using the rate of increase in futures prices**
  - q = [exp(fN)-d]/[u-d]
  - In this case, q is (1.0002-0.9103)/(1.0986-0.9103) or 48%



In this case, the effect of risk adjustment is very small.

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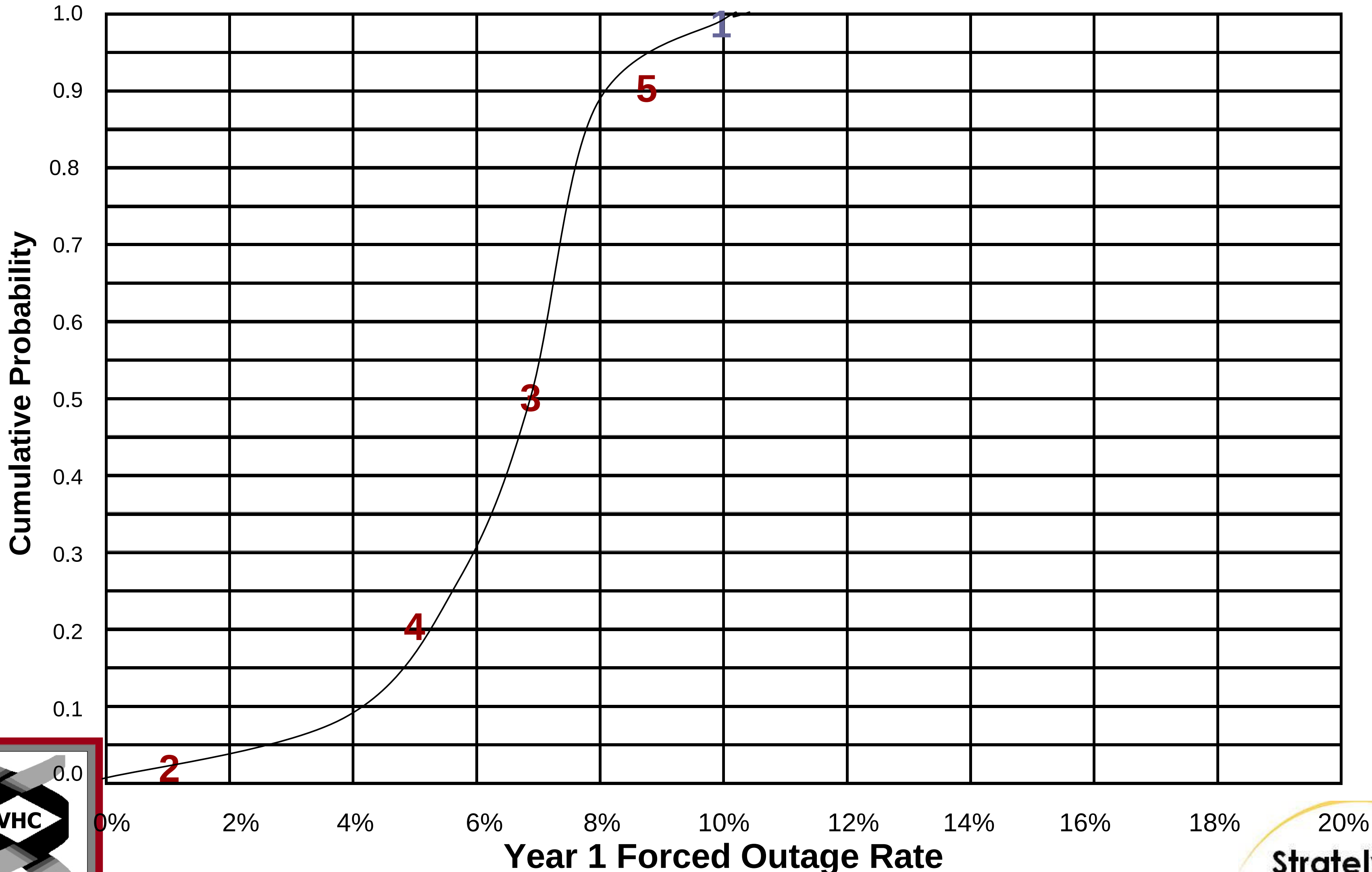
Private uncertainty example: Encode unconditional distribution (cont'd)



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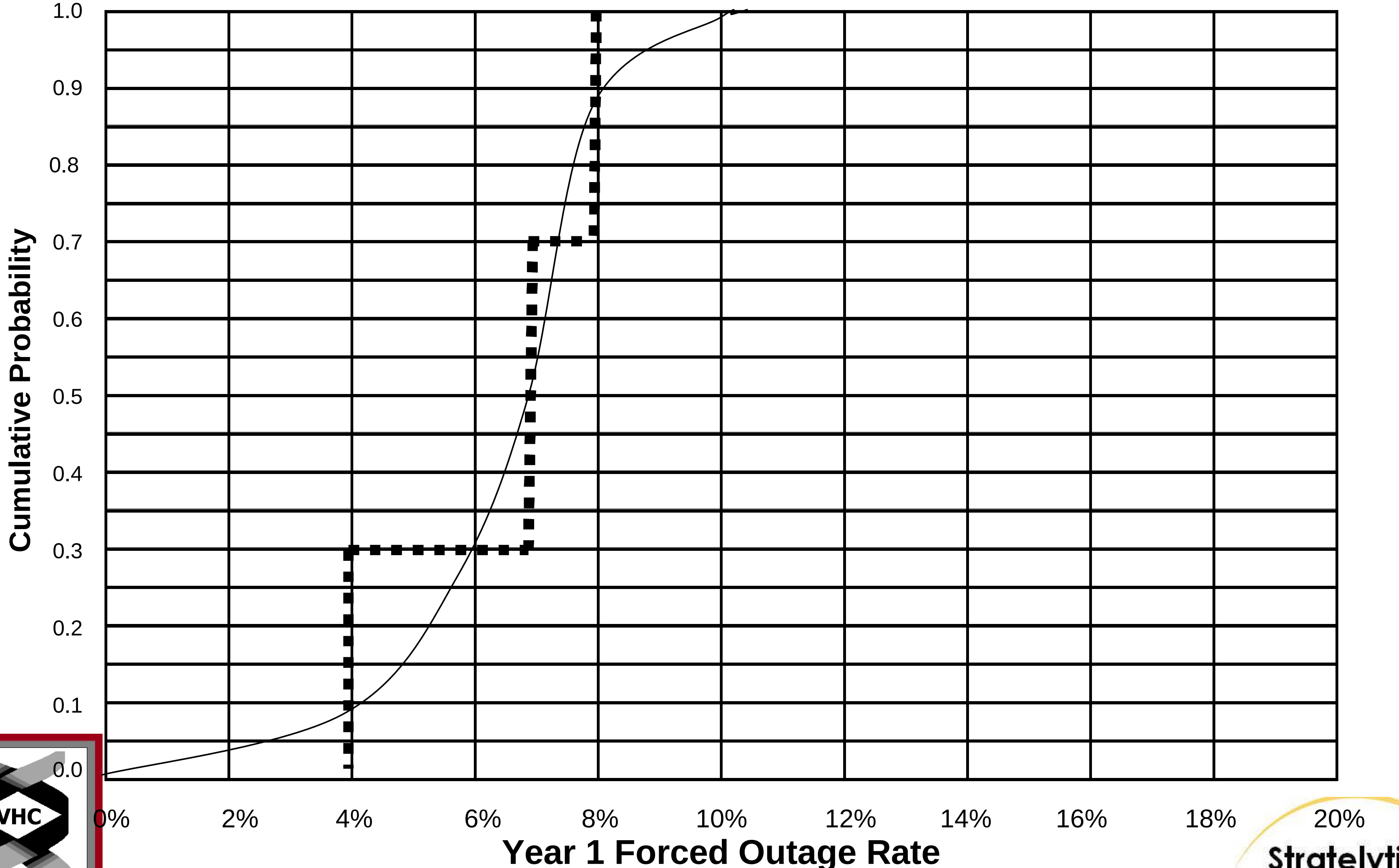
Private uncertainty example: Develop discrete approximation



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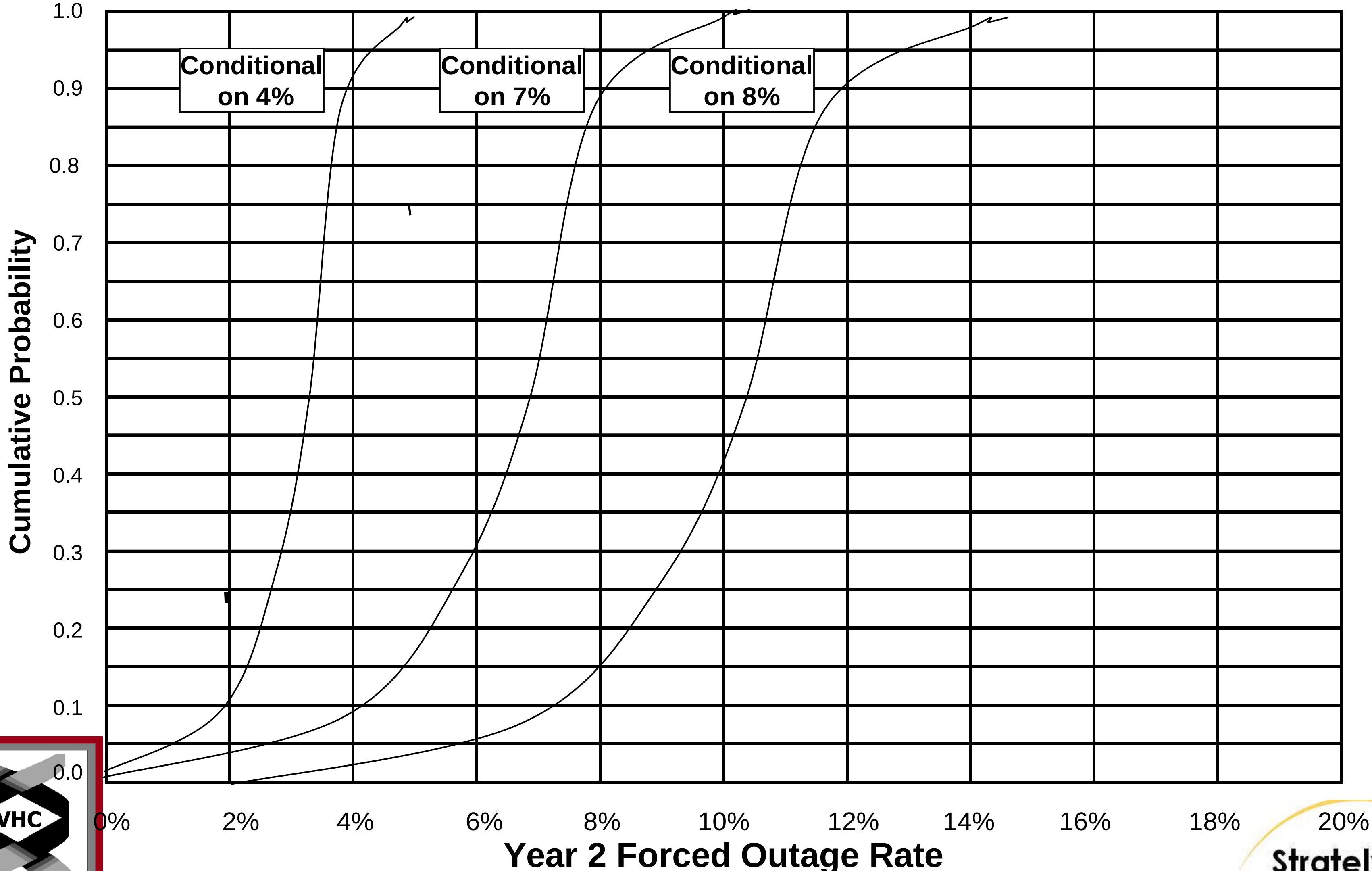
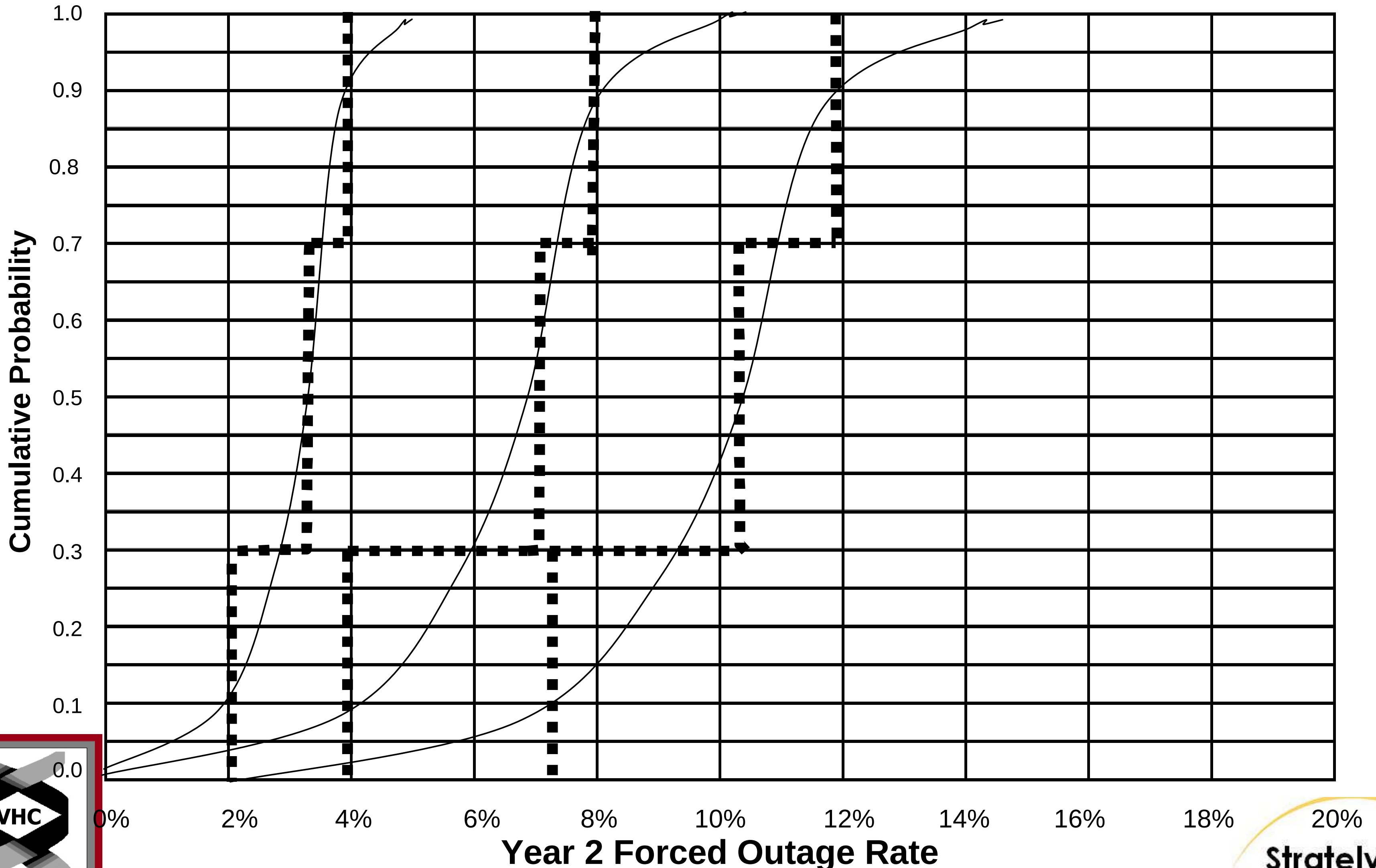
Private uncertainty example: Encode conditional distributions



Private uncertainty example: Develop discrete approximations



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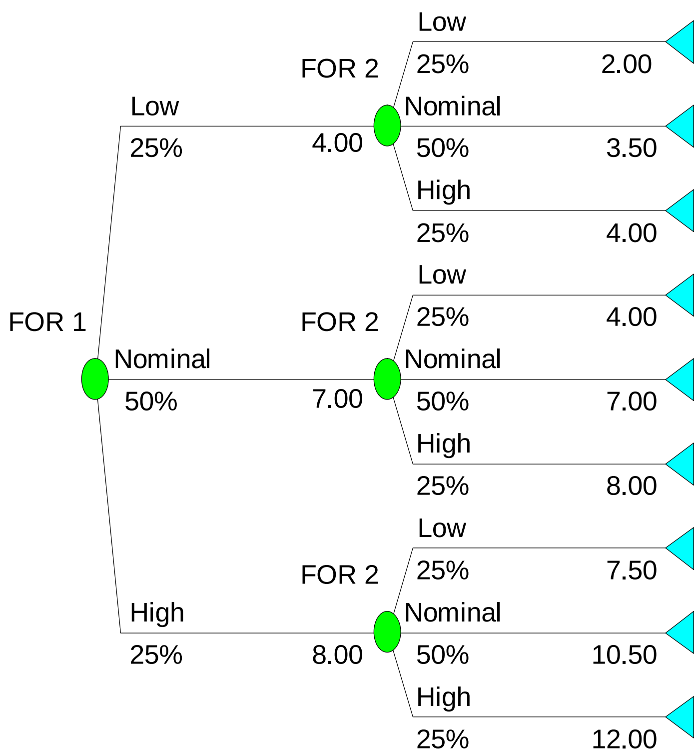
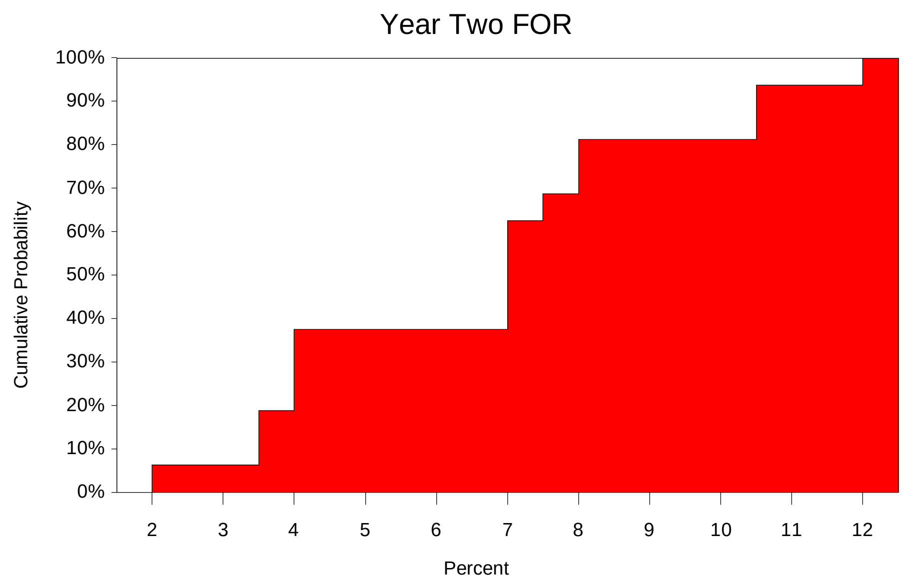
Private uncertainty example: Develop discrete approximations (cont)





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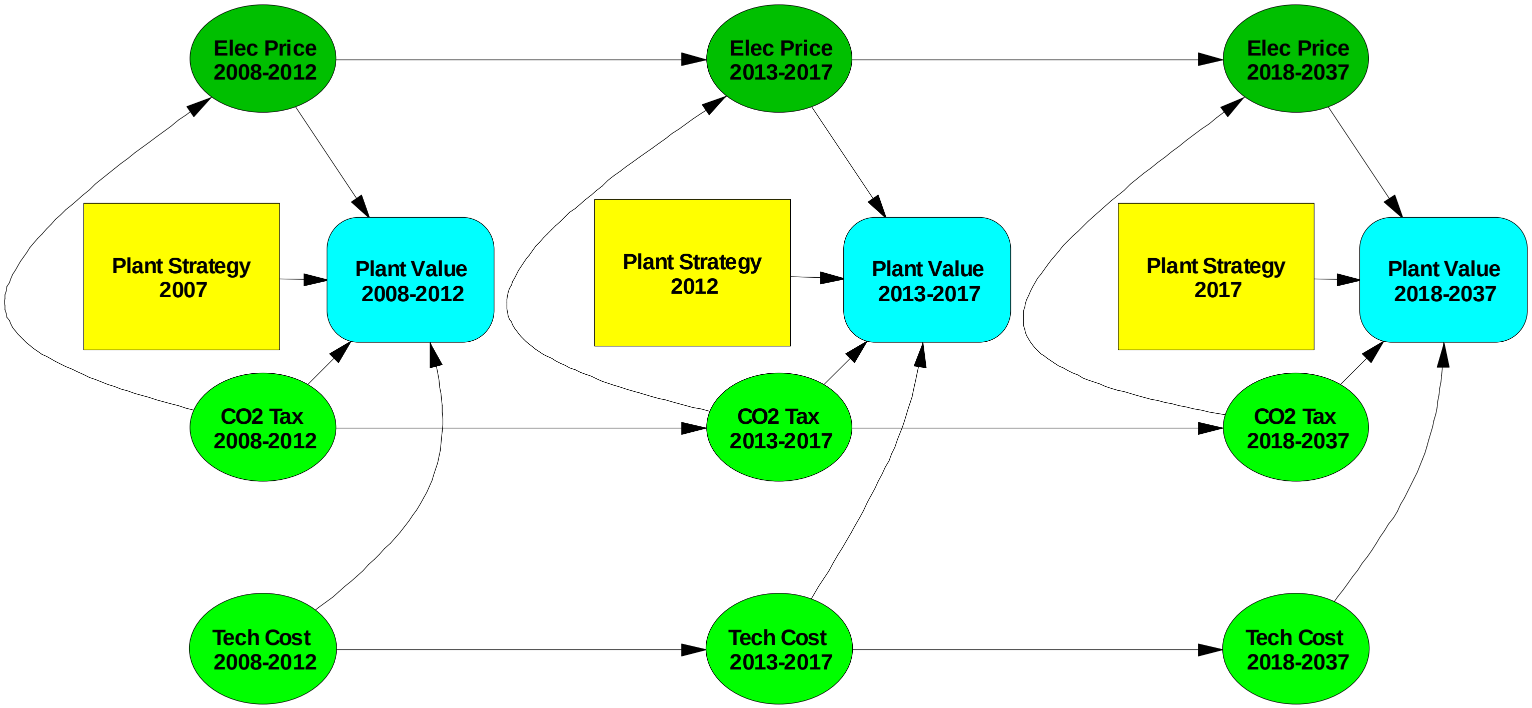
Option List

- **Low Carbon Repower (build IGCC now)**
- **Minimum Investment**
- **Staged Emissions Control Retrofit or Low Carbon Repower**
- **Mothball**

Decision Analysis Influence Diagram



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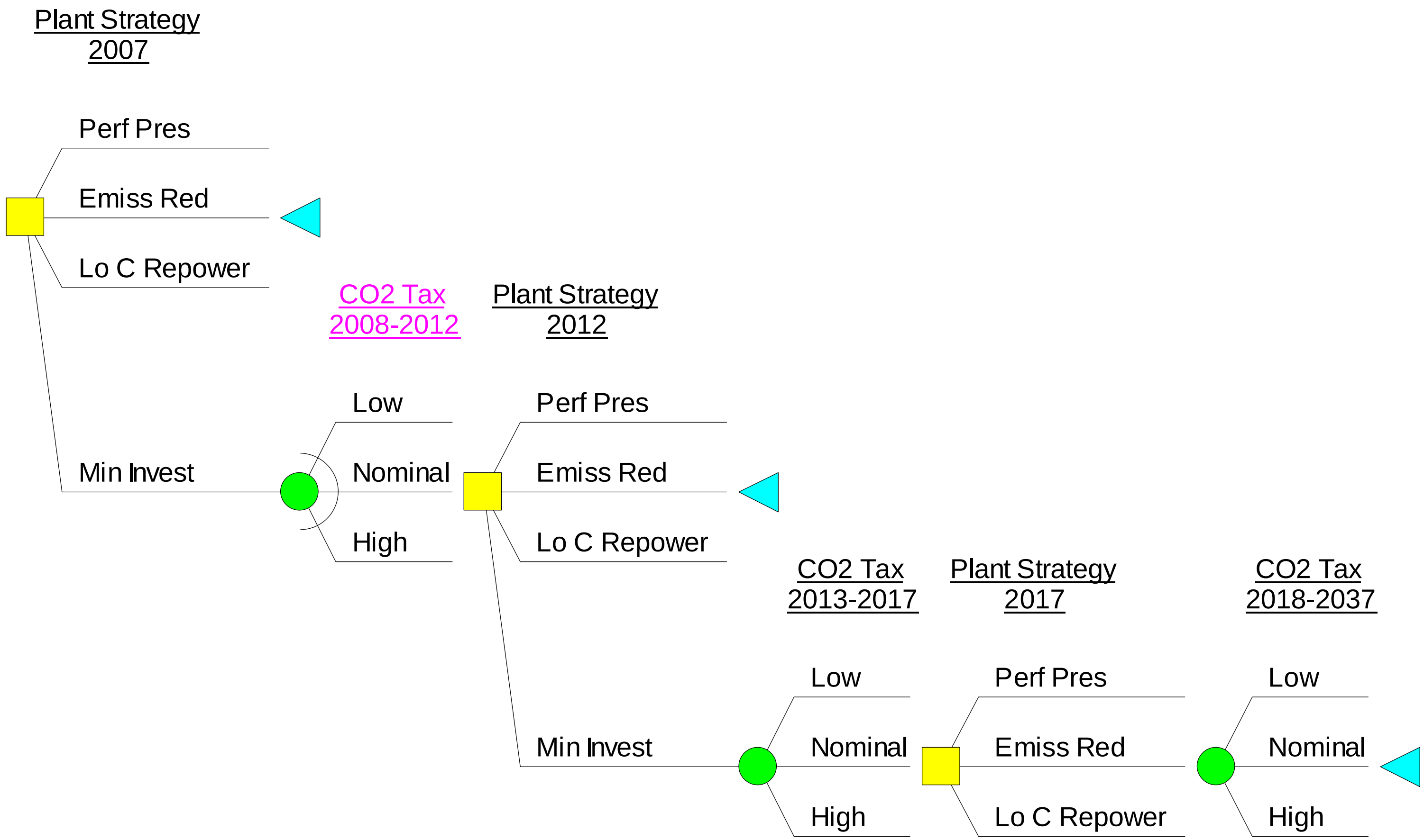
Decision Analysis Decision Tree



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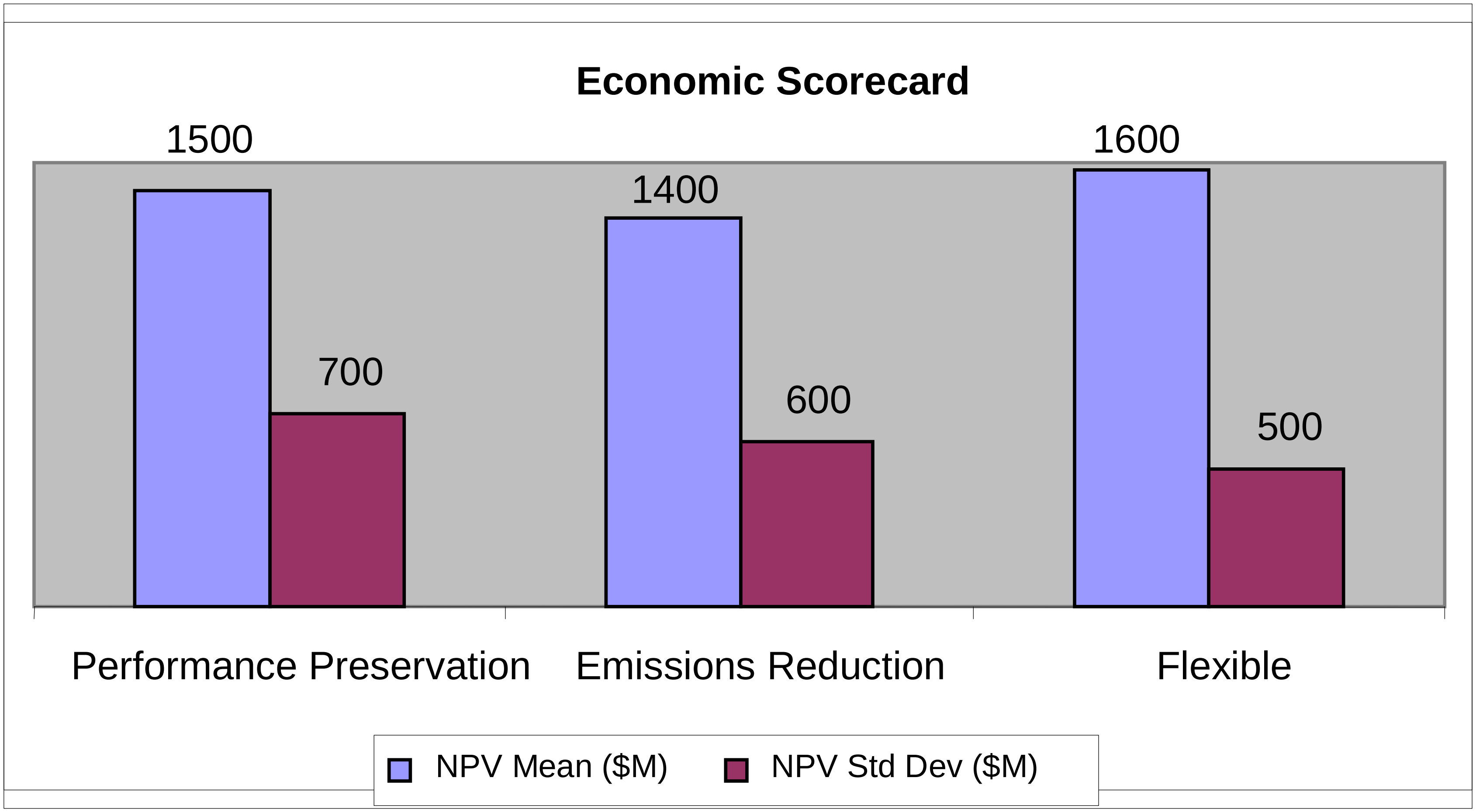
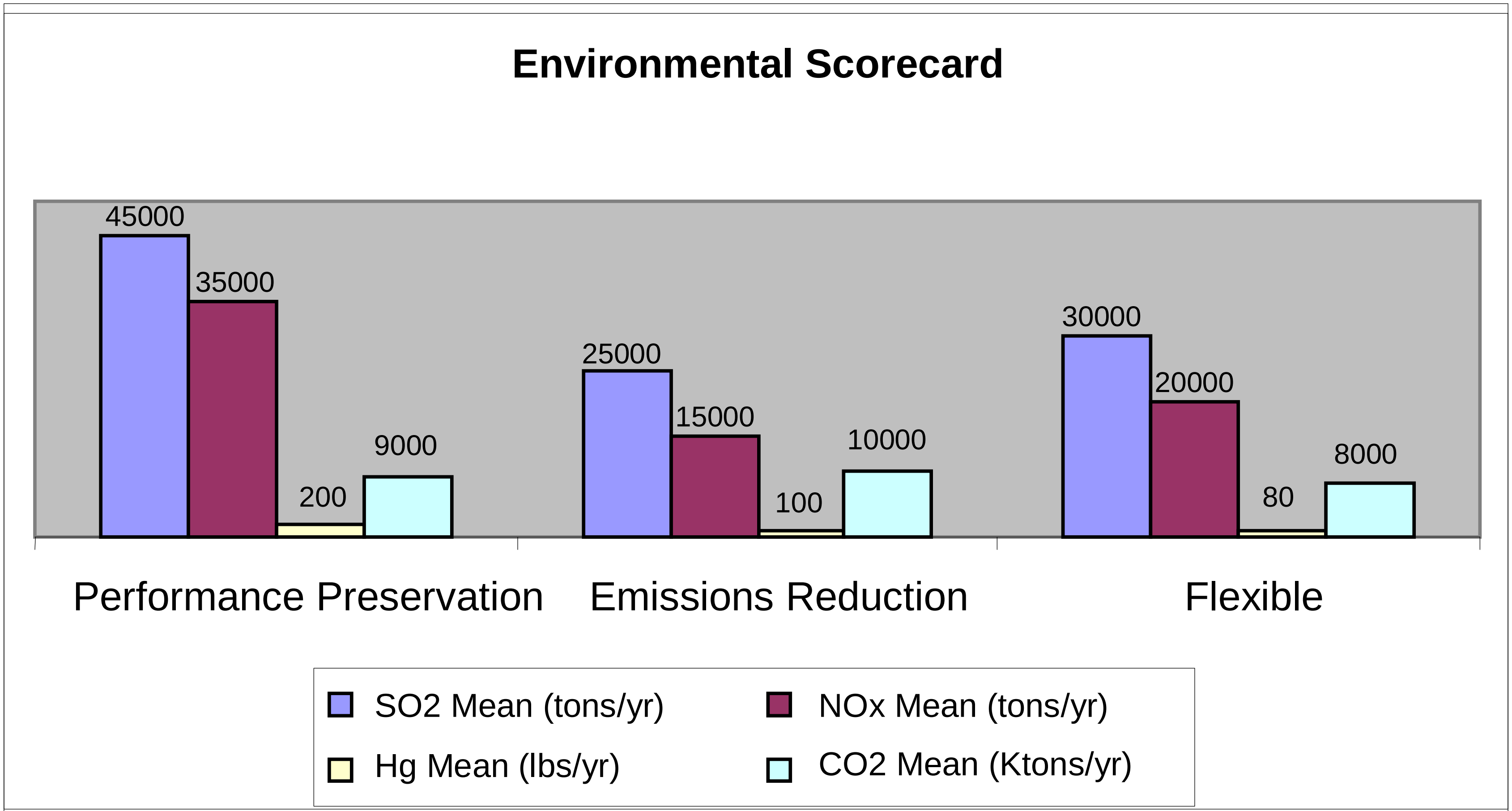
Results



Flexible Strategy has >$100M higher return and >$100M lower risk.

Results (continued)



Flexible Strategy saves >1M tons/year of CO_2, and is comparable to Emissions Reduction Strategy in SO_2, NO_x and Hg emissions.

Recommendations