

# Mobility for the Future:

## City of Cambridge Municipal Vehicle Fleet Options

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December 17<sup>th</sup>, 2006

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# Outline

- Background
- System definition
- Description of uncertainty
- Two stage decision analysis
- Lattice model
- Comparative analysis
- Conclusion

Source: <http://www.skypic.com/ma/12-9679.jpg>



# Background

- City of Cambridge
- Considering expansion of municipal vehicle fleet
- Three vehicle types available:
  - Conventional engine (ICE) vehicle
  - Hybrid-electric vehicle
  - Experimental fuel cell vehicle

Source:  
[http://www.fueleconomy.gov/feg/fc\\_pics/GM\\_Fuel\\_Cell\\_Stack.jpg](http://www.fueleconomy.gov/feg/fc_pics/GM_Fuel_Cell_Stack.jpg)



# Project Goals

- Develop and apply methods of decision analysis in the vehicle fleet
- Recognize and take advantage of uncertainty
- Develop an optimal strategy for vehicle fleet selection
- Assess value of a flexible option on the system



# System Definition

- Discount rate = 30%
  - High rate chosen to make a “business case” for fuel efficient vehicles, supported by literature
- Fleet size = 300 vehicles
- Vehicle miles traveled = 50K / year



# System Definition

- Conventional ICE vehicle
  - Capital cost = \$18K
  - Lease cost = \$2.5K / year
  - Operating cost = \$5K / vehicle / year
  - Fuel economy = 30 mpg (city)



Source: [http://www.autoclub.com.au/uploaded\\_images/new-toyota-camry-713790.jpg](http://www.autoclub.com.au/uploaded_images/new-toyota-camry-713790.jpg)



# System Definition

- Hybrid vehicle
  - Capital cost = \$22K
  - Lease cost = \$2.75K / year
  - Operating cost = \$5.25K / vehicle / year
  - Fuel economy = 30 mpg (city)



Source: <http://www.uwec.edu/piercech/Vehicle/images/ToyotaPrius.jpg>



# System Definition

- Experimental fuel cell vehicle
  - Capital cost = \$30K
  - Lease cost = \$3.25K / year
  - Operating cost = \$5.5K / vehicle / year
  - Fuel economy = 90 mpg (city)



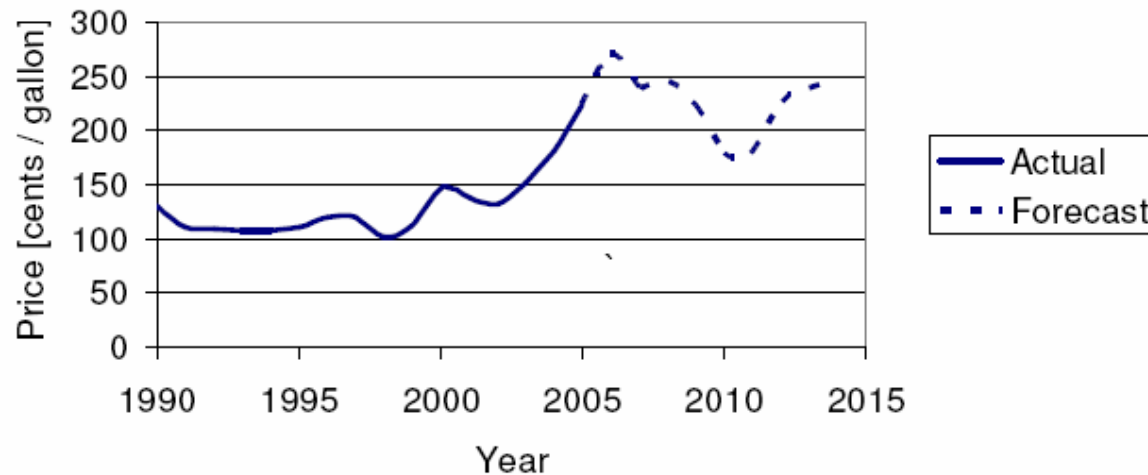
Source: <http://www.geocities.com/joelado/Photos/GM-Precept1.jpg>





# Description of Uncertainty

- Future gasoline costs uncertain
- Modeled by Geometric Brownian Motion based on historic average, volatility



# Description of Uncertainty

- Monte Carlo analysis used to determine probability of fuel prices in future

<b>YEAR</b>	<b>RANGE</b>	<b>2006</b>	<b>2010</b>
Price of fuel below \$3.00 / gallon	Low	99.60%	66.20%
Price of fuel between \$3.00 and \$6.00 / gallon	Medium	0.40%	33.60%
Price of fuel exceeds \$6.00 / gallon	High	0.00%	0.20%



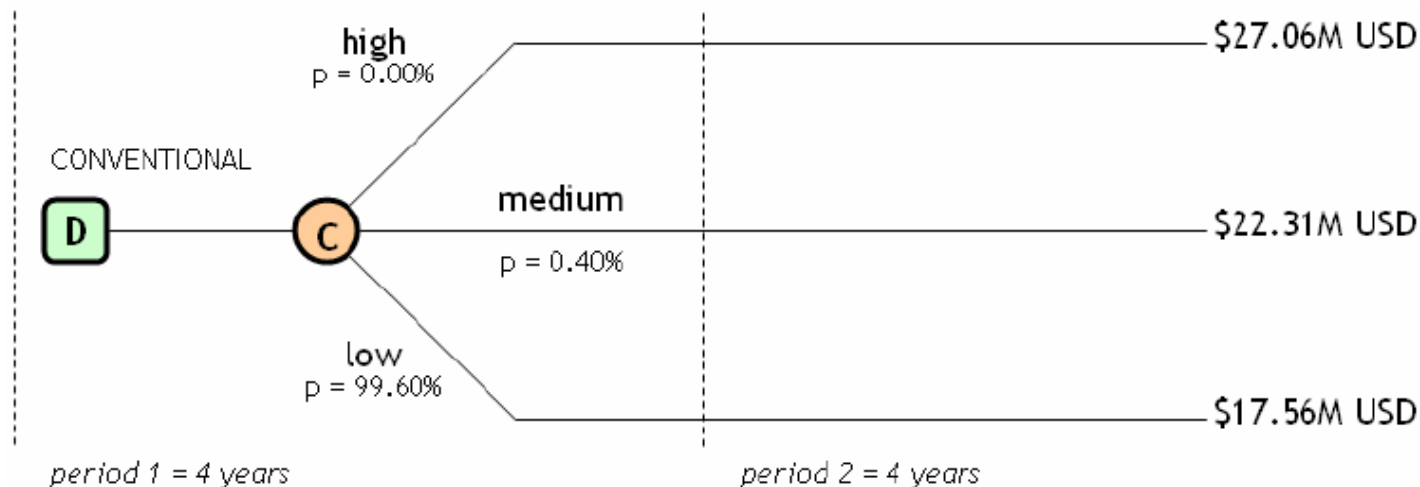
# Two Stage Decision Analysis

- Fuel is cool scenario
  - Conventional ICE vehicle fleet is purchased
  - Baseline for comparison with flexible case
- Flexible future scenario
  - Four year flexible leasing option
  - Fleet can be changed depending on fuel costs



# Two Stage Decision Analysis

- *Fuel is Cool* scenario results:
  - Net present cost = \$17.58 M

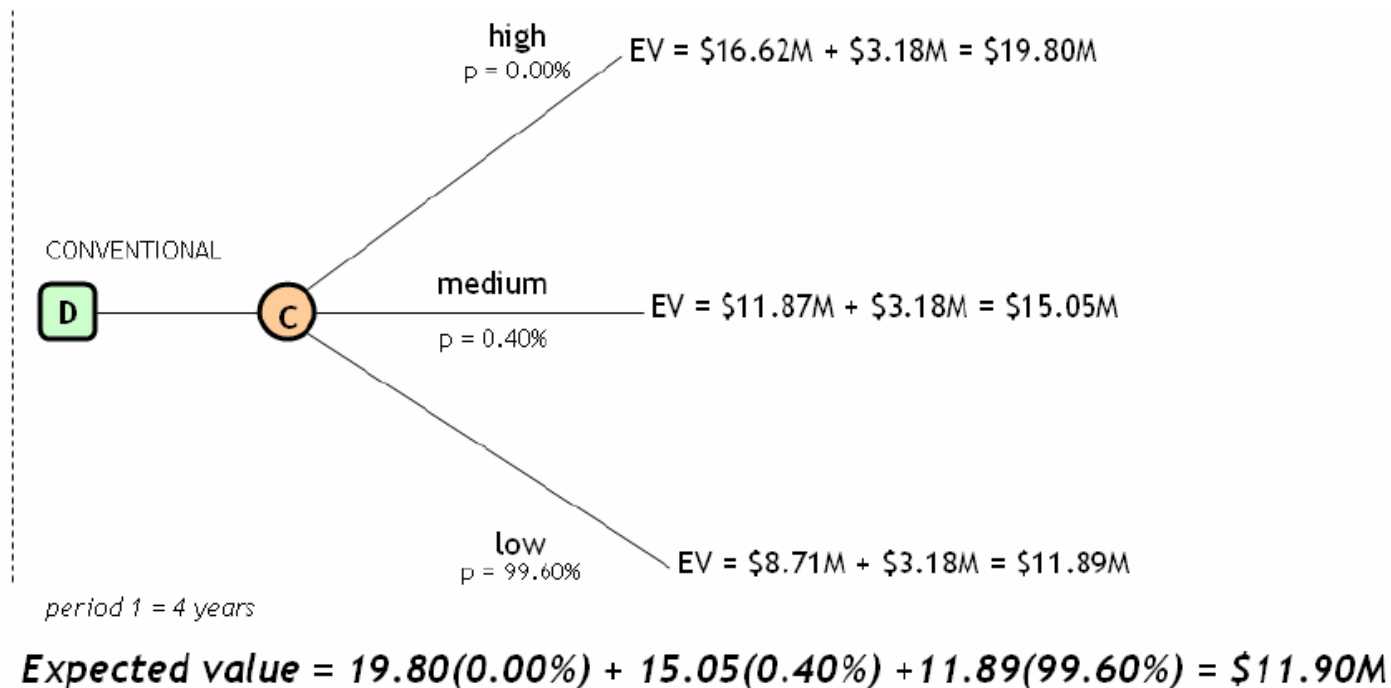


$$\text{Expected value} = 27.06(0.00\%) + 22.31(0.40\%) + 17.56(99.60\%) = \$17.58\text{M}$$



# Two Stage Decision Analysis

- *Flexible Future* scenario results:
  - Net present cost = \$11.90 M



# Two Stage Decision Analysis

- Optimal strategy:
  - Lease a conventional fleet for first four years
  - After four years, switch to hybrid fleet
- Expected savings of \$5.68M in costs



# Lattice Model Analysis

- Alternative decision analysis
- City may fuel cell fleet as a demonstration
- Flexible option: switch to hybrids in any year if fuel costs are too high
- Equivalent to a “real” *put* option *on* the system
- Value of flexible option compared to base case fuel cell fleet without option



# Lattice Model Analysis

- Input parameters:

INPUT	VALUE
<i>fuel price inputs</i>	
Fuel price in 2006 (S)	\$2.50 / gallon
Average annual fuel price increase	\$0.11 / gallon
Standard deviation in fuel price	\$0.63 / gallon
Percent average fuel price increase ( $v$ )	4.60%
Percent standard deviation ( $\sigma$ )	6%
Time step ( $\Delta t$ )	1 (annual)
<i>lattice parameters</i>	
“Up” path modifier ( $u$ )	1.23
“Down” path modifier ( $d$ )	0.81
Probability of the up path outcome ( $p$ )	0.60





# Lattice Model Analysis

- Fuel price outcome and probability:

FUEL PRICE [USD / gallon]								
2006	2007	2008	2009	2010	2011	2012	2013	2014
2.50	2.65	2.82	2.99	3.18	3.37	3.58	3.80	4.04
	2.35	2.50	2.65	2.82	2.99	3.18	3.37	3.58
		2.22	2.35	2.50	2.65	2.82	2.99	3.18
			2.09	2.22	2.35	2.50	2.65	2.82
				1.97	2.09	2.22	2.35	2.50
					1.85	1.97	2.09	2.22
						1.74	1.85	1.97
							1.64	1.74
								1.55

PROBABILITY LATTICE								
2006	2007	2008	2009	2010	2011	2012	2013	2014
1.00	0.88	0.78	0.69	0.61	0.54	0.48	0.42	0.37
	0.12	0.21	0.27	0.32	0.36	0.38	0.39	0.39
		0.01	0.04	0.06	0.09	0.12	0.15	0.18
			0.00	0.01	0.01	0.02	0.03	0.05
				0.00	0.00	0.00	0.00	0.01
					0.00	0.00	0.00	0.00
						0.00	0.00	0.00
							0.00	0.00
								0.00



# Lattice Model Analysis

- Decision framework:

DECISION FRAMEWORK								
2006	2007	2008	2009	2010	2011	2012	2013	2014
FC	FC	FC	FC	FC	FC	FC	FC	FC
	FC	FC	FC	FC	FC	FC	FC	FC
		FC	FC	FC	FC	FC	FC	FC
			FC	FC	FC	FC	FC	FC
				FC	FC	FC	FC	FC
					HYB	HYB	FC	FC
						HYB	HYB	HYB
							HYB	HYB
								HYB

Note: FC = maintain fuel cell fleet  
 HYB = exercise option, switch to hybrid fleet



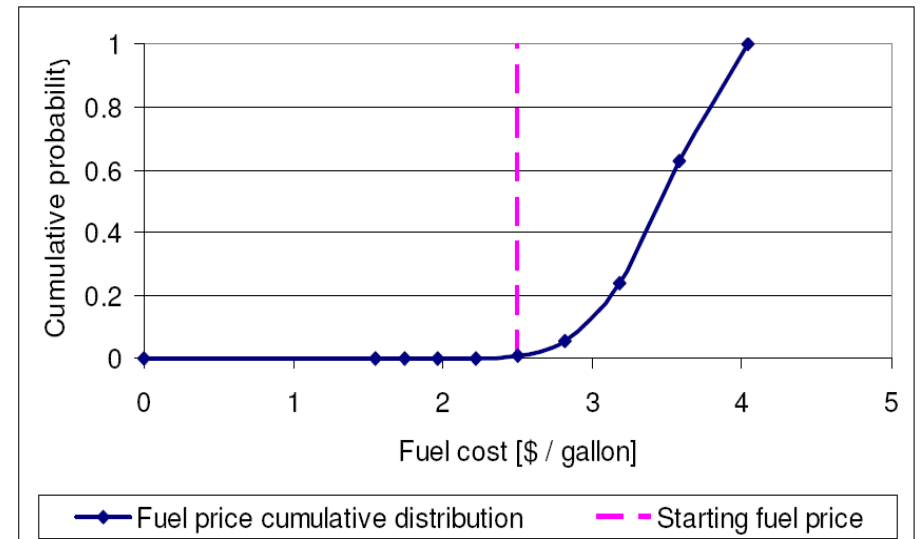
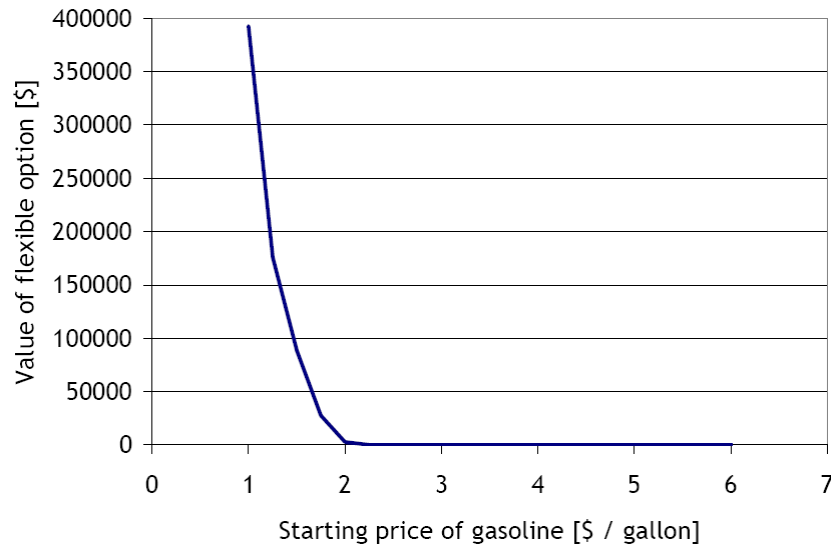
# Lattice Model Analysis

- Results:
  - Base case Net Present Cost = \$12.1K
  - Flexible option Net Present Cost = \$12.1K
- No incremental value from option



# Lattice Model Analysis

- Sensitivity analysis to starting fuel price:
  - Option value increases at lower price
  - But probability price decrease is negligible



# Comparative Analysis

- Decision tree analysis
  - Computationally intensive
  - Can handle dependent decision paths
- Lattice model
  - Less computations
  - Assumes path independence, but assumption is valid in this study
- Lattice model is preferred in this study



# Conclusions

- Developed and implemented decision analysis, real options under uncertainty
- Optimal strategy
  - First buy conventional ICE, then hybrids
- Put option on vehicle fleet system provides negligible value



# Many thanks!

## Are there any questions?



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