Modeling Market-Based Generation Expansion Planning in Competitive Markets

FERC Technical Conference on Planning Models and Software

Washington, DC
June 9-10, 2010

Vladimir KORITAROV
Center for Energy, Environmental, and Economic Systems Analysis
Decision and Information Sciences Division (DIS)
ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, DIS-221
Argonne, IL 60439
Tel: 630-252-6711
Email: Koritarov@anl.gov

A New Class of Models Is Being Developed for Modeling Capacity Expansion in Competitive Electricity Markets

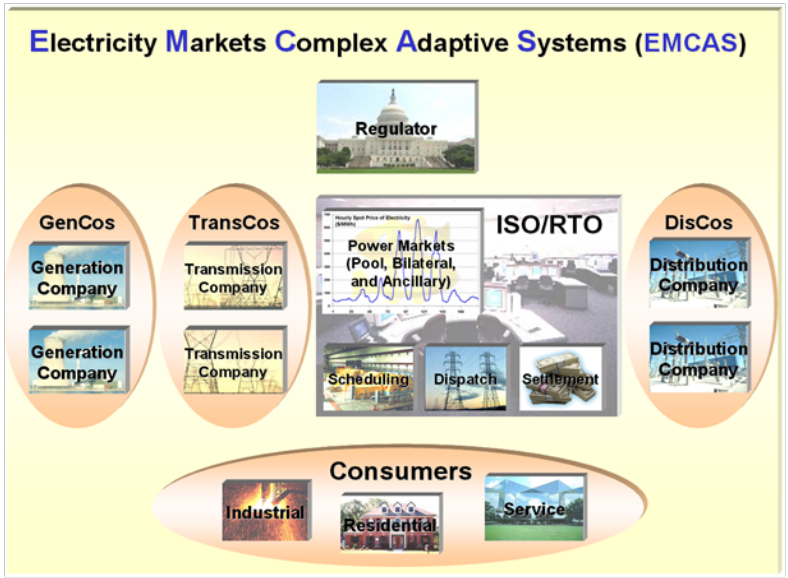
- Multiple competing market participants instead of single decision maker
- Each market participant (e.g., generation company) makes its own independent decisions
- Market participants have only limited information about the competition
- Markets are also open to new entrants
- Ideally an individual player cannot control the market
- Market participants face multiple uncertainties (demand forecast, fuel prices, electricity market prices, actions of competitors, new market entrants, etc.)
- Projection of future market prices of electricity is a major input for decision-making process

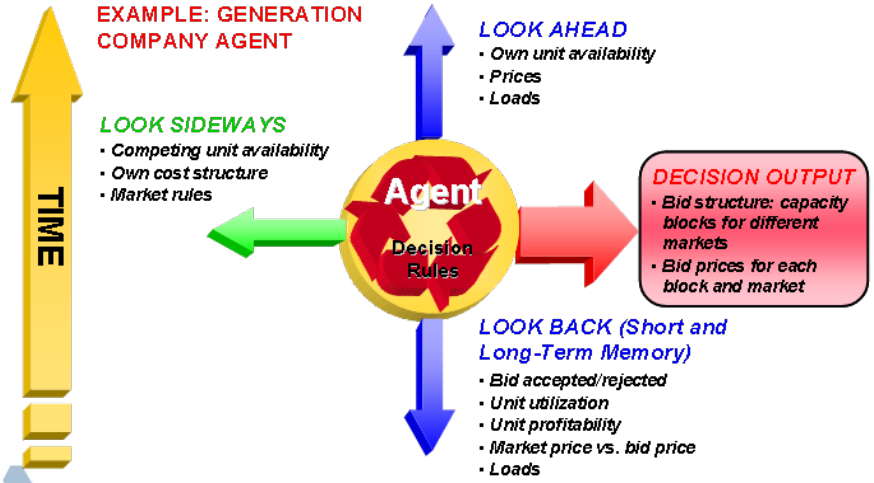
Objectives for Constructing New Capacity in Restructured Markets Differ from those under Vertically Integrated Systems

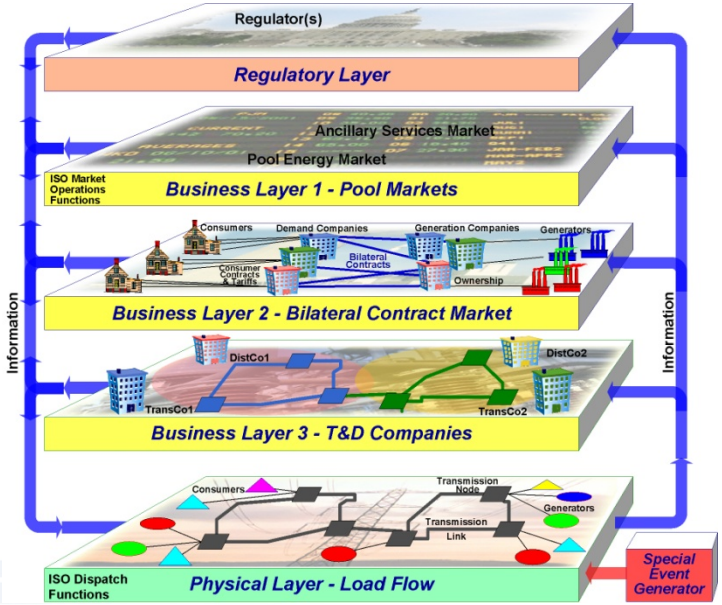
- Expansion investments are based on financial considerations, not lowest societal cost or energy security concerns
  - Profits are often the main driving force behind the decision making process
  - Financial decision criteria are typically based on measures such as rate of return on investment, payback period, and risk indicators
  - Other factors such as market share may influence the decision making process
- Capacity expansion by competitors and new market entrants are uncertain
- Emphasis is on the risk and risk management for corporate survival versus guaranteed rate of return under the traditional regulatory structure

Argonne's EMCAS Model Has Been Designed to Study Restructured Power Markets

- Uses an agent-based modeling approach to represent multiple market participants (agents) with decentralized decision-making under uncertainty
- Alternative company strategies can be simulated
- Incorporates learning and adaptation
- Allows testing of market rules
- Allows market monitoring for price manipulation

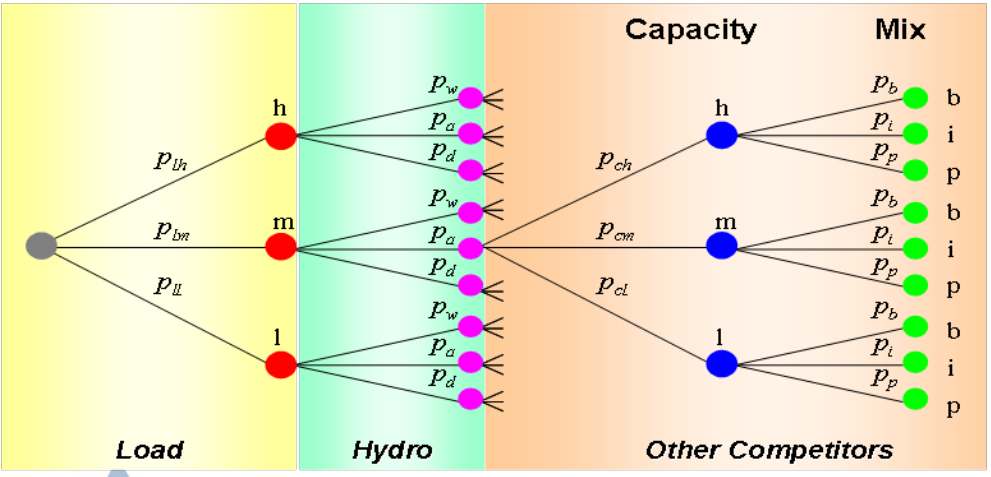


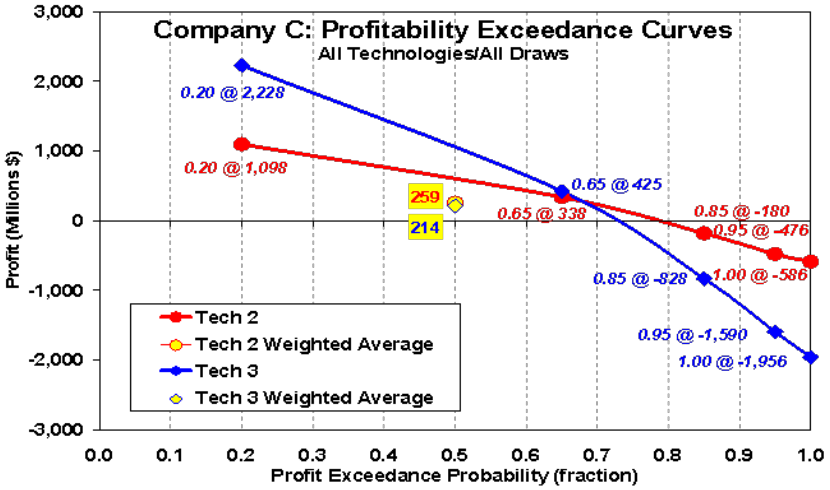




Agent-Based Modeling of Investment Decision Making in Competitive Electricity Markets

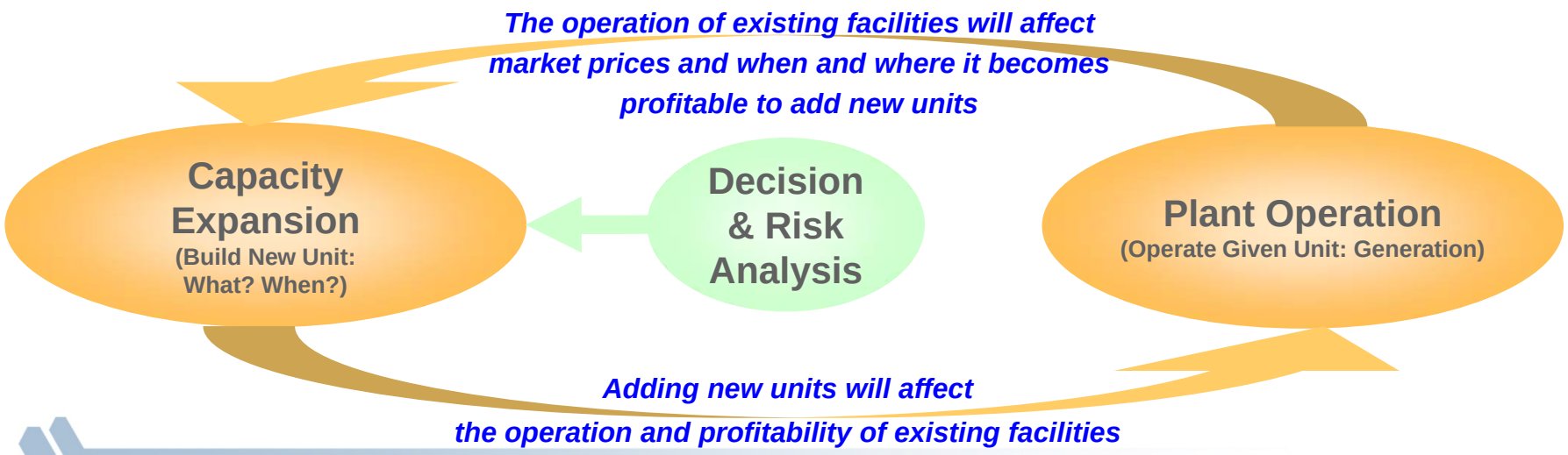
- Generation companies are represented as individual agents performing profit-based company-level investment planning
- Generation companies develop expectations and make independent investment decisions each year under multiple uncertainties
- Uncertainties are often modeled as scenarios with associated probabilities of occurrence
- Argonne's EMCAS model uses a scenario tree and calculates profitability curves for various investment options



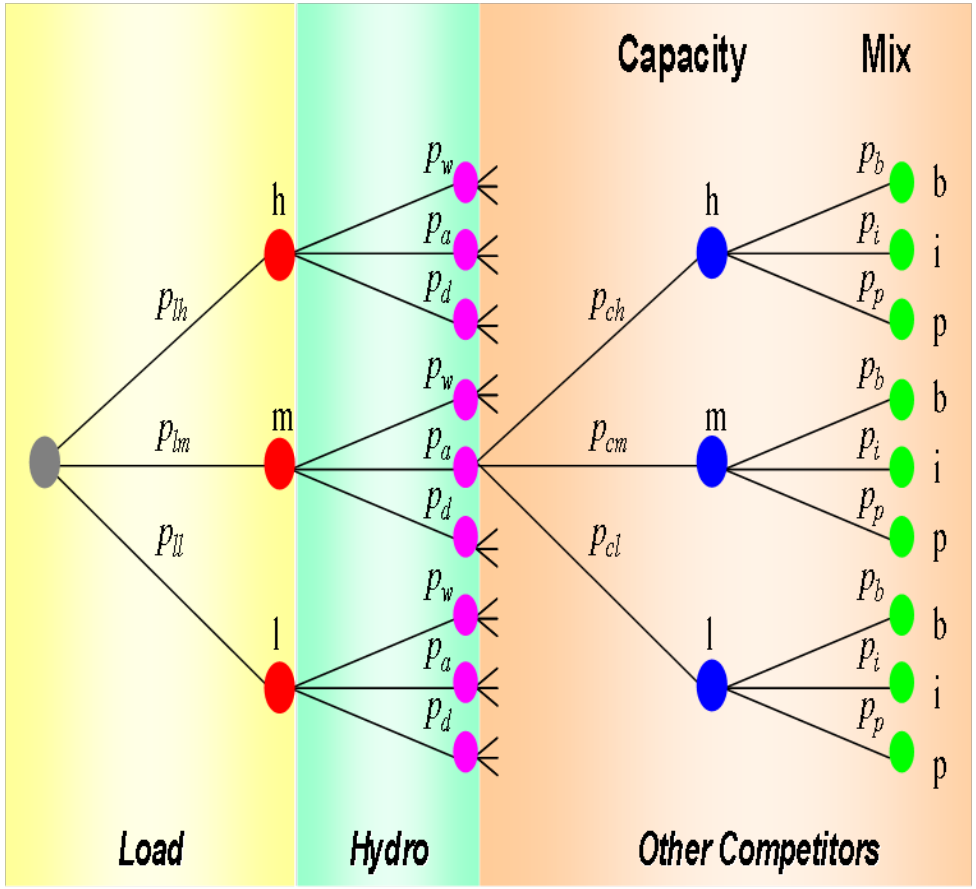


EMCAS Profit-Based Expansion Model Integrates Three Key Components

- Generation capacity investment (expansion) decisions
  - When, what, how much (*and where*) should I invest?
- Operational decisions
  - How much will my unit be dispatched under various futures?
  - How much profit will it make under all reasonable outlooks?
- Decision and risk analysis
  - How much risk do I want to take?
  - How do I trade off potentially conflicting objectives?



In EMCAS Uncertainties are Represented as Scenarios



Multiple Possible Futures

GenCo agents compute expected profits under all scenarios to estimate profitability of an investment project

Simulation Procedure Timeline: Agents Develop Expectations and Make Investment Decisions each Year

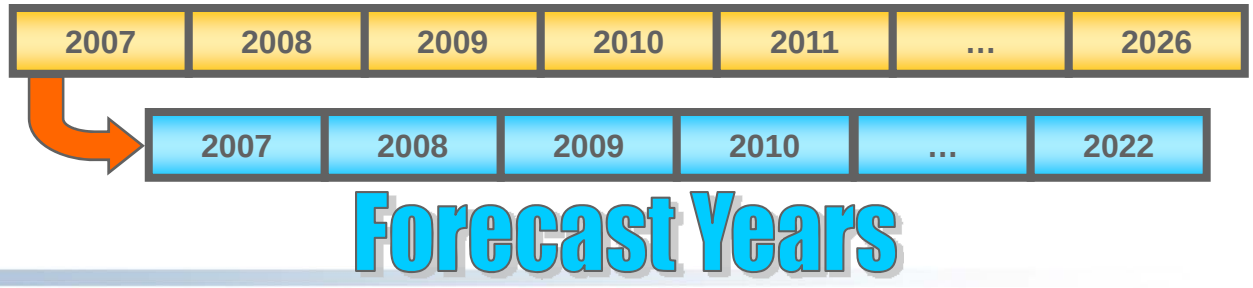
- EMCAS simulates any user-specified number of ***Decision Years***. This is the study period or planning horizon. At the beginning of each decision year, GenCo agents decide if, what, and how much to build. If GenCo decides to build a new unit(s), construction will start on January 1 in that decision year.

- Starting in each decision year, a number of ***Forecast Years*** are simulated; each GenCo agent evaluates candidate technologies over all Forecast Years. The number of forecast years is equal to the largest total of construction period plus payback period for a candidate unit.

GT	
Construction:	2 years
Payback Period:	8 years
Total:	12 years

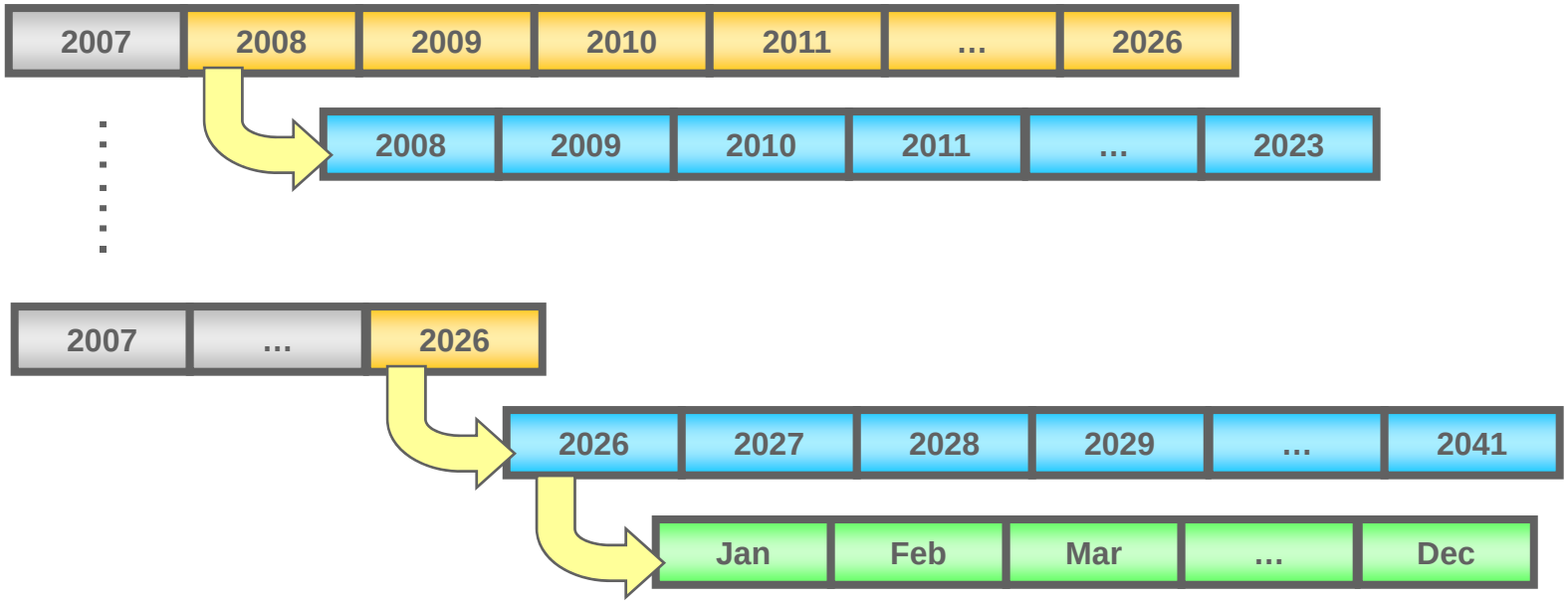
NGCC	
Construction:	3 years
Payback Period:	13 years
Total:	16 years

16 forecast years needed



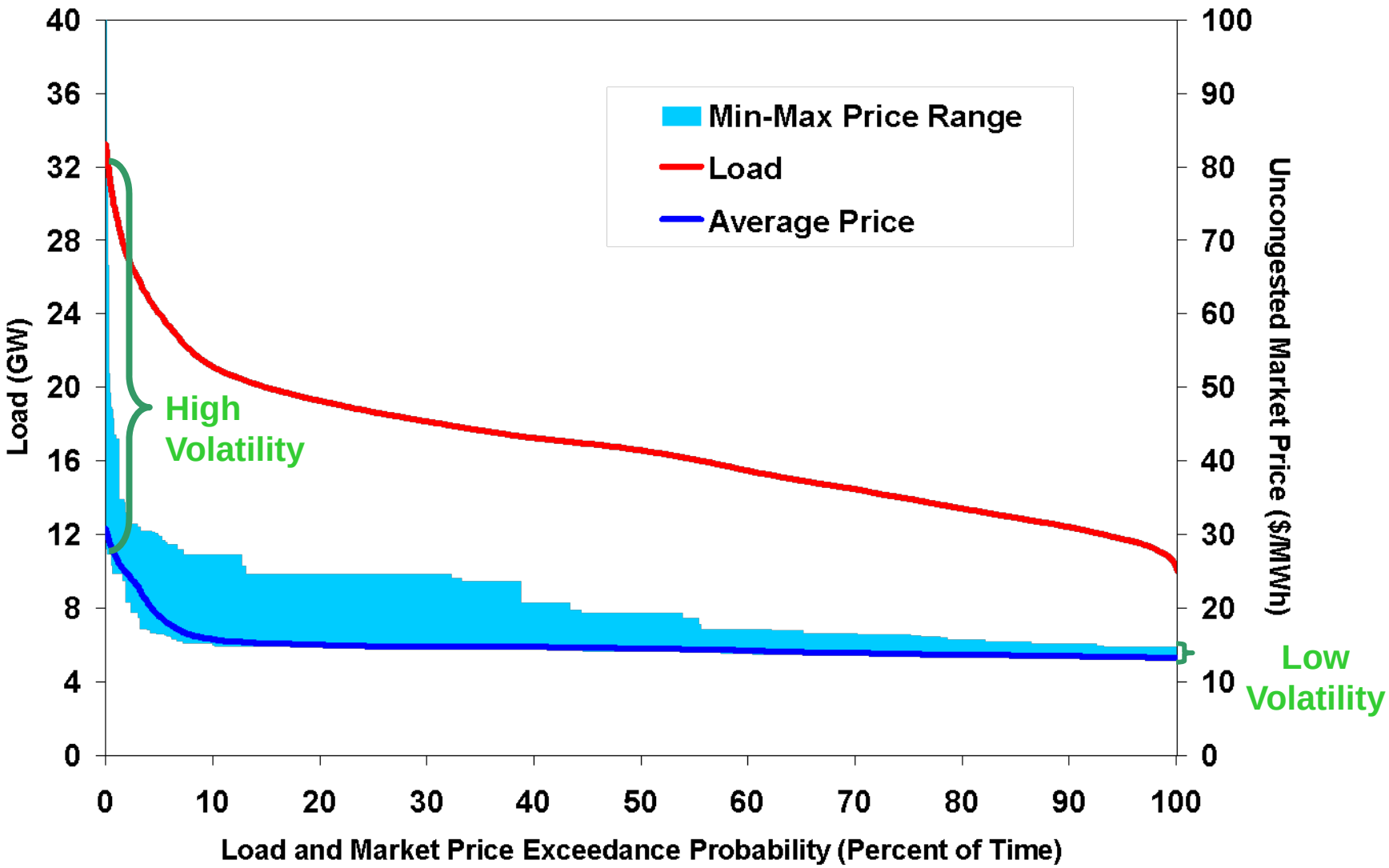
Simulation Procedure - Timeline

- After the build decision have been made by all GenCos for the current year, the process starts over again from the next decision year.

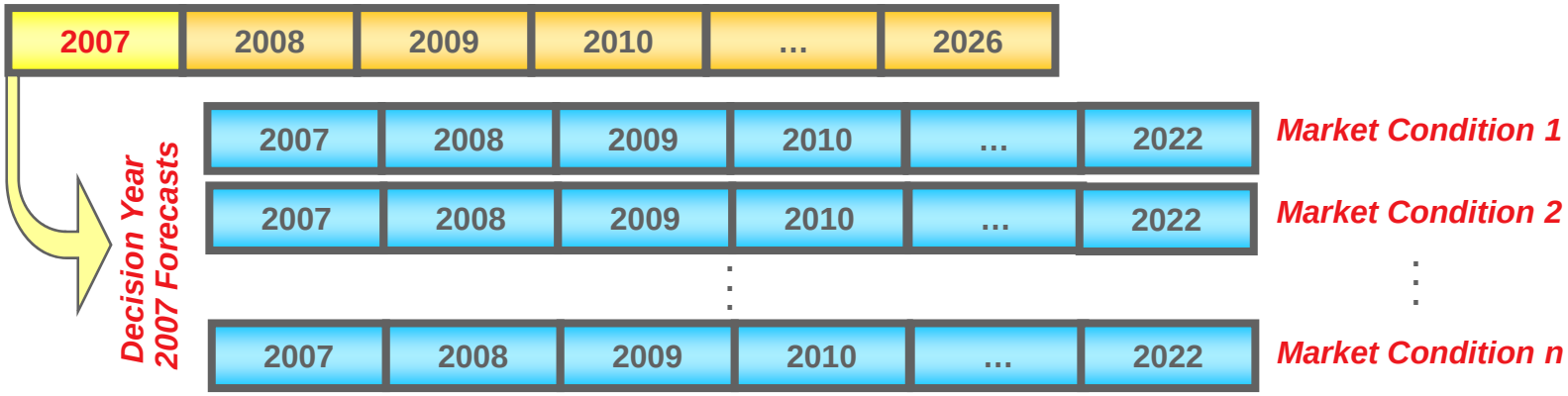


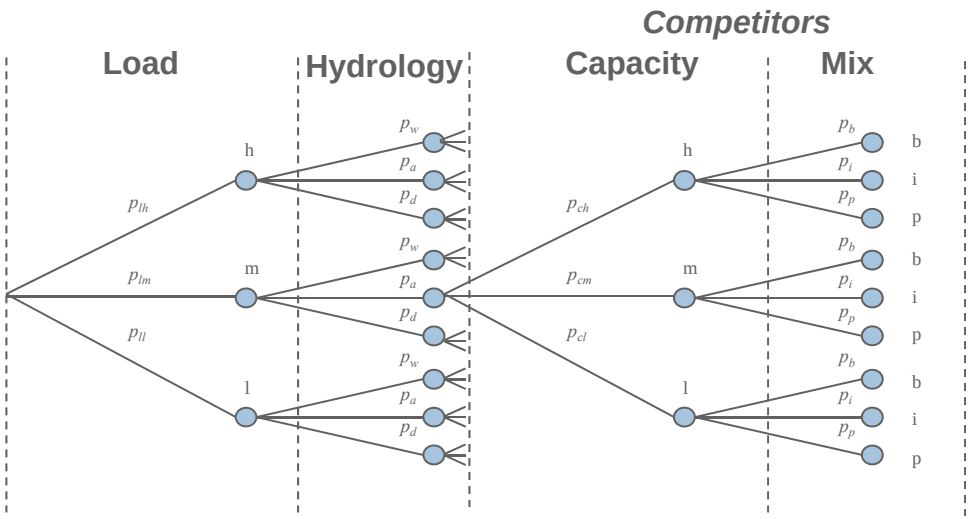
- For each Forecast Year, a probabilistic monthly dispatch simulation is performed to provide a set of *Monthly Price Exceedance Curves*
- These curves are used by the GenCos to determine the expected dispatch of candidate units.

Load Exceedance Curves Are Used to Depict Prices and Price Volatility over the Entire Range of Loads



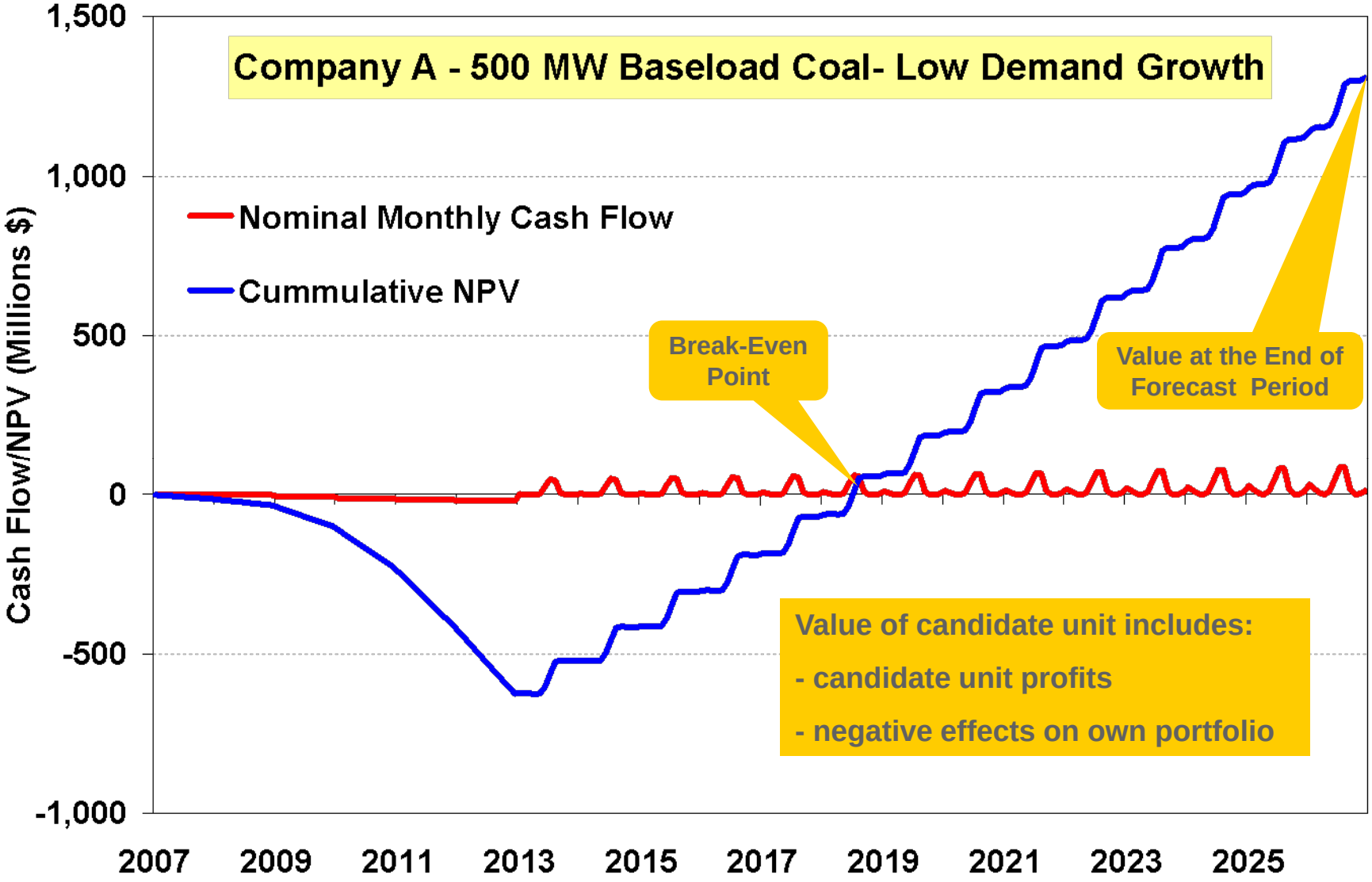
In each Decision Year, a GenCo may Opt to Start the Construction of One or More Technologies Based on Anticipated Market Conditions



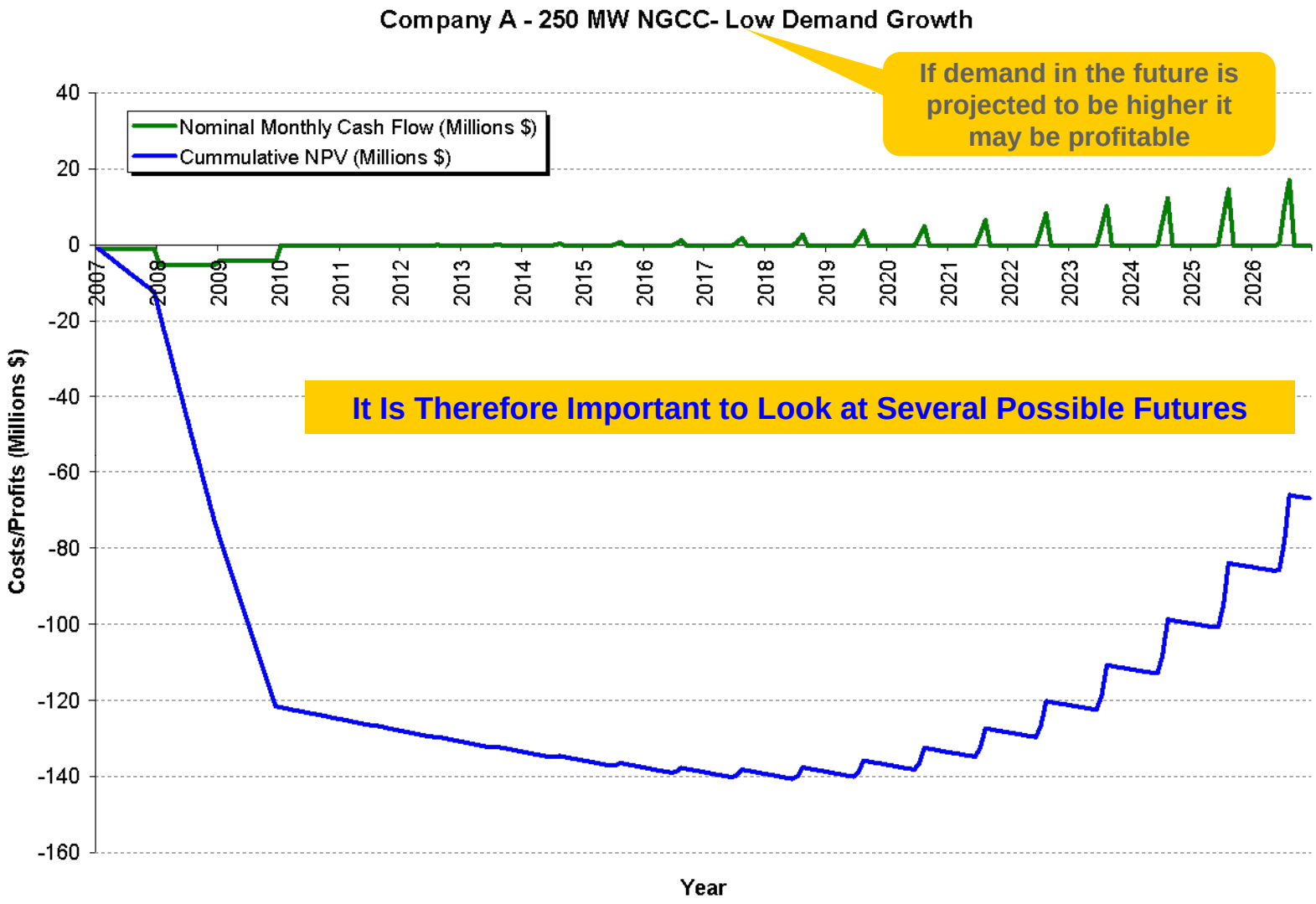


Each Market Condition Has a Different Financial Consequence on the GenCo Build Decision

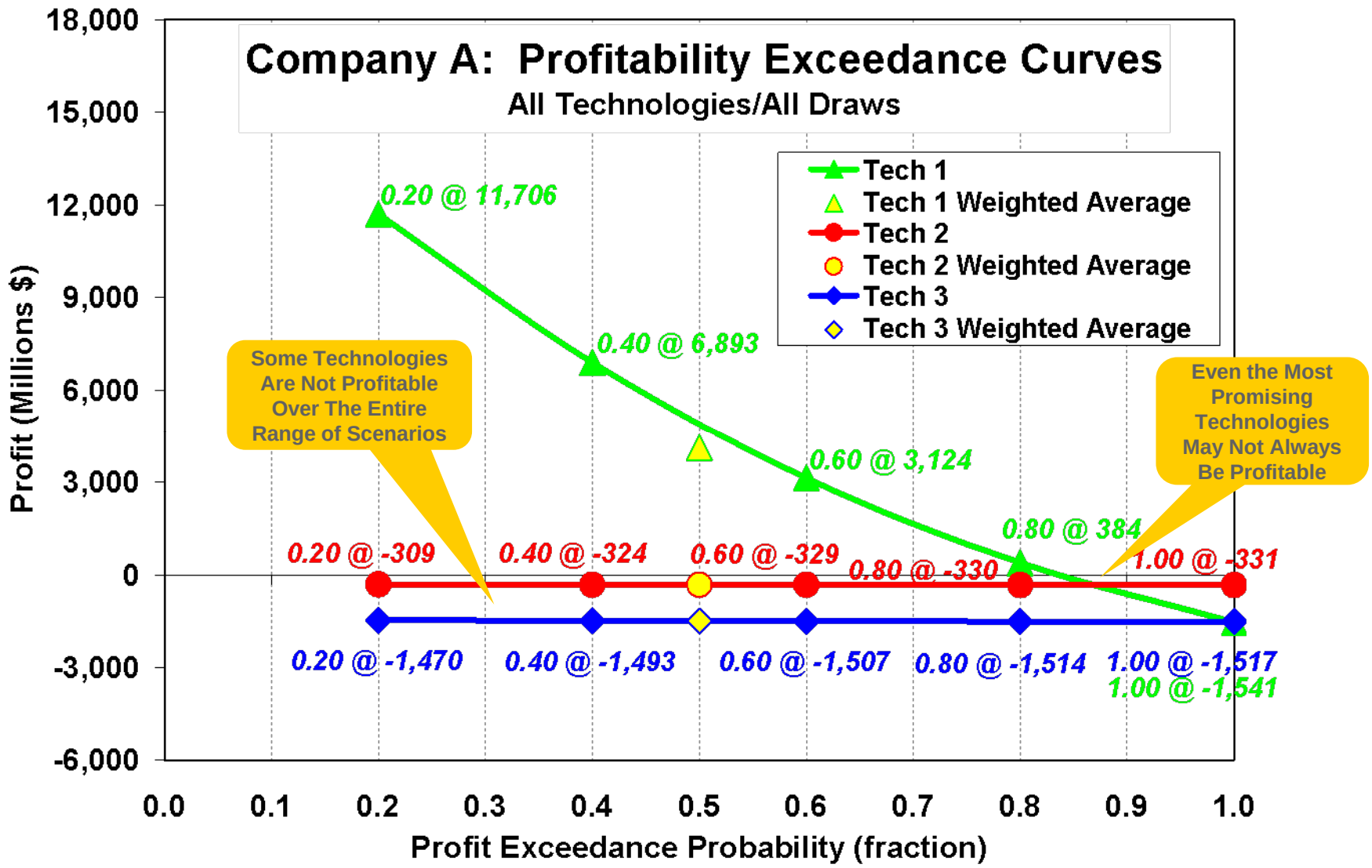
GenCos Evaluate Candidate Units: One Scenario



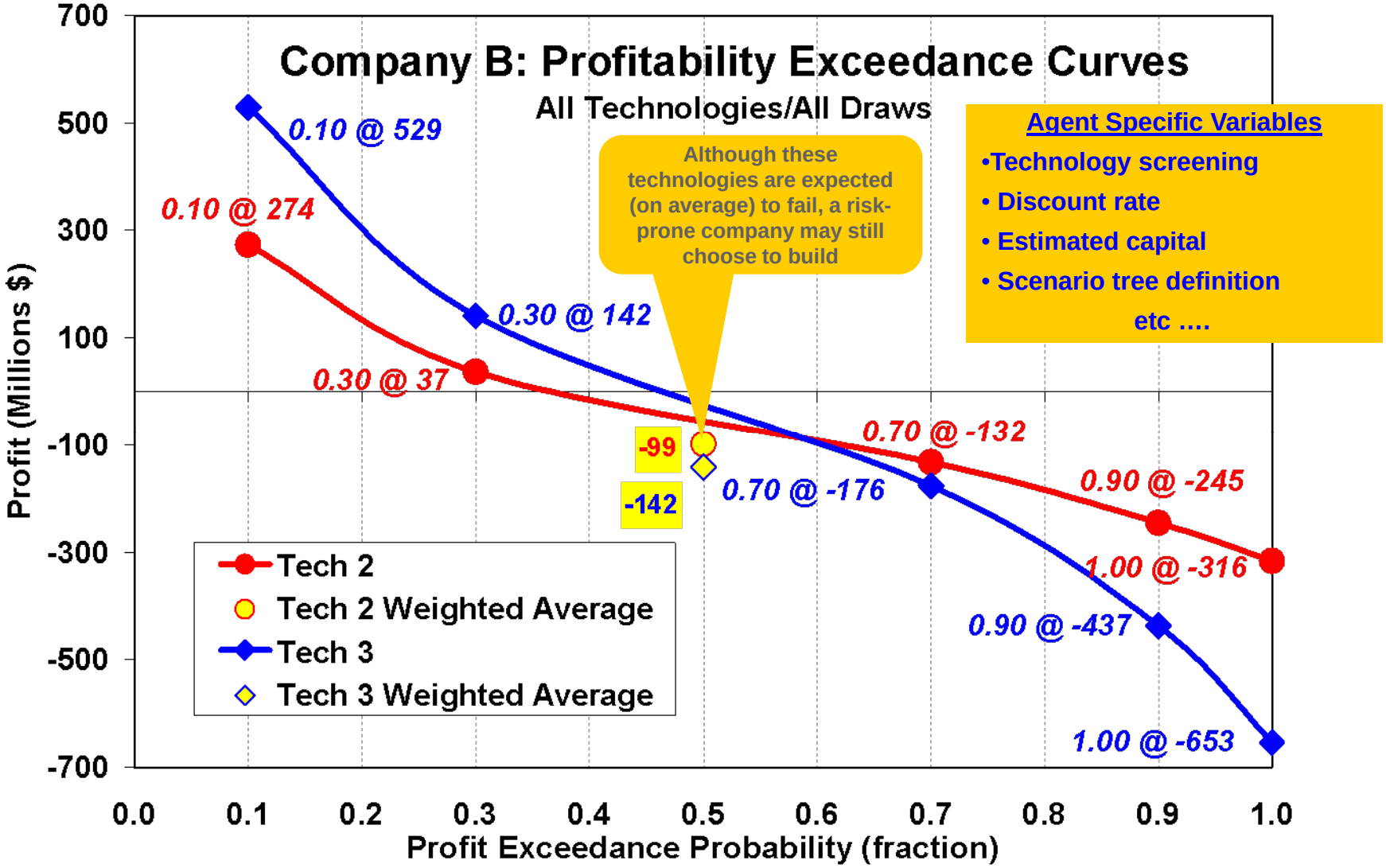
Under Some Scenarios a New Unit Will Not Become Profitable



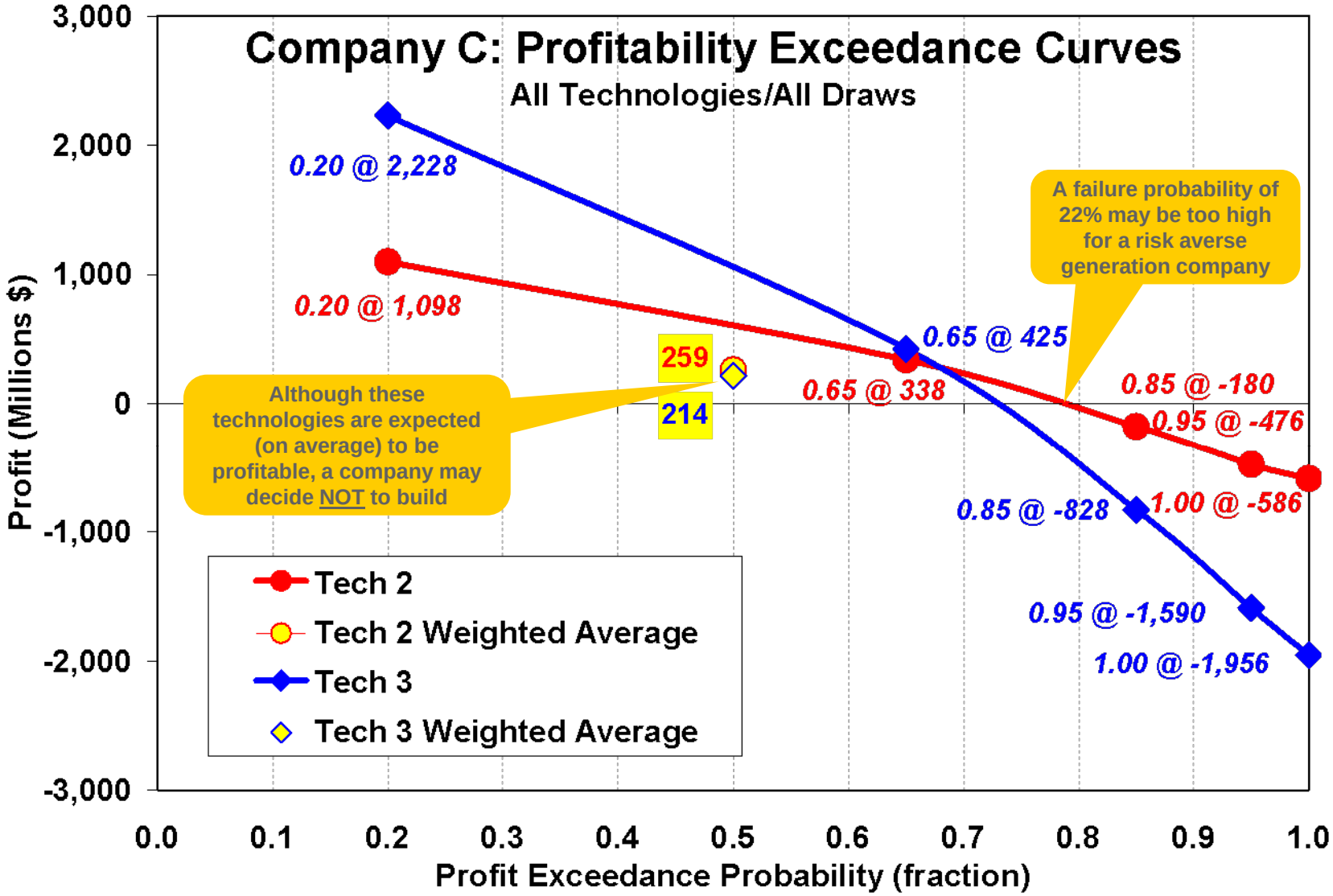
EMCAS Expansion Module Evaluates Technologies Under All Possible Futures Defined in the Scenario Tree to Compute Profit Probability



GenCos Evaluate Candidate Units: Company B



GenCos Evaluate Candidate Units: Company C



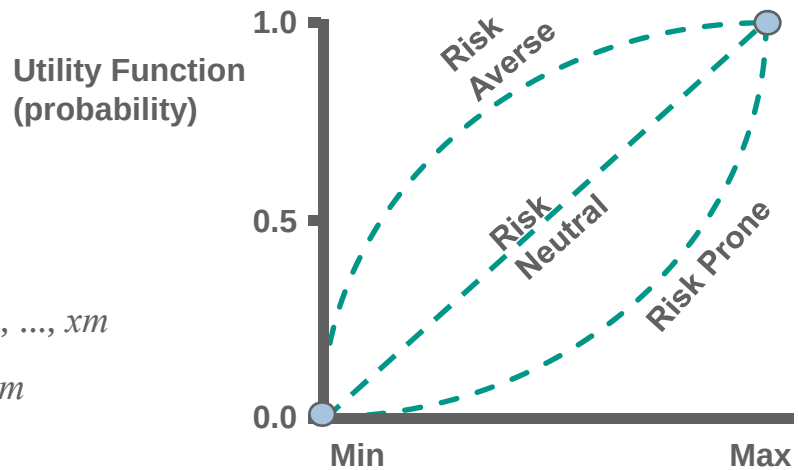
Agents Choose the Alternative with the Highest Expected Utility Based on their Risk Preference and Multi-Attribute Utility Theory

$$u(\mathbf{x}) = \sum_{i=1}^{m} k_i \cdot u_i(x_i)$$

where $u(x)$ total utility for attribute set $x = x1, x2, \ldots, xm$

$u_i(x_i)$ utility for single attribute, $i = 1,2, \ldots, m$

k_i trade-off weight, attribute i



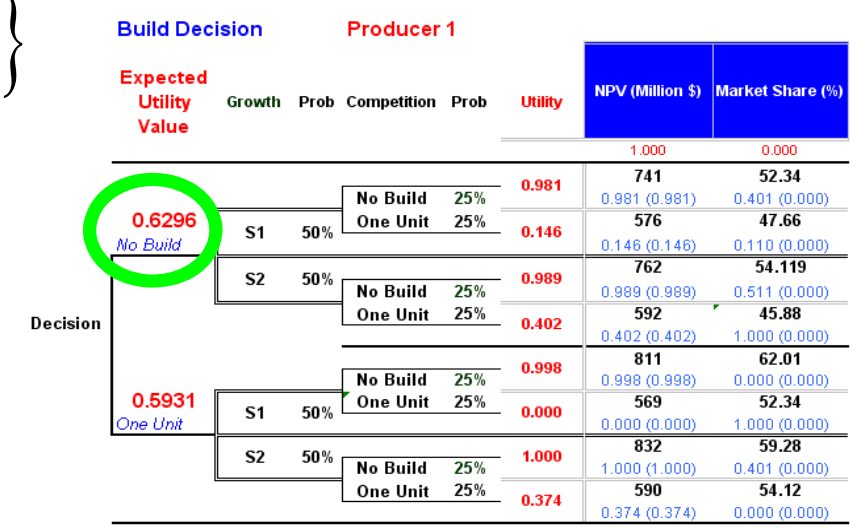
$$u_i(x_i) = 1/(1 - e^{\beta_i}) \cdot \left\{ 1 - e^{\beta_i (x_i - \underline{x}_i)/(\overline{x}_i - \underline{x}_i)} \right\}$$

where $u_i(x_i)$ utility for single attribute, $i = 1,2, \ldots, m$

β_i risk parameter, attribute i

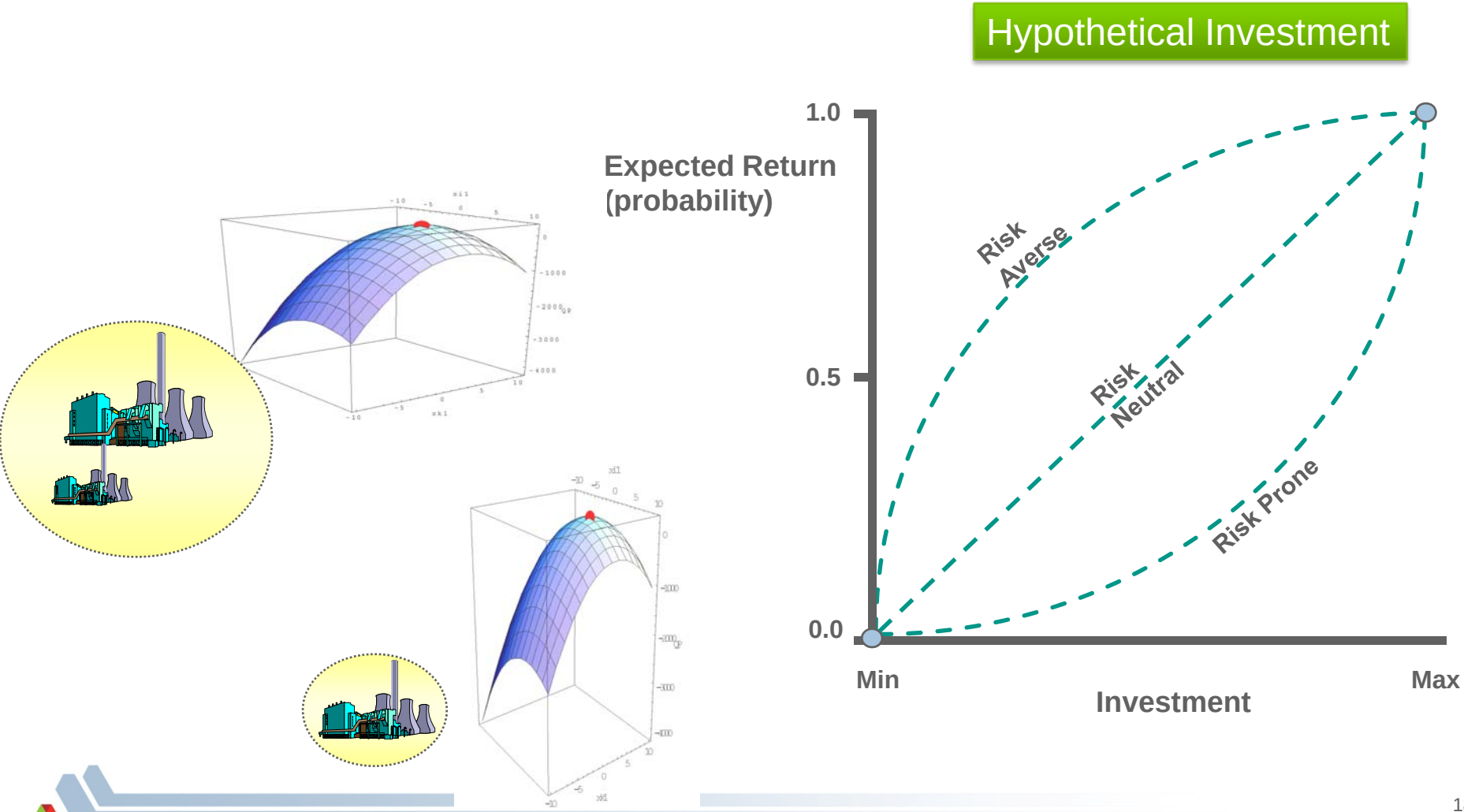
$\overline{x}_i$ upper limit, attribute i

$\underline{x}_i$ lower limit, attribute i



Corporate Utility and Risk Preferences

- Decision maker's preference (Utility Function)
- Different GenCos have different risk preferences

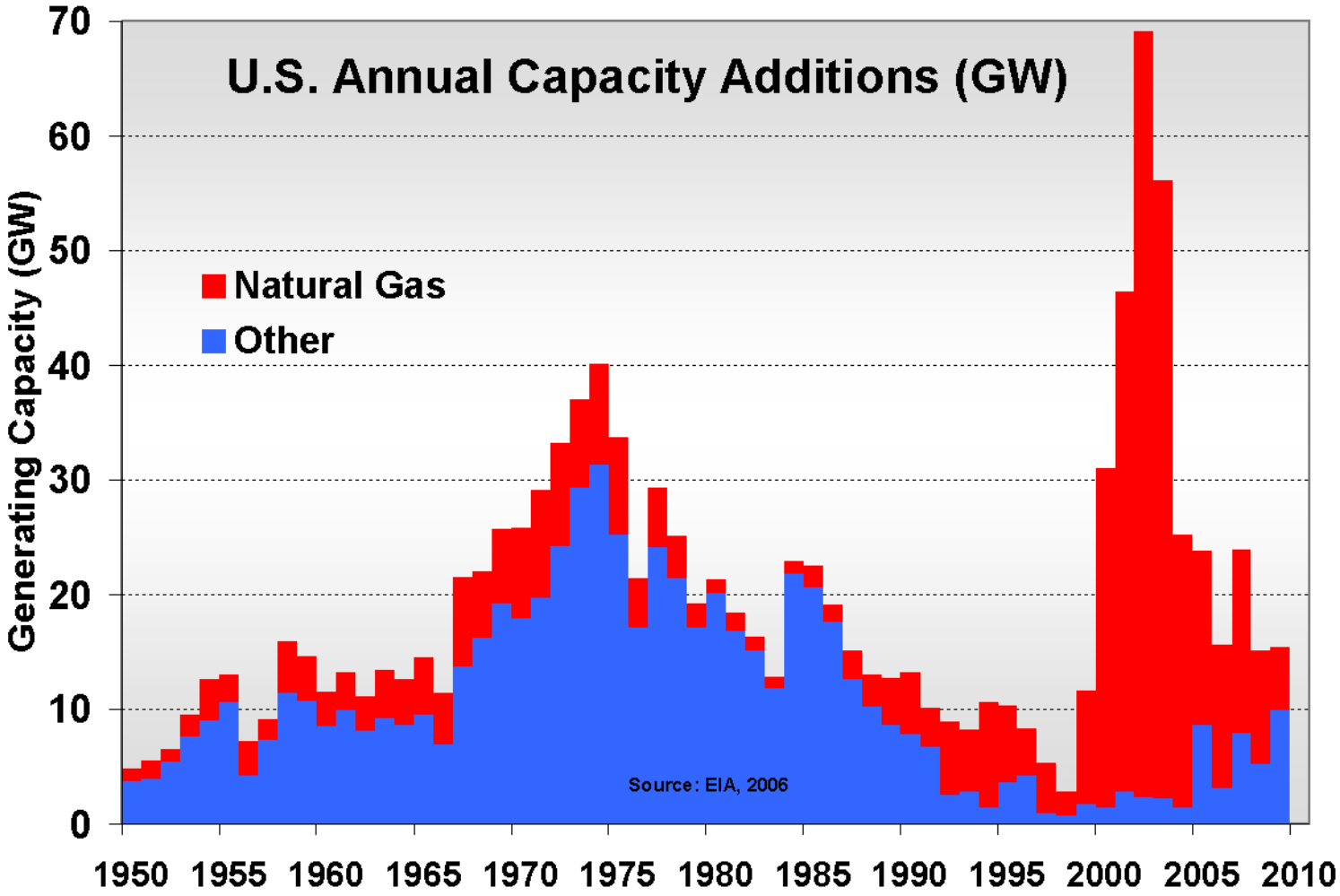


The Final Capacity Decision Taken by GenCo Is the One that Yields the Highest Corporate Utility

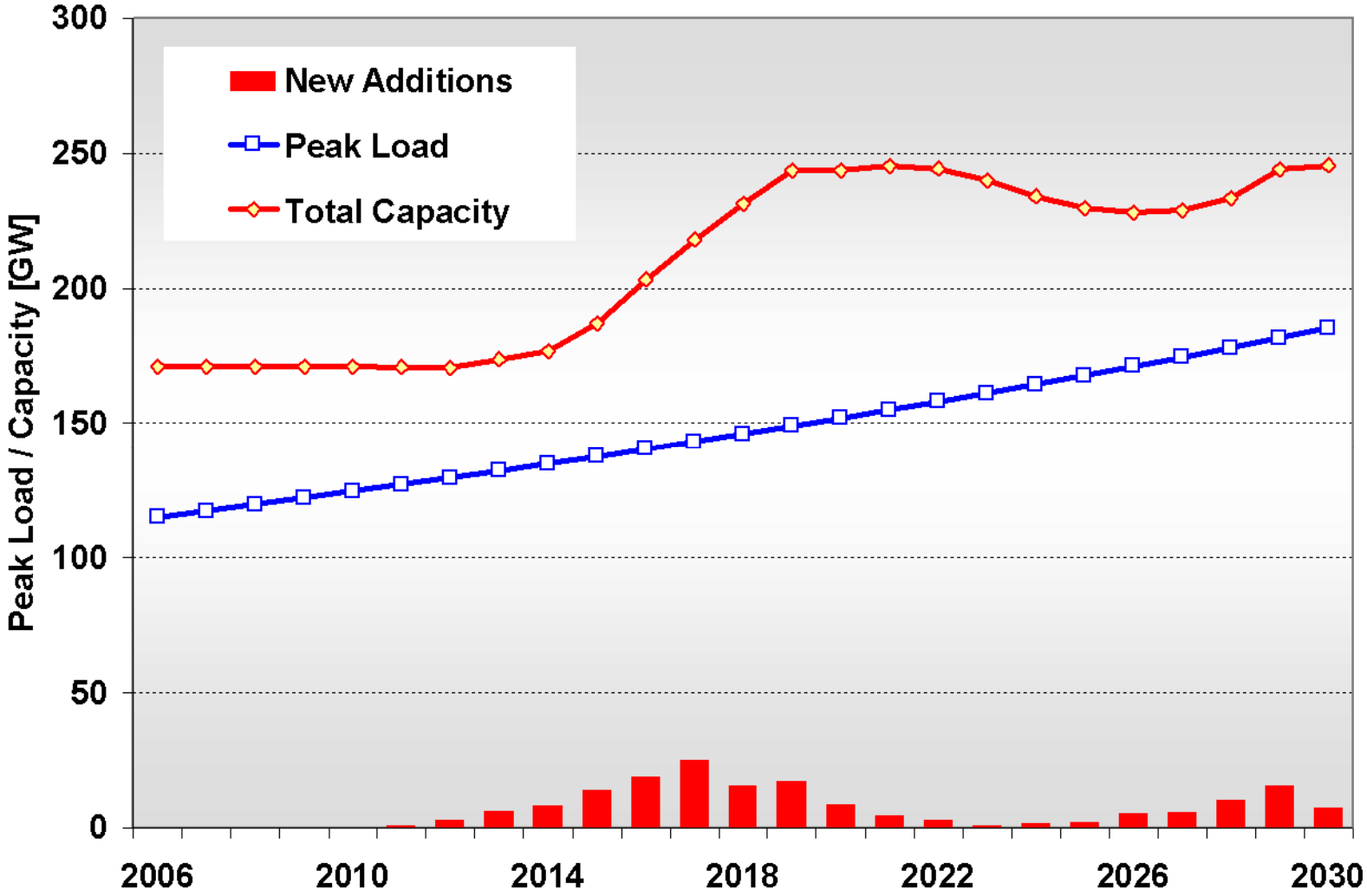
Build Decision — **Producer 1**

Decision	Expected Utility Value	Growth	Prob	Competition	Prob	Utility	NPV (Million $)	Market Share (%)
							1.000	0.000
	0.6296 *No Build*	S1	50%	No Build	25%	0.981	741 0.981 (0.981)	52.34 0.401 (0.000)
				One Unit	25%	0.146	576 0.146 (0.146)	47.66 0.110 (0.000)
		S2	50%	No Build	25%	0.989	762 0.989 (0.989)	54.119 0.511 (0.000)
				One Unit	25%	0.402	592 0.402 (0.402)	45.88 1.000 (0.000)
	0.5931 *One Unit*	S1	50%	No Build	25%	0.998	811 0.998 (0.998)	62.01 0.000 (0.000)
				One Unit	25%	0.000	569 0.000 (0.000)	52.34 1.000 (0.000)
		S2	50%	No Build	25%	1.000	832 1.000 (1.000)	59.28 0.401 (0.000)
				One Unit	25%	0.374	590 0.374 (0.374)	54.12 0.000 (0.000)

Capacity Expansion in Deregulated Systems often Follows a Cyclical Pattern



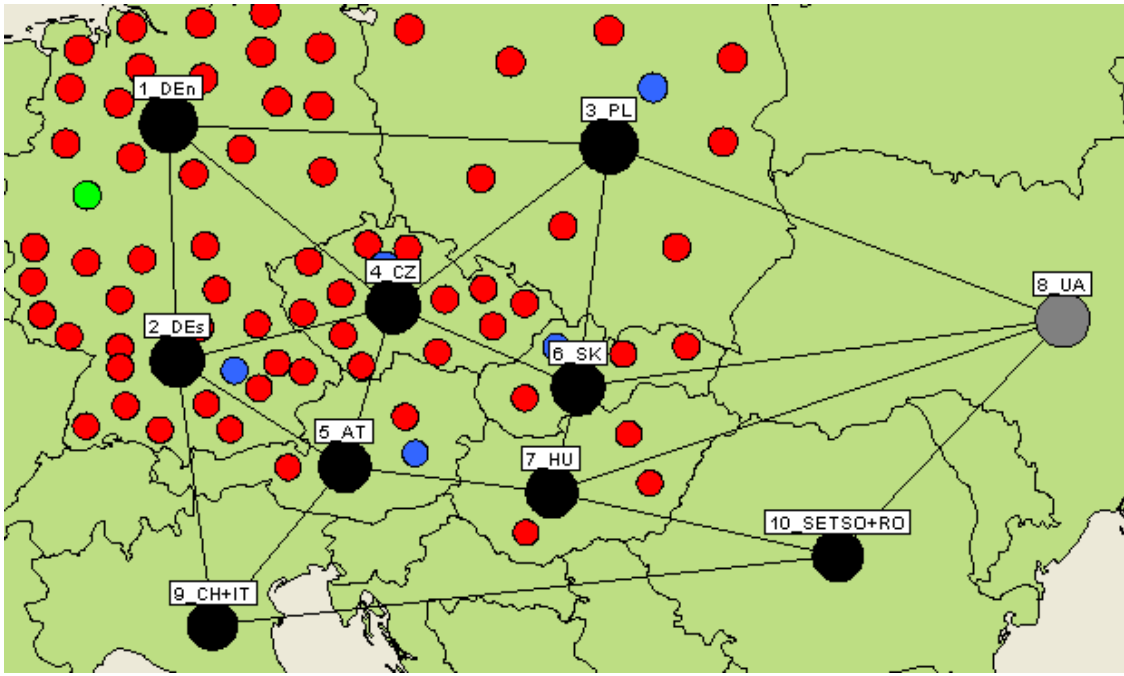
The ABMS Expansion Results Can Reproduce such Behavior



Case Study using the Central European Demo Case

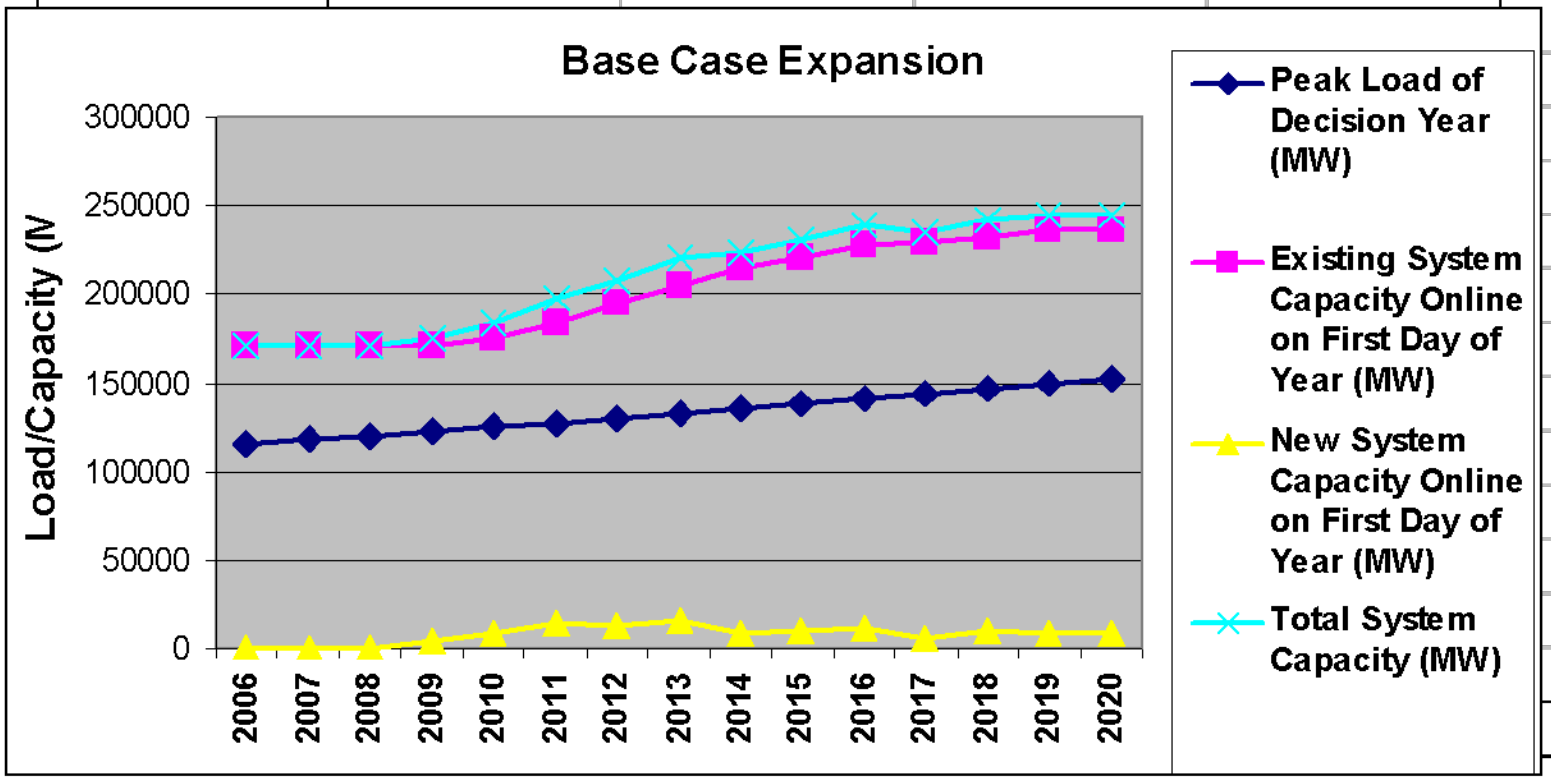
- Capacity expansion cases:
  1. Base capacity expansion case
  2. Expansion case with modified GenCo parameters
  3. Expansion case with modified parameters for nuclear candidate (sensitivity analysis)

- Setup of Central European Case:
  - 10 zones
  - 13 GenCos
  - 68 thermal power plants, 5 hydro power plants, 1 wind plant
  - Generating capacity mix:
    - Nuclear
    - Base load coal
    - Natural gas (CC)
    - Natural gas (GT)
    - Hydro power plants
    - Wind plants
  - Loads in 9 nodes, generation in 7 nodes, 1 node without generation or load



Case 1: Base Case Capacity Expansion

Online Year	Baseload Coal	Gas-Turbine	NGCC	Nuclear 1000	Grand Total
2009		16			16
2010		30	4		34
2011		42	9		51
2012		34	12		46
2013	3	30	15		48
					13
					13
					15
					7
					10
					8
					9
					5
					4
					7
					10
					8
					8
					312

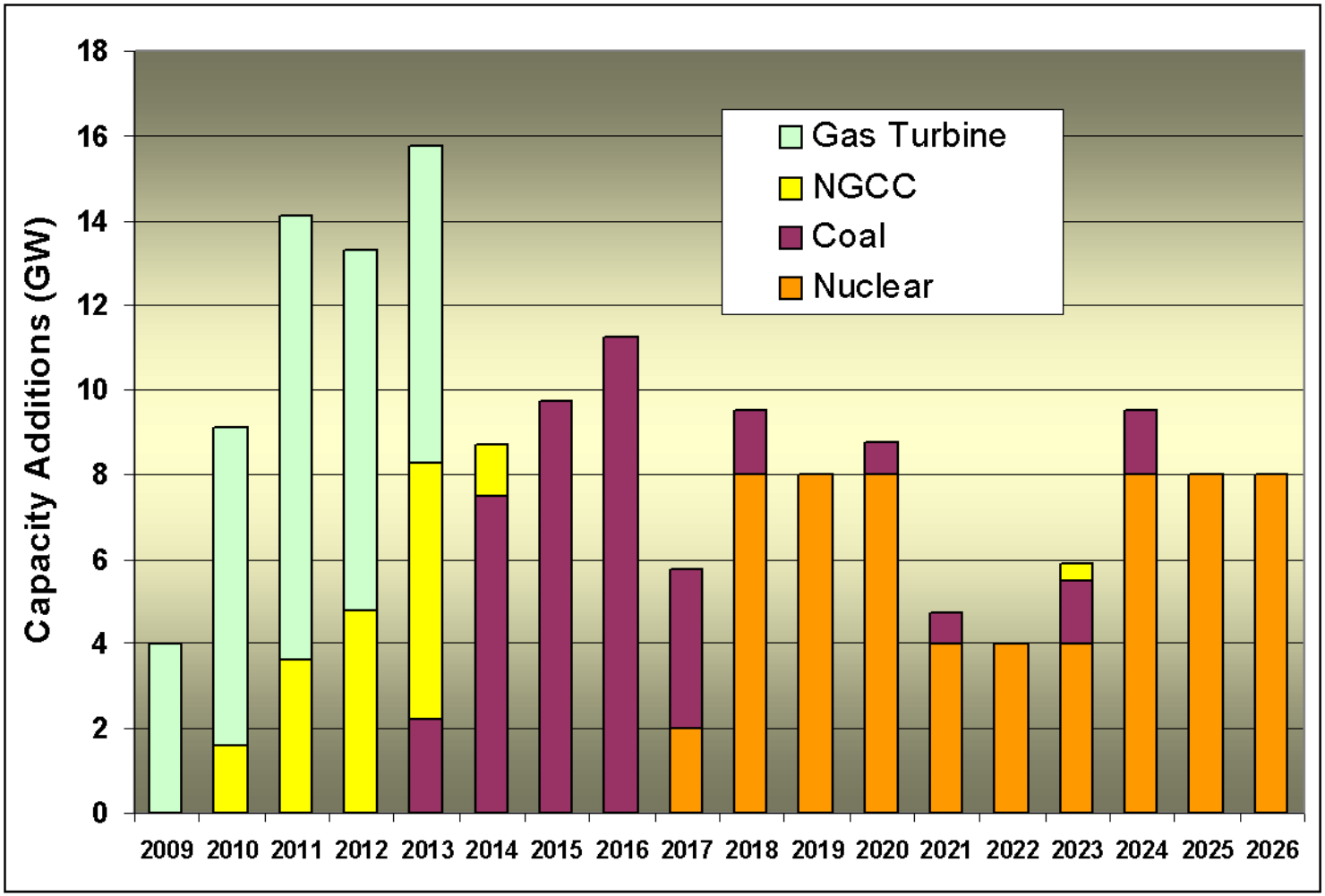


Case 1: Base Case Capacity Expansion

Online Year	Baseload Coal	Gas-Turbine	NGCC	Nuclear 1000	Grand Total
2009		4000			4000
2010		7500	1600		9100
2011		10500	3600		14100
2012		8500	4800		13300
2013	2250	7500	6000		15750
2014	7500		1200		8700
2015	9750				9750
2016	11250				11250
2017	3750			2000	5750
2018	1500			8000	9500
2019				8000	8000
2020	750			8000	8750
2021	750			4000	4750
2022				4000	4000
2023	1500		400	4000	5900
2024	1500			8000	9500
2025				8000	8000
2026				8000	8000
Grand Total	40500	38000	17600	62000	158100

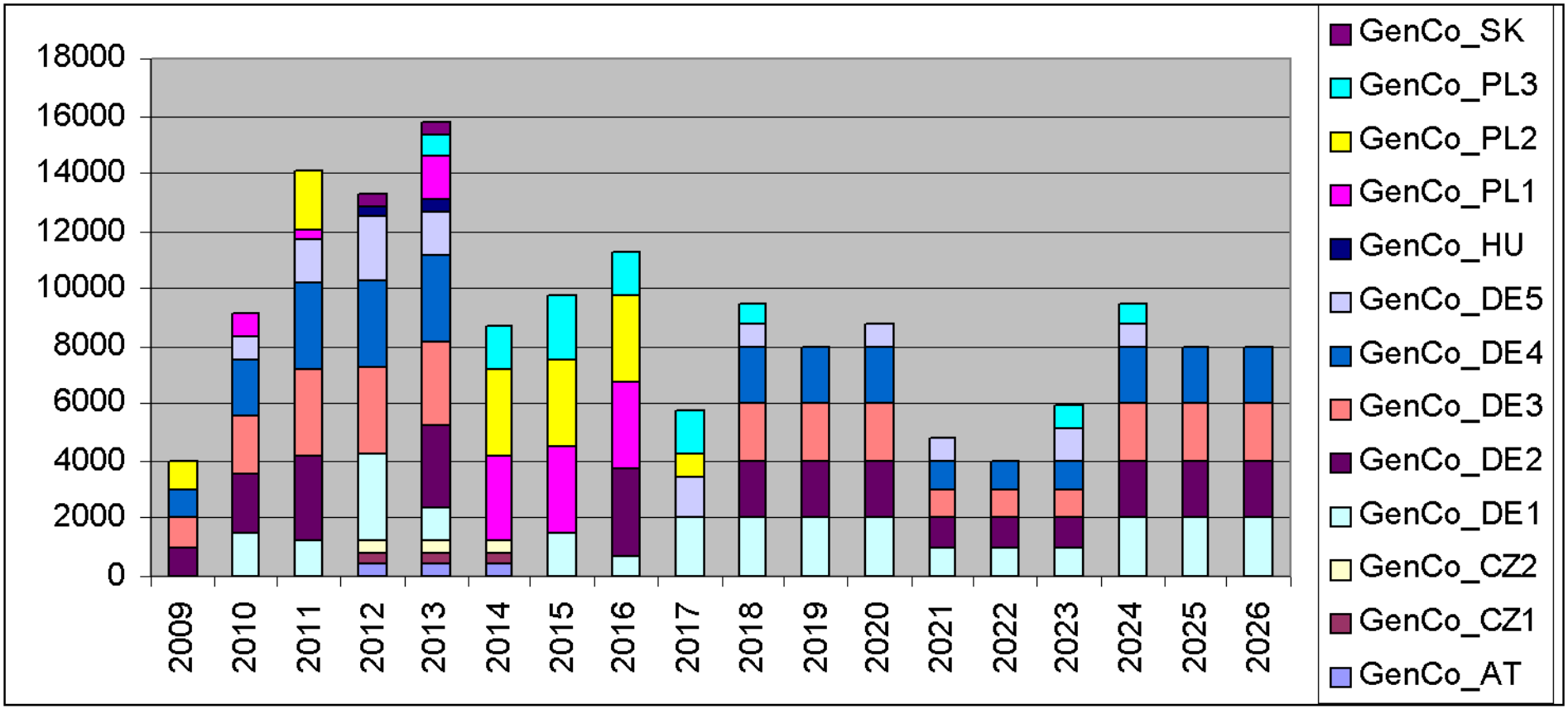
Case 1: Base Case Capacity Expansion by Technology Type

Total new capacity additions (2009-2026): 158.1 GW



Case 1: Base Case Capacity Expansion by GenCo

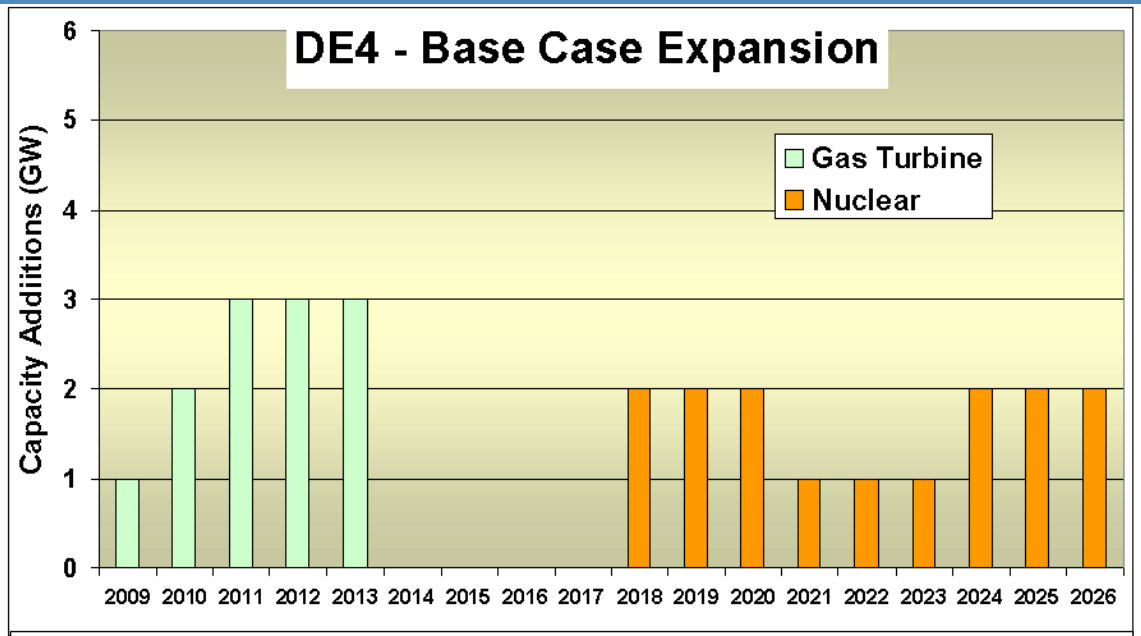
Total new capacity additions (2009-2026): 158.1 GW

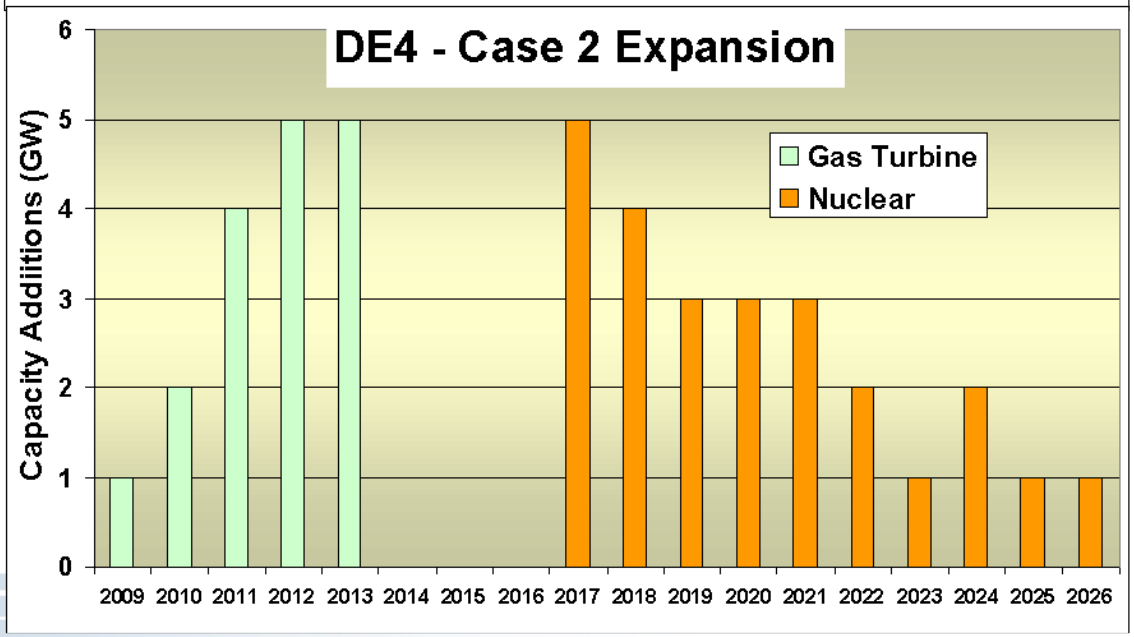


Case 2: Modified Parameters for GenCo DE4 (Build Limit Increased from 10% to 20%)

GenCo DE4	
Base case construction:	
Gas Turbines:	12 GW
Nuclear:	15 GW
Total:	**27 GW**
Case 2 construction:	
Gas Turbines:	17 GW
Nuclear:	25 GW
Total:	**42 GW**

Entire System	
Base case:	**158.1 GW**
Case 2:	**161.7 GW**





Case 2: Capacity Expansion Case with Modified Parameters for GenCo_DE4

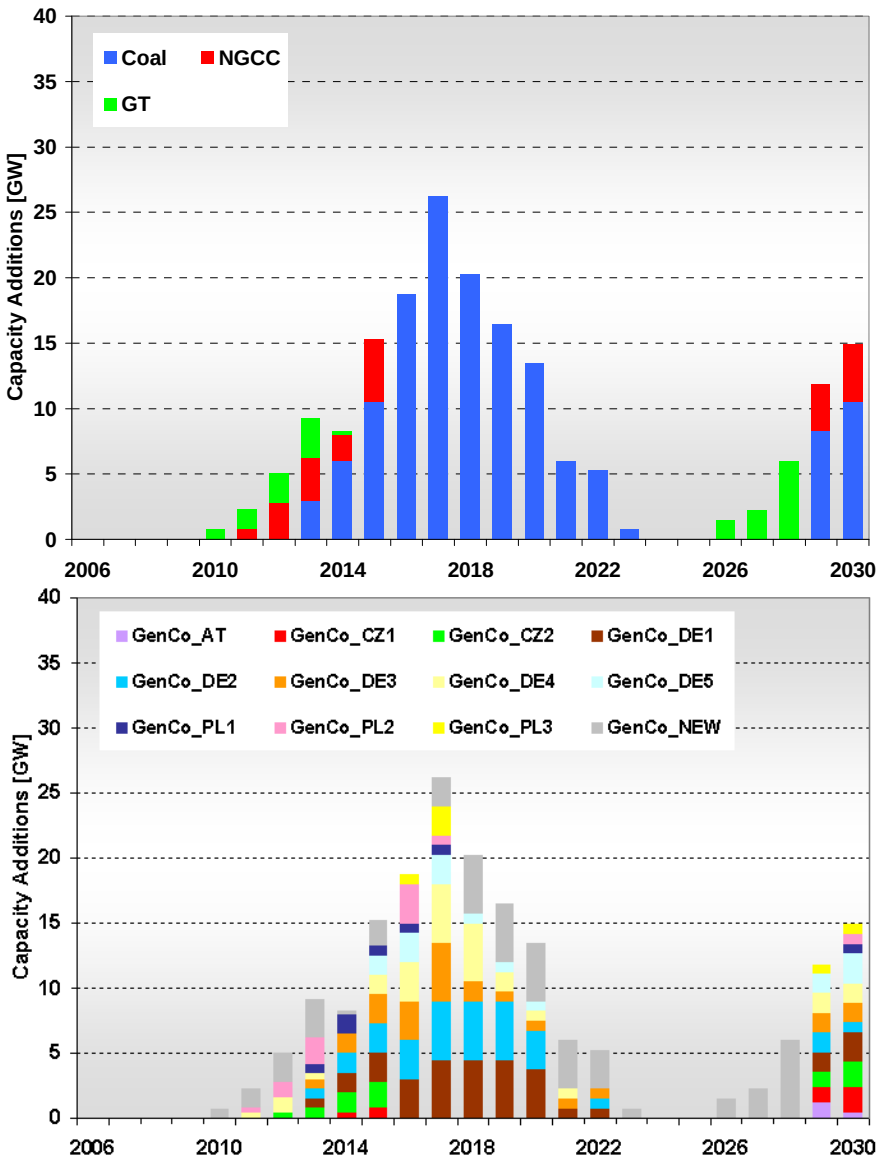
Online Year	Baseload Coal	Gas-Turbine	NGCC	Nuclear 1000	Grand Total
2008		1000			1000
2009		4500			4500
2010		10250	2000		12250
2011		10500	2800		13300
2012		10250	2800		13050
2013	2250	3250	7600		13100
2014	4500		400		4900
2015	8250				8250
2016	14250				14250
2017	6000			5000	11000
2018	2250			10000	12250
2019				9000	9000
2020	1500			9000	10500
2021	750			9000	9750
2022				8000	8000
2023			1600	4000	5600
2024				5000	5000
2025				4000	4000
2026				2000	2000
Grand Total	39750	39750	17200	65000	161700

Note: The total new capacity in the Base Case was 158,100 MW!

Case 3: Modified Parameters for Nuclear Candidate

Total new nuclear units in service by year:

		Case 3-1	Case 3-2	Case 3-3	Case 3-4
Year	Base Case	Capital Costs Reduced to 1200 €/kW	DR Reduced from 6% to 5%	Target PB Period 20 Years	Target PB Period 22 Years
2009					
2010					
2011					
2012					
2013		1	1		
2014					
2015					
2016		4	3		
2017	2	14	7		
2018	8	11	10		
2019	8	8	8		
2020	8	8	8		2
2021	4	8	4		2
2022	4	8	4		2
2023	4	8	4		2
2024	8	4	8		2
2025	8	4	4		2
2026	8	8	8		4
Total	**62**	**86**	**69**	**0**	**16**

Outputs from EMCAS Long-Term Expansion Simulations

- Capital investment plans
  - By technology
  - By company
- Generation by unit
- Price forecasts
  - Monthly price distributions
  - Chronological price bands
- Monthly reliability indices
- Consumer costs
- Company revenues, costs, profits