

‘Behold!’

The jaws of darkness do devour it up:  
So quick bright things come to confusion.

\*

# Draft Conservation Assessment of Commercial Sector Lighting Measures

# These are Draft

- Will be updated with fresh data from  
Commercial Building Stock  
Assessment
  - Lighting Intensity
  - Stock of Lighting Equipment
  - Hours of Operation

# Context

- Technical & Economic Potential
  - Not yet adjusted for achievable potential
  - Economic Potential based on TRC  
Benefit/Cost Ratio  $\geq 1.0$
  - New avoided costs

# Context

- Costs & savings modeled under Council Inputs
  - 4.75% Discount Rate
  - Zero Externalities Credit
  - Program costs at 20% of capital cost

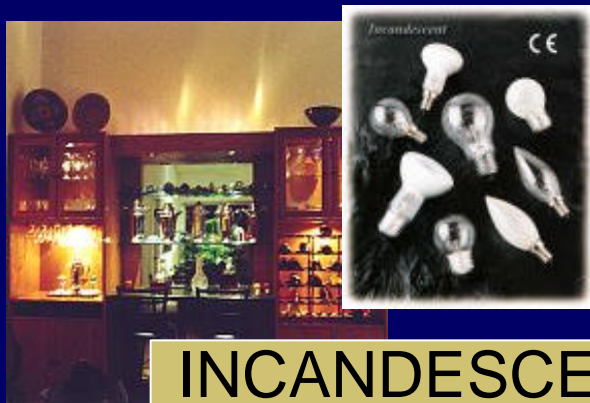
# Four Sources of Lighting



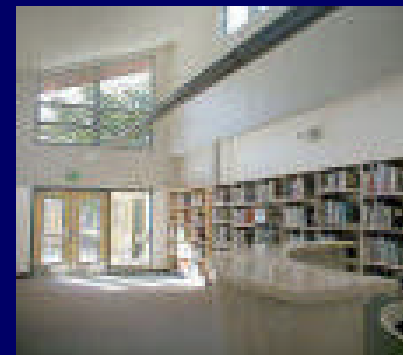
FLUORESCENT



HID

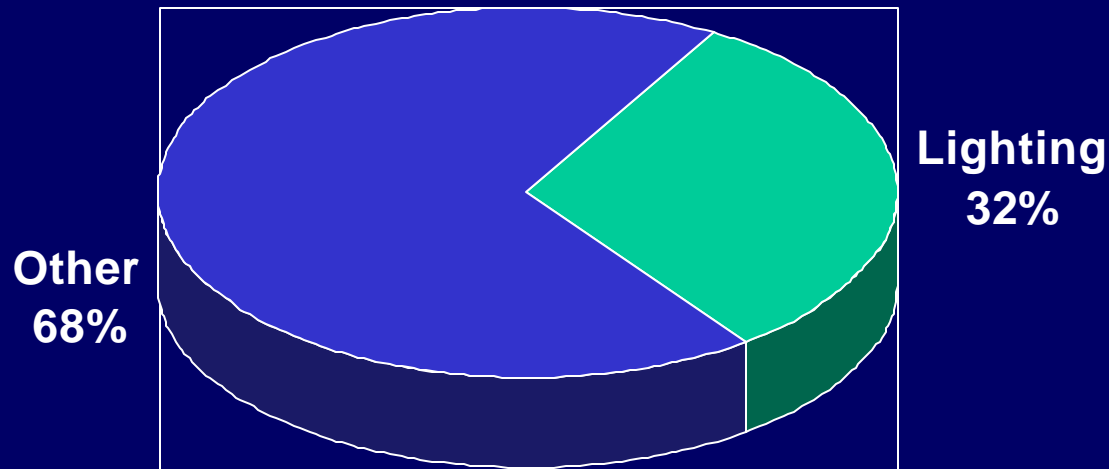


INCANDESCENT



DAYLIGHT

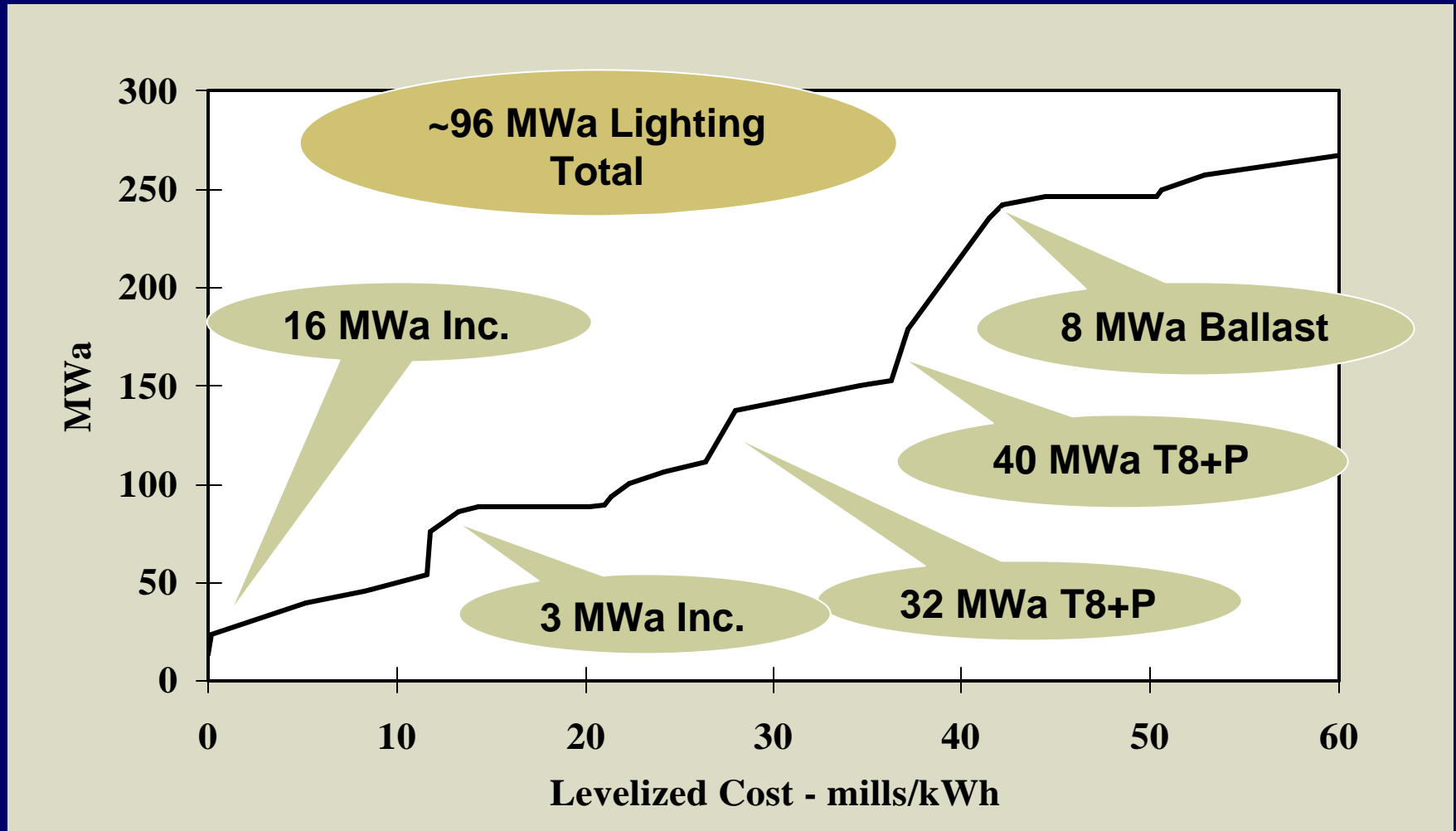
# Lighting Share of Commercial Electricity Use: 1996 Power Plan



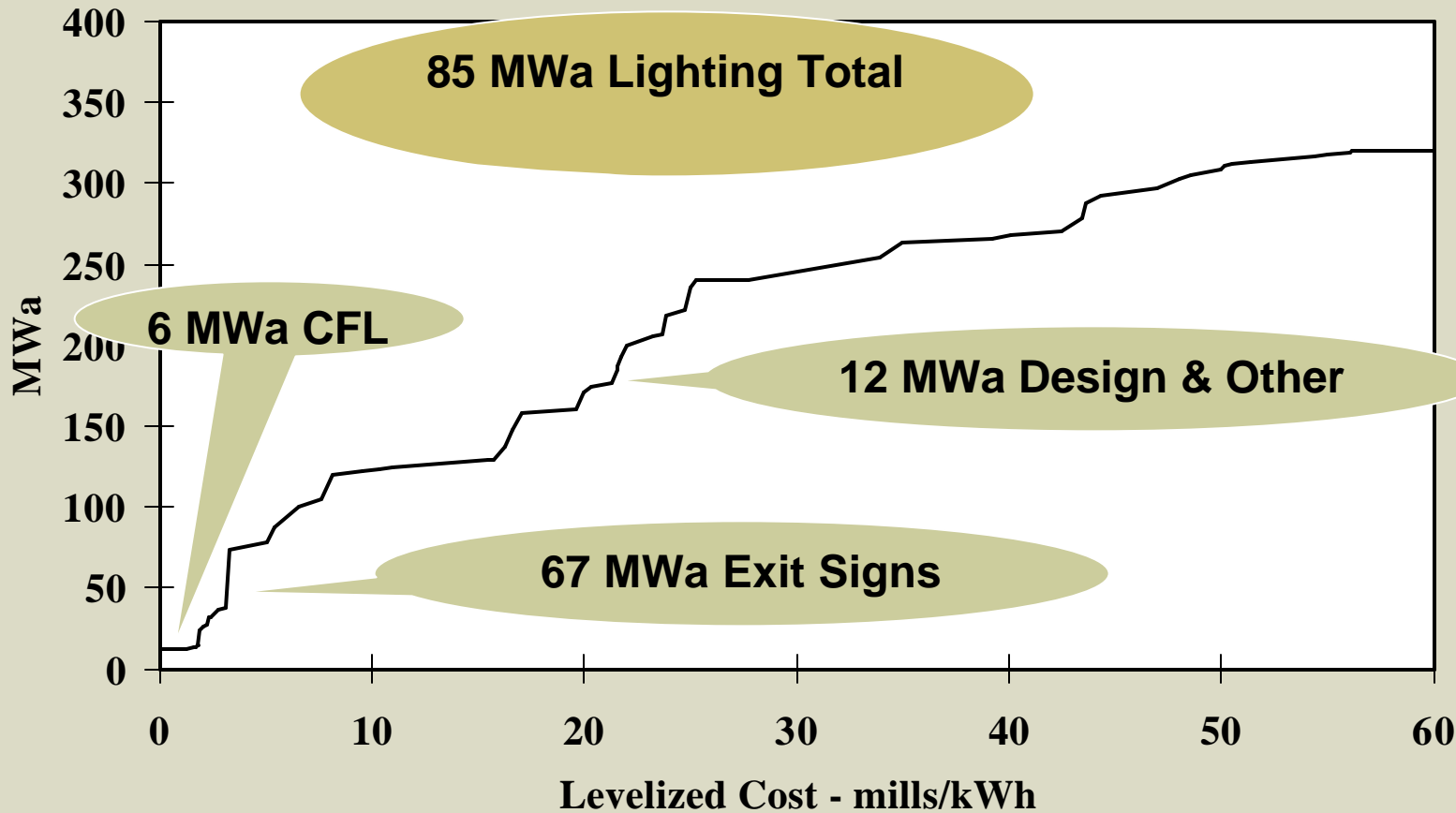
**1620 MWa Lighting - 2002**

# 1996 Plan Commercial Supply Curve

## All Conservation in Existing Buildings



# 1996 Plan Commercial Supply Curve All Conservation in New Buildings



# What's New in Lighting



- Better Phosphors
- Better CFLs
- Better HIDs
- Better Fixtures

# Fluorescent Technology

System	Vintage	Lumens per Watt	Gain over T12	Gain over 7T8	Gain over 8T8
T12 ES MB	Pre 1990	63			
700 T8 EB	Early 90s	77	21%		
800 T8 EB	Late 90s	85	35%	11%	
HP T8 RS EB	Today	88	39%	14%	3%
HP T8 IS EB	Today	94	48%	22%	10%

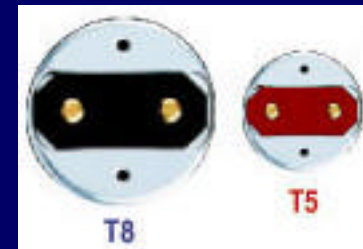
Source: Robert Sardinsky, Rising Sun Enterprises

# High-Performance T8

- Brighter due to better phosphors
- Allow more retrofit options combined with low, medium or high output ballast
  - 4-lamp to 2-lamp, 3-lamp to 2 lamp
  - 2-lamp to 1-lamp
  - Spacing changes
- Longer life and slower Lamp Lumen Depreciation (LLD)

# High Performance T8 and T5

- Competing with HID in high-mount
  - Similar or better luminous efficacy
  - Instant on
  - Stable color and better CRI
  - Multi-tube fixtures allow switching control for day lighting applications



# CFLs

- Finally hitting the main stream
- Up 42, 57 and 70 Watt with reflectors
- Prices falling
- User acceptance growing



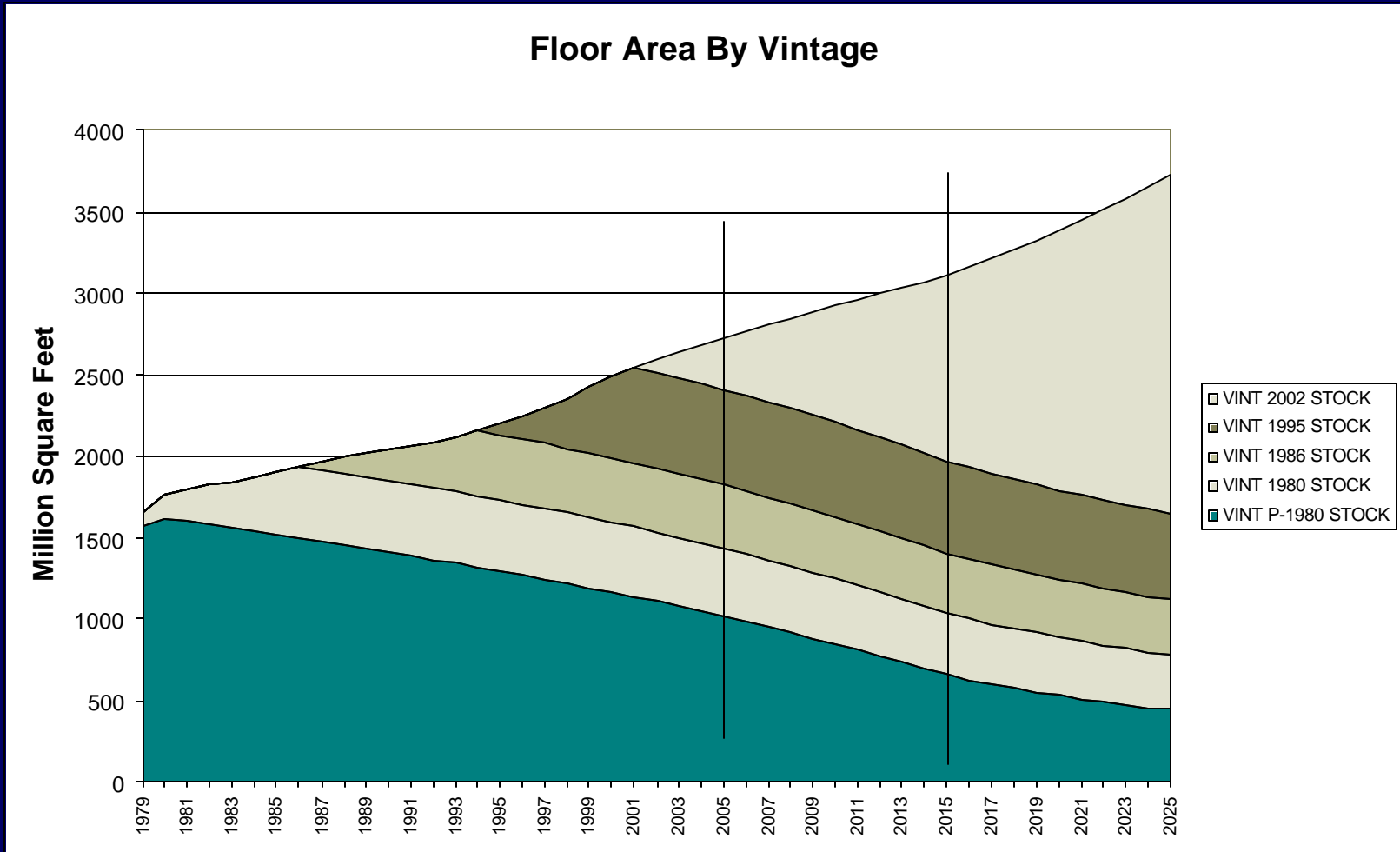
# High Intensity Discharge (HID)

- Pulse-Start Metal Halide
  - 94 lumens/Watt (versus 70 probe start)
  - Better CRI and more stable color
  - Quasi-Dimmable
  - Faster re-strike times (5 minutes)
  - More efficient ballasts

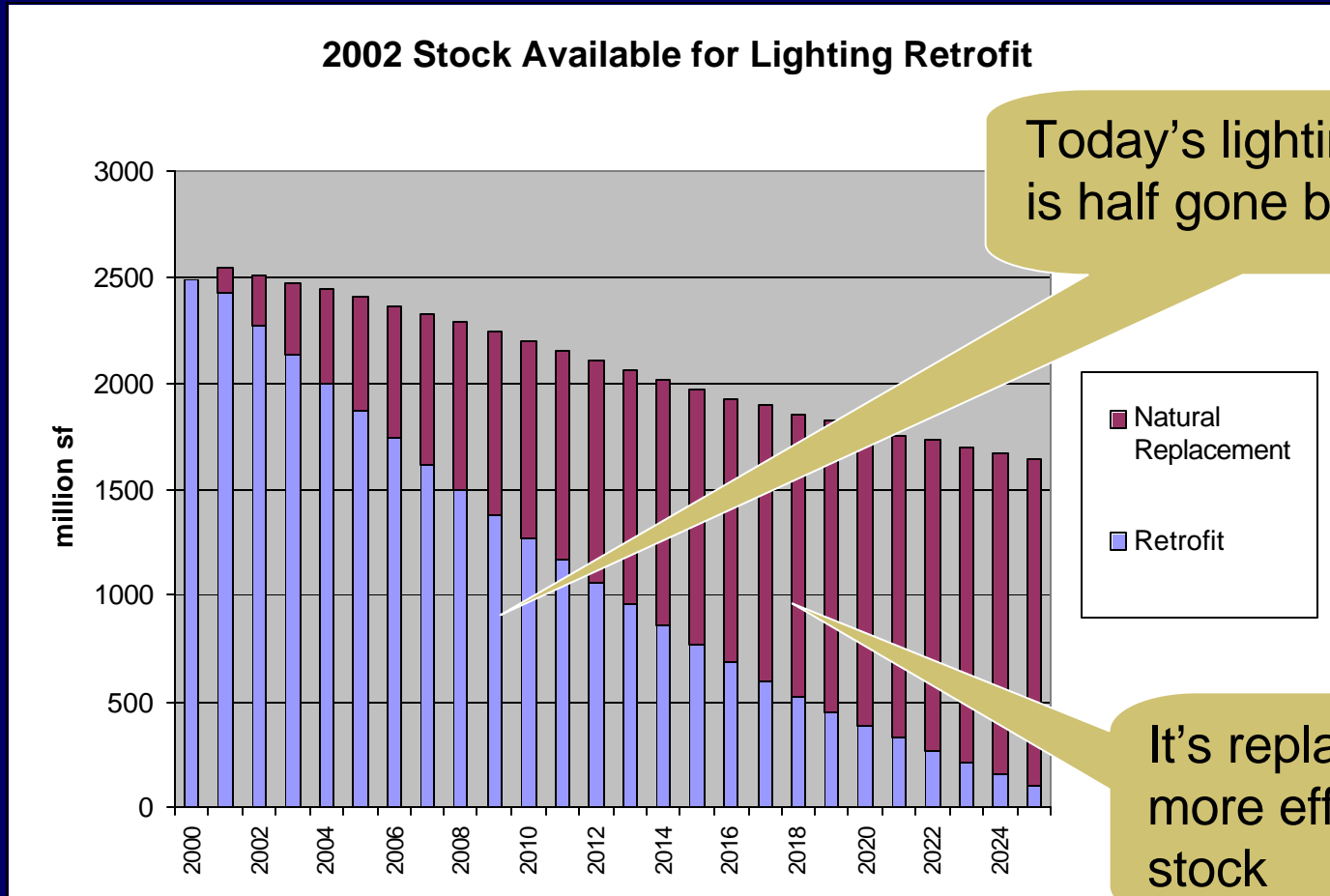
# Key Drivers for Supply Curves

- Luminous Efficacy
- Cost: Materials, labor, profit, O&M
- Hours of operation
- Saturation of base technology
- Penetration of new technology
- Floor area stock

# Floor Area Stock: Vintage Matters



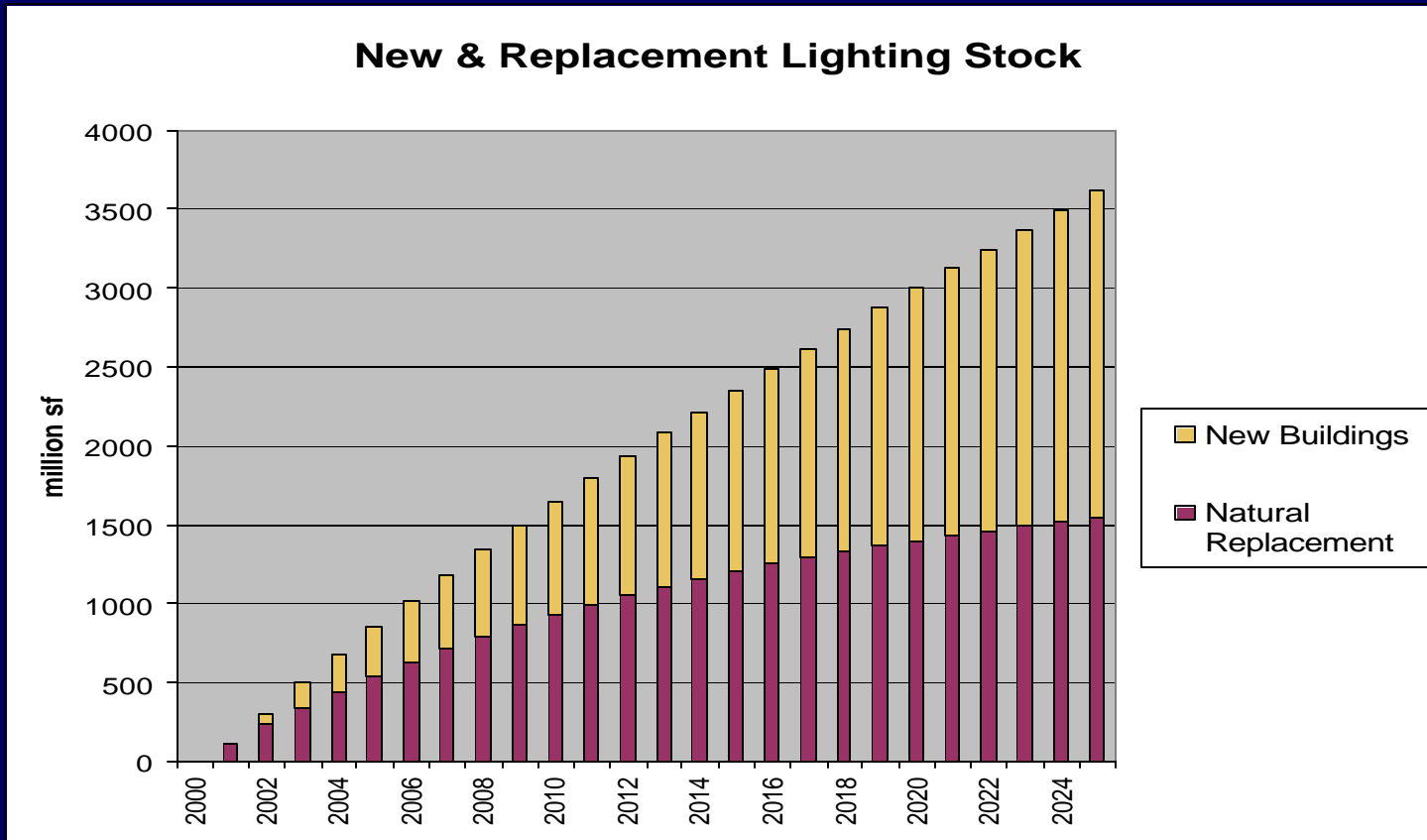
# Lighting System Replacement Rates: Estimate 45% replaced in 12 years



Today's lighting stock is half gone by 2011

It's replaced by more efficient base stock

# By 2025 most of the potential is in Replacement and New Building Stock



# Basic Algorithm

Identify measures with lumen output similar to base technology

Calculate Watts saved

Estimate capital & labor cost

Calculate ongoing lamp and ballast replacement costs for measure and base tech.

Adjust savings for heating and cooling interaction by building type & HVAC

Calculate kWh saved per sf-year by building type

Estimate the saturation of the base technology that the measure applies to

Estimate the penetration of the measure on the base technology



Cost-effectiveness of measures by building type

Multiply times relevant floor area by activity type by year.

# Base Technology Mix – 2002 Stock

	Fluorescent	Incadescent	HID	Total
<b>Large Office</b>	78%	19%	3%	100%
<b>Small Office</b>	78%	19%	3%	100%
<b>Restaurant</b>	27%	70%	3%	100%
<b>Large Retail</b>	56%	29%	15%	100%
<b>Small Retail</b>	62%	29%	9%	100%
<b>Grocery</b>	73%	14%	13%	100%
<b>Warehouse</b>	69%	7%	24%	100%
<b>School</b>	66%	29%	5%	100%
<b>Health</b>	80%	15%	5%	100%
<b>Hospitality</b>	28%	65%	7%	100%
<b>Misc</b>	55%	30%	15%	100%

# Base Technology Mix – Post 2002 Stock

Post 2002 Stock	Fluorescent	Incadescent	HID	Total
Large Office	70%	20%	10%	100%
Small Office	70%	20%	10%	100%
Restaurant	55%	41%	4%	100%
Large Retail	54%	26%	20%	100%
Small Retail	59%	28%	13%	100%
Grocery	60%	14%	26%	100%
Warehouse	60%	5%	35%	100%
School	70%	19%	11%	100%
Health	80%	14%	6%	100%
Hospitality	29%	55%	16%	100%
Misc	61%	20%	20%	100%

# Fluorescent Measures

- Eleven retrofit measures
- Five “natural replacement” measures
- Applied to 10 activity types
- Assume 20% - 30% already T8

## Costs Include:

- Materials
- Labor
- Engineering when required
- Profit
- Ongoing replacement costs for lamps and ballasts

# Fluorescent Retrofit Inputs

Pre-Retrofit Condition	Post Retrofit Condition	Delamp	Input Watts		Savings
			Pre	Post	Watts
4-L 4ft FL T-12/M	3-L ST-8/EE/NLO	4-L to 3-L	144.0	82.0	62.0
4-L 4ft FL T-12/M	2-L ST-8/EB/HLO	4-L to 2-L	144.0	78.0	66.0
3-L 4ft FL T-12/M	2-L ST-8/EE/NLO	3-L to 2-L	108.0	55.0	53.0
3-L 4ft FL T-12/M	3-L 8T8/EE/RLO	3-L to 3-L	108.0	72.0	36.0
2-L 4ft T-12/M	2-L 8T8/EE/RLO	2-L to 2-L	72.0	48.0	24.0
2-L 8ft T-12/M	4-L 8T-8/EE/RLO	2-L to 4-L	126.0	95.0	31.0
2-L 8ft T-12/M HO	4-L ST-8/EE/NLO	2-L to 4-L	210.0	105.0	105.0
2-L 8ft T-12/M VHO	4-L ST-8/EB/HLO	2-L to 4-L	398.0	156.0	242.0
4-L 7T8EEB	2-L ST-8/EB/HLO	4-L to 2-L	103.9	78.0	25.9
3-L 7T8EEB	2-L ST-8/EE/NLO	3-L to 2-L	84.4	55.0	29.4
2-L 7T8EEB	2-L 8T8/EE/RLO	2-L to 2-L	58.4	48.0	10.4

Each Measure is applied to estimates of the base technology saturation and penetration estimate for the retrofit by building type

Example:  
Measure 1 saturation is 5% and penetration is 60% in Large Offices

# Fluorescent Retrofit Costs

	Cost
Lamp	\$2003
7T8	\$ 1.65
8T8	\$ 2.00
PT8	\$ 3.25
F96T8	\$ 8.50

Delamp Conversion	Materials	Labor	Total
4-L to 3-L	\$ 5.00	\$ 9.98	\$ 14.98
4-L to 2-L	\$ 10.00	\$ 9.98	\$ 19.98
3-L to 2-L	\$ 5.00	\$ 9.98	\$ 14.98
3-L to 3-L	\$ -	\$ -	\$ -
2-L to 2-L	\$ -	\$ -	\$ -
2-L to 4-L	\$ 10.00	\$ 19.97	\$ 29.97

Ballast cost adjustment for multiple lamps (\$2003 2L Base)				
Number	FEMP	Adj	EB	PEB
1	19.71	0.93	\$ 12.07	\$ 18.57
2	21.22	1.00	\$ 13.00	\$ 20.00
3	22.74	1.07	\$ 13.93	\$ 21.43
4	24.26	1.14	\$ 14.86	\$ 22.86

# Fluorescent Retrofit Outputs

- Long operating hours generate cost-effective savings
- Even 7T8 to HPT8 is cost-effective for 3L and 4L conversions
  - Means open season on 1990s T8 retrofits
  - 2L 7T8 to 2L ST8 rarely cost-effective
- 2-Lamp T12 retrofits hurt by high labor

# Fluorescent Retrofit Outputs

Measure	Grocery	Health	Hospitality	Large (>20,000 ft2) Office	Large (>20,000 ft2) Retail	Restaurant	School	Small (<=20,000 ft2) Office	Small (<=20,000 ft2) Retail	Warehouse
Replace: 2-L 4ft T-12/M With : 2-L 8T8/EE/RLO	2.5	0.9	0.7	1.0	1.1	1.6	0.4	0.5	1.0	0.8
Replace: 2-L 7T8EEB With : 2-L 8T8/EE/RLO	1.1	0.4	0.3	0.5	0.5	0.7	0.2	0.2	0.4	0.3
Replace: 2-L 8ft T-12/M HO With : 4-L ST-8/EE/NLO	4.8	2.2	1.7	2.6	2.9	3.5	1.2	1.3	2.6	1.8
Replace: 2-L 8ft T-12/M VHO With : 4-L ST-8/EB/HLO	403.6	10.0	5.5	10.9	16.7	27.3	3.6	4.1	9.1	6.3
Replace: 2-L 8ft T-12/M With : 4-L 8T-8/EE/RLO	1.5	0.7	0.5	0.7	0.8	1.1	0.3	0.4	0.7	0.6
Replace: 3-L 4ft FL T-12/M With : 2-L ST-8/EE/NLO	5.6	1.6	1.1	1.8	2.0	3.3	0.8	0.9	1.6	1.2
Replace: 3-L 4ft FL T-12/M With : 3-L 8T8/EE/RLO	6.1	1.3	0.9	1.4	1.5	3.2	0.6	0.7	1.3	1.0
Replace: 3-L 7T8EEB With : 2-L ST-8/EE/NLO	2.2	0.9	0.6	1.0	1.1	1.4	0.4	0.5	0.9	0.7
Replace: 4-L 4ft FL T-12/M With : 2-L ST-8/EB/HLO	10.3	2.2	1.5	2.5	2.7	5.3	1.0	1.1	2.2	1.6
Replace: 4-L 4ft FL T-12/M With : 3-L ST-8/EE/NLO	5.6	1.7	1.3	1.9	2.1	3.3	0.8	0.9	1.8	1.3
Replace: 4-L 7T8EEB With : 2-L ST-8/EB/HLO	2.6	0.9	0.6	1.0	1.1	1.5	0.4	0.5	0.9	0.6

# Fluorescent Natural Replacement

- Assume natural replacement meets code
- Select measures that go beyond code
- Include only incremental materials costs
- Less savings per fixture at less cost

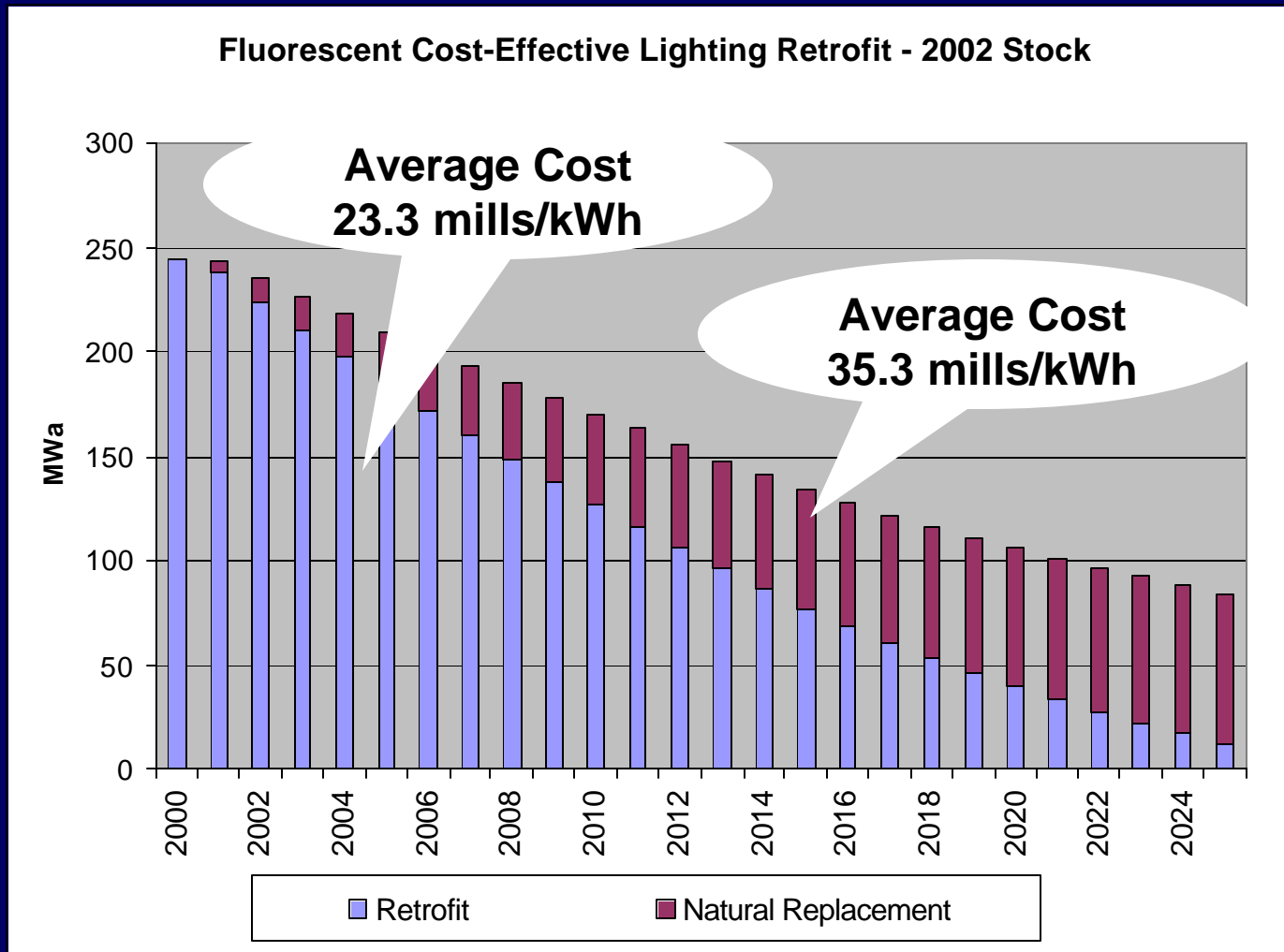
# Fluorescent Natural Replacement: Inputs

Pre-Retrofit Condit	Post Retrofit Condit	Delamp	Input Watts		Savings
			Pre	Post	Watts
2-L F96T8/EB/NLO	4-L 8T-8/EE/RLO	2-L to 4-L	110.0	95.0	15.0
2-L 8ft T-12/M HO	4-L ST-8/EE/NLO	2-L to 4-L	210.0	105.0	105.0
4-L 7T8EEB	2-L ST-8/EB/HLO	4-L to 2-L	103.9	78.0	25.9
3-L 7T8EEB	2-L ST-8/EE/NLO	3-L to 2-L	84.4	55.0	29.4
2-L 7T8EEB	2-L 8T8/EE/RLO	2-L to 2-L	58.4	48.0	10.4

# Fluorescent Natural Replacement: Outputs

Sum of Total Regional B/C Ratio	Catego									
Measure	Grocery	Health	Hospital ity	Large (>20,000 ft2) Office	Large (>20,000 ft2) Retail	Restaur ant	School	Small (≤20,000 ft2) Office	Small (≤20,000 ft2) Retail	Wareho use
Replace: 2-L 7T8EEB With : 2-L 8T8/EE/RLO	0.8	0.7	0.8	0.8	0.8	0.6	0.5	0.6	0.9	0.9
Replace: 2-L 8ft T-12/M HO With : 4-L ST-8/EE/NLO	2.8	2.2	2.1	3.6	2.6	2.1	1.4	1.9	2.5	2.2
Replace: 2-L F96T8/EB/NLO With : 4-L 8T-8/EE/RLO	0.4	0.3	0.4	0.4	0.4	0.3	0.3	0.3	0.4	0.4
Replace: 3-L 7T8EEB With : 2-L ST-8/EE/NLO	1.5	1.2	1.2	1.4	1.5	1.1	0.8	0.9	1.5	1.2
Replace: 4-L 7T8EEB With : 2-L ST-8/EB/HLO	1.3	1.1	1.2	1.2	1.3	1.0	0.8	0.9	1.4	1.2

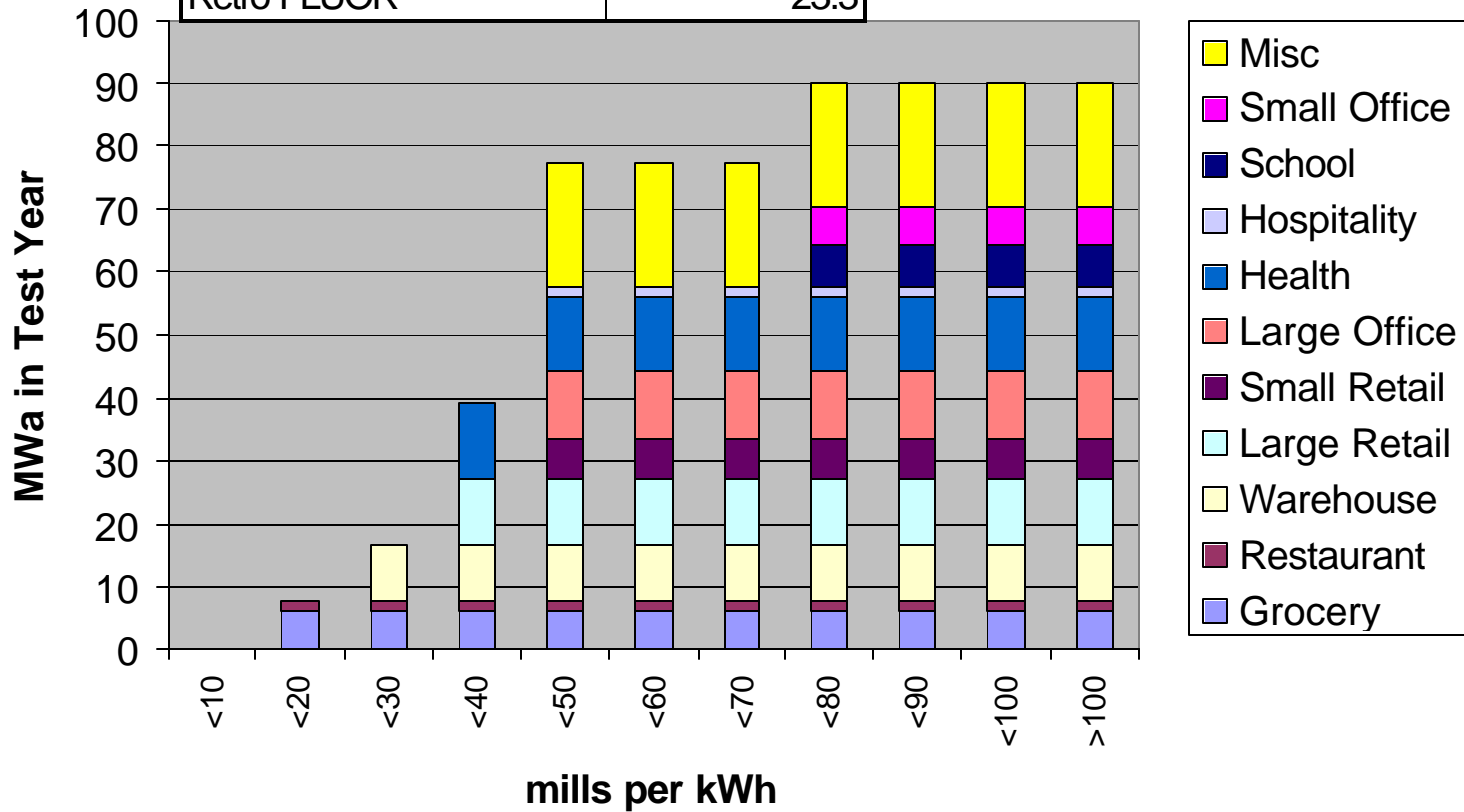
# Fluorescent Retrofit & Natural Replacement: Results



## Cost of Retrofit Savings by Activity - Fluorescent Systems

**Test Year 2015**

Measures with B/C>1.00	Levelized Cost
Retro FLUOR	23.3

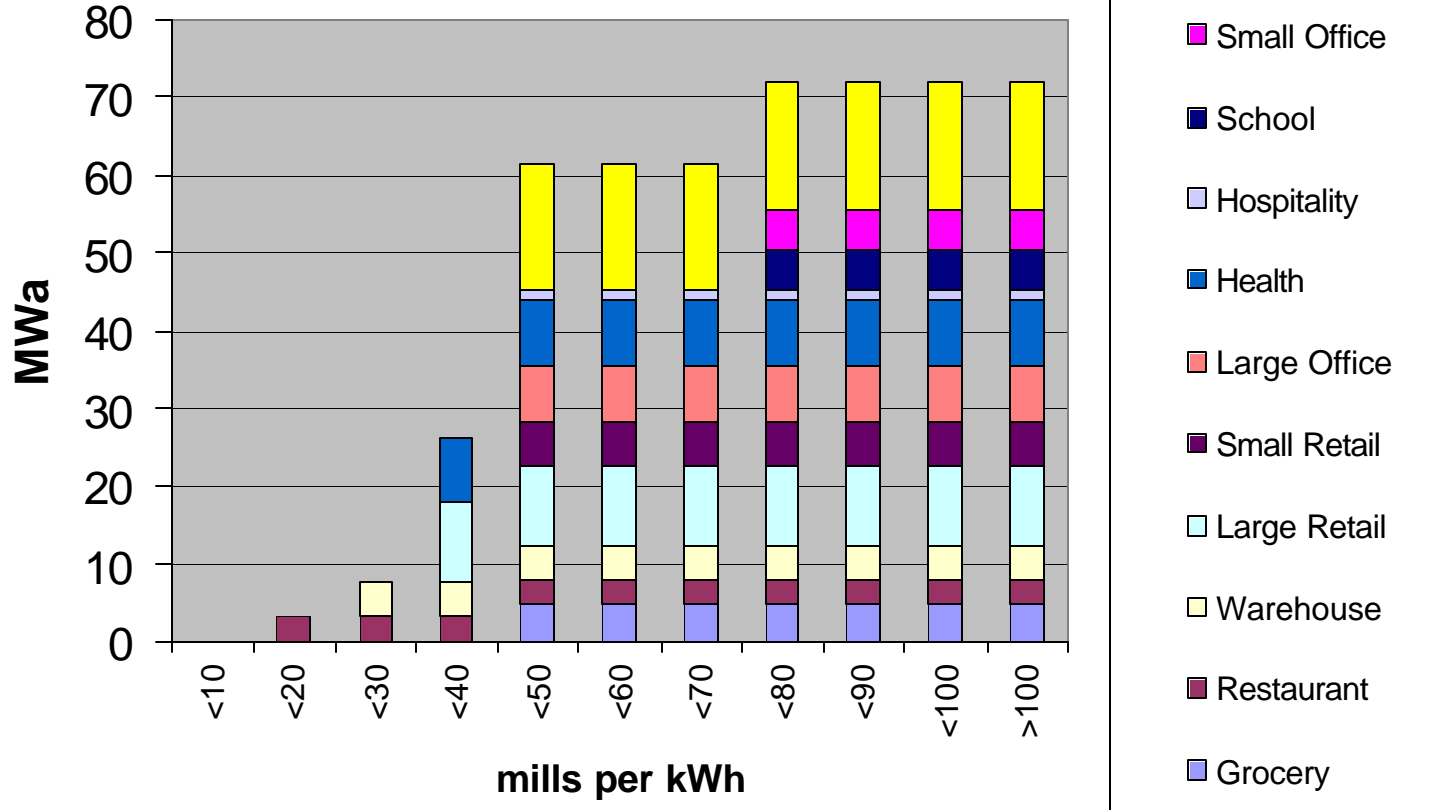


# Fluorescent Retrofit: Results

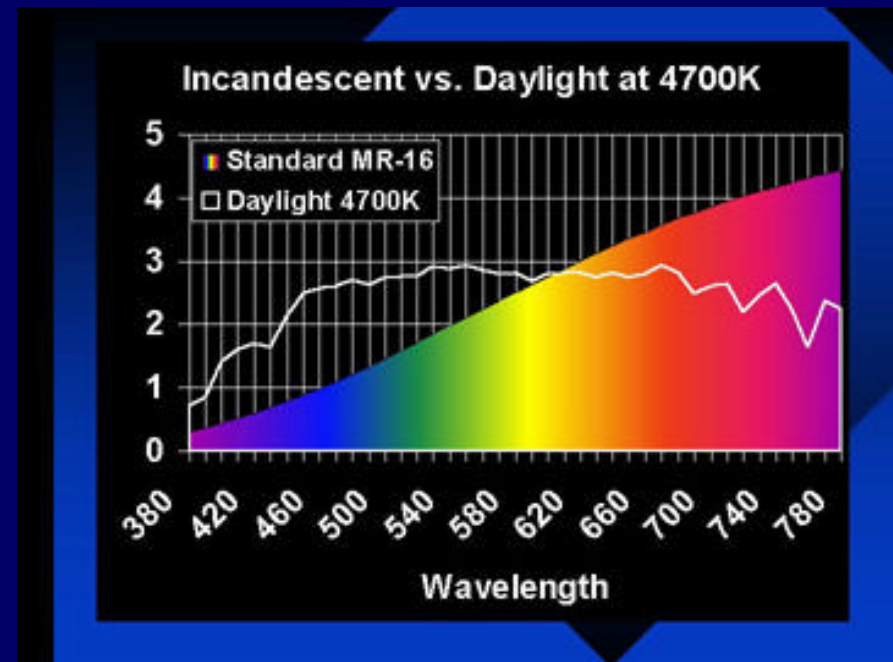
Test Year 2015

### Cost of Natural Replacement Savings by Activity - Fluorescent

Measures with B/C>1.00	Levelized Cost
NR-FLUOR	35.3



# Incandescent Systems



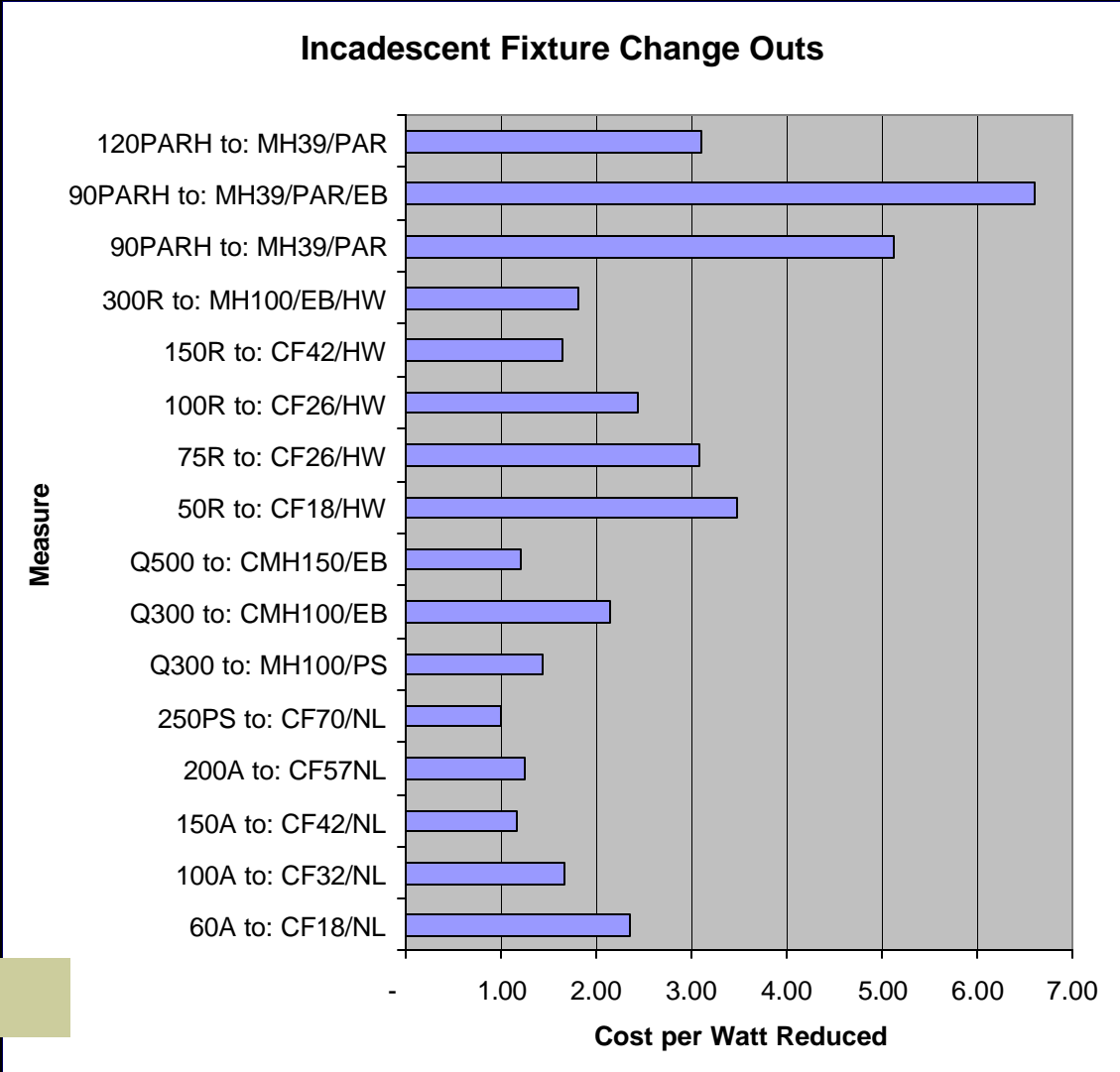
# Typical Conversion: Incandescent to CFL



# Incandescent Retrofit Inputs

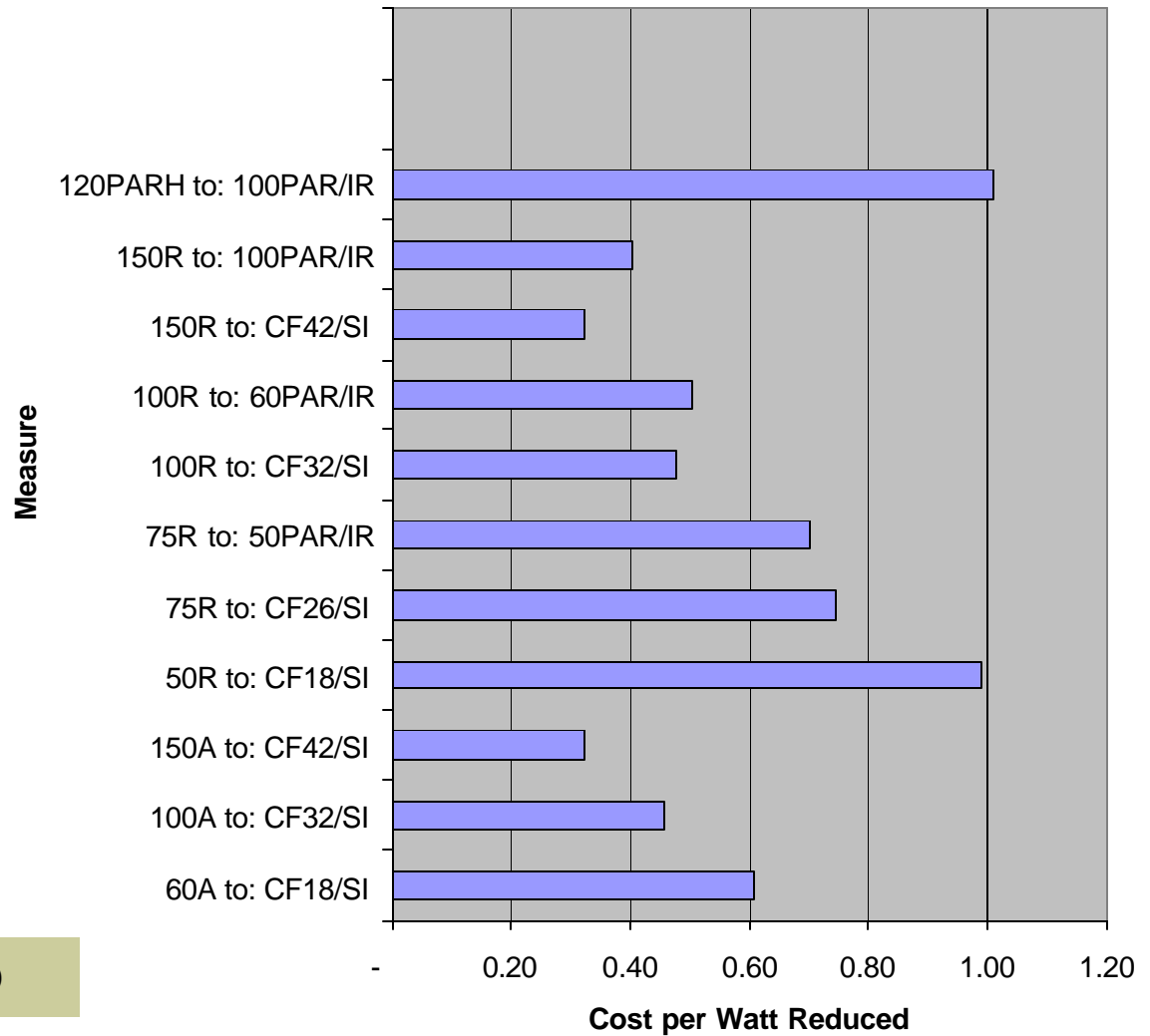
- 35 Measures were summarized
- Calculate cost per Watt saved by measure category
- Normalized costs & savings per sf
- Ran 6 measure categories on 10 building types

# Incandescent Retrofit Inputs



Source: Jim Benya for ETO

## Incandescent Lamp Change Outs



Source: Jim Benya for ETO

# Summary Incandescent Measures

Retrofit	Cost \$/Watt Reduction	Post/Pre Watts
INC to CFL-SI	0.48	34%
INC to CFL-FIX	1.72	34%
INC to MH-FIX	1.41	36%
INC SPOT to MH-FIX	4.23	45%
INC SPOT to INC SPOT-FIX	0.93	72%
INC SPOT to INC SPOT-EE	0.72	70%
INC SPOT to CFL-FIX	2.28	34%

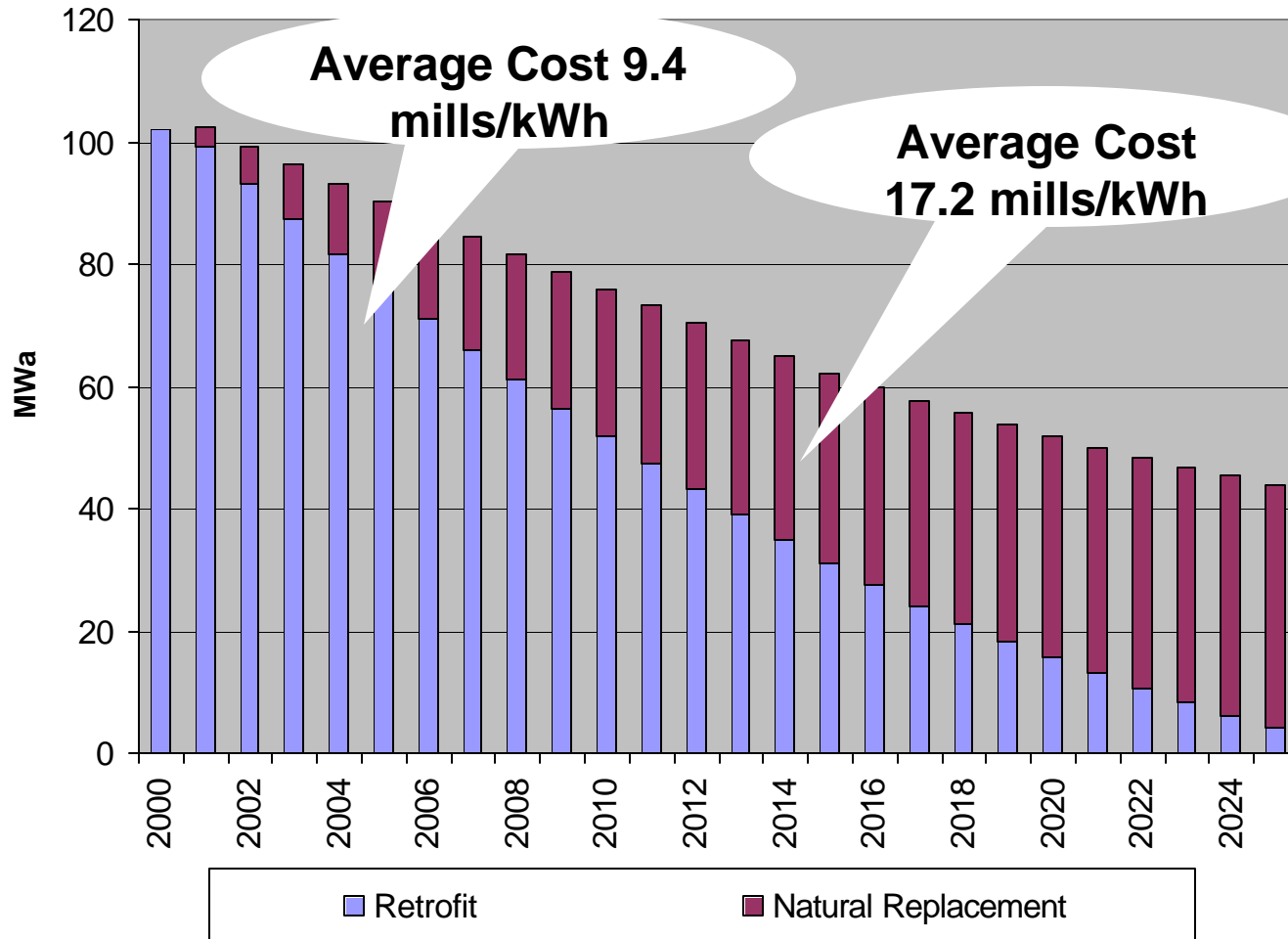
# Incandescent Outputs

- Cost-effective TRC basis
  - Labor savings on replacement lamps
  - Except for INC to INC EE
- Cost-effective on power system
  - But for CFL-Fixture in short-hour apps
- Results similar for retrofit and natural replacement cases
- Levelized Costs are <10 mills/kWh

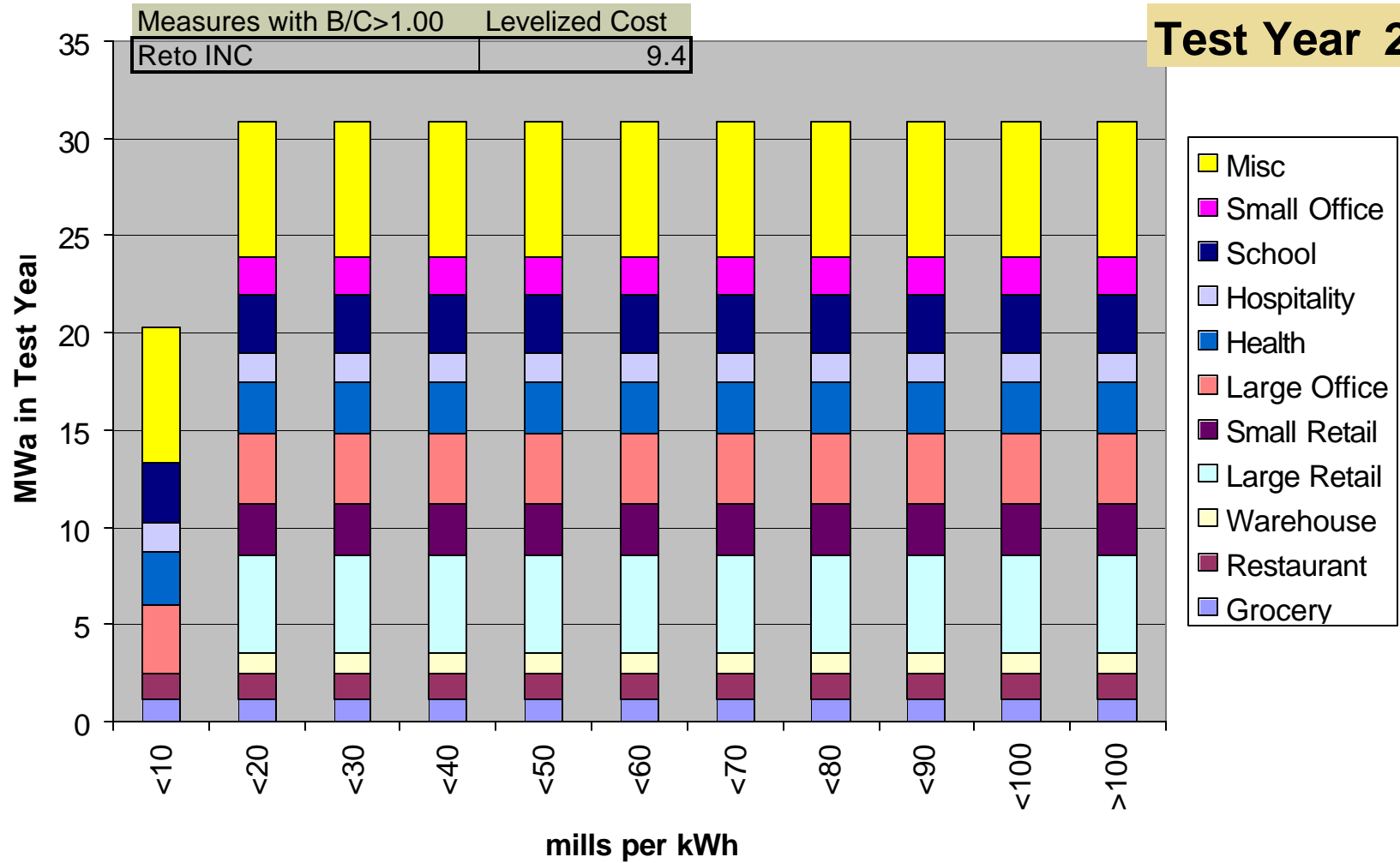
# Incandescent Retrofit Outputs

Sum of Total Regional B/C Ratio	Category									
Measure	Grocery	Health	Large (>20,000 ft2)			Restaur	School	Small (<=20,000 ft2)		Wareho
			Hospital	Office	Retail			Office	Retail	
INC SPOT to CFL-FIX	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0
INC SPOT to INC SPOT-FIX	0.6	0.5	0.5	0.6	0.6	0.5	0.4	0.4	0.6	0.6
INC SPOT to MH-FIX	15.6	2.4	1.4	2.4	2.7	10.6	1.0	1.1	1.9	1.9
INC to CFL-FIX	9999.0	52.4	10.5	20.7	134.3	9999.0	4.5	4.9	20.9	12.4
INC to CFL-SI	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0
INC to MH-FIX	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0	9999.0

### Incandescent Cost-Effective Measures - 2002 Stock



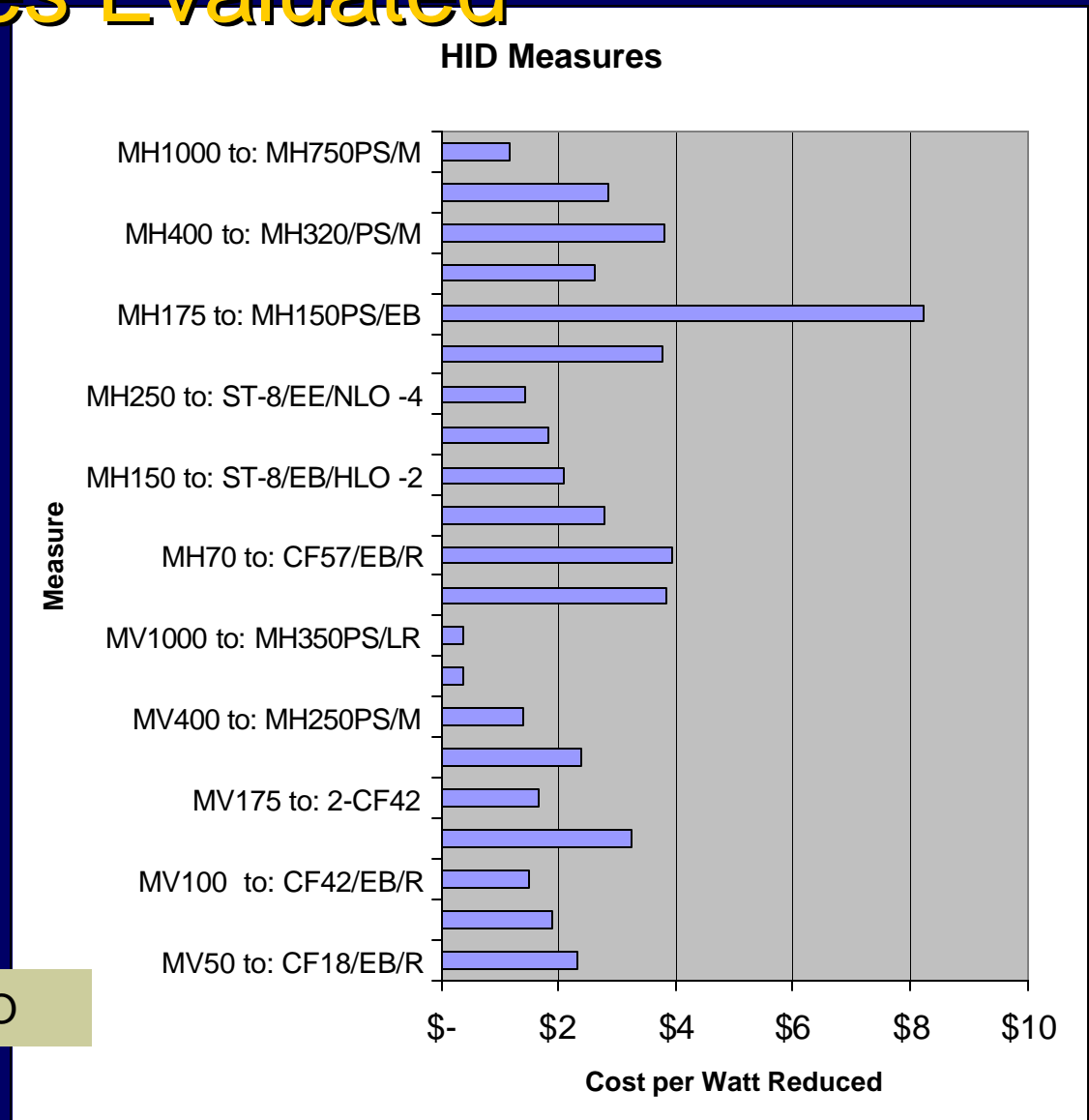
## Cost of Retrofit Savings by Activity - Incandescent Systems



# HID Systems

- 21 Measures were summarized
- Calculate cost per Watt saved by measure category
- Normalized costs & savings per sf
- Ran 6 measure categories on 10 building types

# HID Measures Evaluated



Source: Jim Benya for ETO

# HID Summary Measures

Retrofit	Cost \$/Watt Reduction	Post/Pre Watts
Small MV to CF-R	1.57	37%
Large MV to MHPS	1.58	49%
Small MH to CF-R	3.02	58%
Med MH to LF	1.52	40%
Large MH to MHPS	2.23	76%

# HID Results - Retrofit

Measure	Data	Category									
		Grocery	Health	Hospitality	Large (>20,000 ft2) Office	Large (>20,000 ft2) Retail	Restaurant	School	Small (<=20,000 ft2) Office	Small (<=20,000 ft2) Retail	Warehouse
Large MH to MHPS	Sum of Total Regional B/C Ratio	0.8	0.7	0.7	0.8	0.8	0.7	0.5	0.6	0.8	0.8
	Sum of Bulk System B/C Ratio	1.8	1.0	0.8	1.1	1.3	1.3	0.5	0.6	1.1	0.8
Large MV to MHPS	Sum of Total Regional B/C Ratio	1.1	0.9	1.0	1.1	1.1	0.9	0.7	0.8	1.2	1.1
	Sum of Bulk System B/C Ratio	2.5	1.5	1.1	1.5	1.8	1.9	0.8	0.8	1.6	1.2
Med MH to LF	Sum of Total Regional B/C Ratio	1.3	1.1	1.1	1.3	1.3	1.1	0.8	0.9	1.3	1.2
	Sum of Bulk System B/C Ratio	2.6	1.5	1.1	1.6	1.9	2.0	0.8	0.8	1.6	1.2
Small MH to CF-R	Sum of Total Regional B/C Ratio	0.5	0.4	0.4	0.5	0.5	0.4	0.3	0.3	0.5	0.5
	Sum of Bulk System B/C Ratio	1.3	0.8	0.6	0.8	0.9	1.0	0.4	0.4	0.8	0.6
Small MV to CF-R	Sum of Total Regional B/C Ratio	0.9	0.7	0.8	0.8	0.8	0.7	0.6	0.6	0.9	0.9
	Sum of Bulk System B/C Ratio	2.5	1.5	1.1	1.5	1.8	1.9	0.8	0.8	1.6	1.2

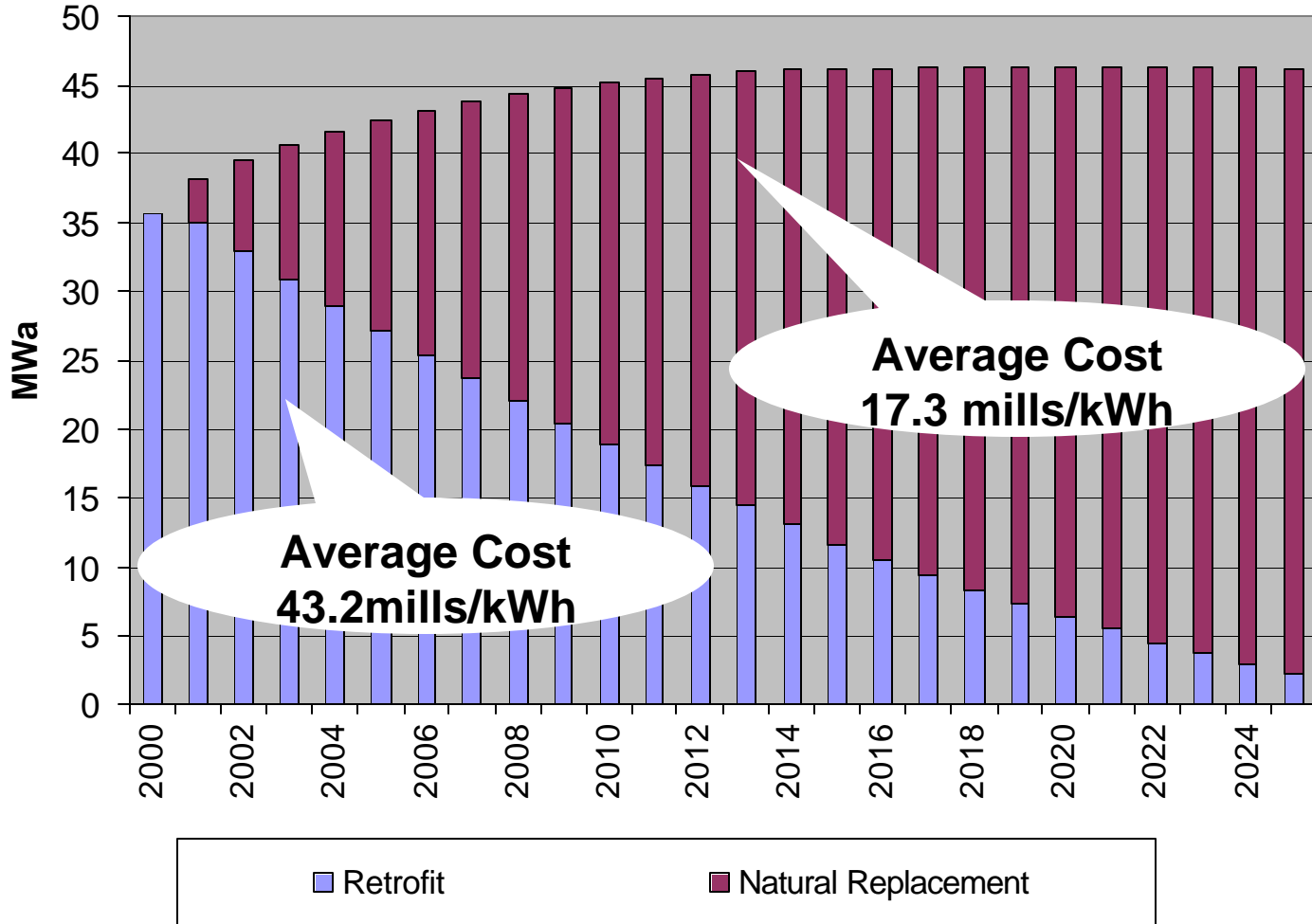
# HID Results- Natural Replacement

Measure	Data	Category									
		Grocery	Health	Hospitality	Large (>20,000 ft2) Office	Large (>20,000 ft2) Retail	Restaurant	School	Small (<=20,000 ft2) Office	Small (<=20,000 ft2) Retail	Warehouse
Large MH to MHPS	Sum of Total Regional B/C Ratio	1.00	0.81	0.83	0.95	0.97	0.80	0.63	0.69	1.01	0.94
	Sum of Bulk System B/C Ratio	2.17	1.29	0.93	1.32	1.58	1.64	0.66	0.69	1.36	1.02
Large MV to MHPS	Sum of Total Regional B/C Ratio	2.82	2.33	2.39	2.71	2.78	2.26	1.80	2.00	2.91	2.71
	Sum of Bulk System B/C Ratio	6.36	3.78	2.72	3.87	4.64	4.79	1.93	2.01	3.99	2.98
Med MH to LF	Sum of Total Regional B/C Ratio	3.63	2.86	2.82	3.36	3.51	2.96	2.14	2.38	3.53	3.18
	Sum of Bulk System B/C Ratio	6.02	3.58	2.57	3.66	4.39	4.54	1.83	1.91	3.77	2.82
Small MH to CF-R	Sum of Total Regional B/C Ratio	0.61	0.46	0.50	0.56	0.55	0.52	0.37	0.42	0.58	0.57
	Sum of Bulk System B/C Ratio	1.69	1.00	0.72	1.03	1.23	1.27	0.51	0.53	1.06	0.79
Small MV to CF-R	Sum of Total Regional B/C Ratio	1.99	1.53	1.77	1.89	1.80	1.67	1.30	1.46	1.99	2.03
	Sum of Bulk System B/C Ratio	8.92	5.30	3.81	5.43	6.51	6.73	2.71	2.82	5.59	4.18

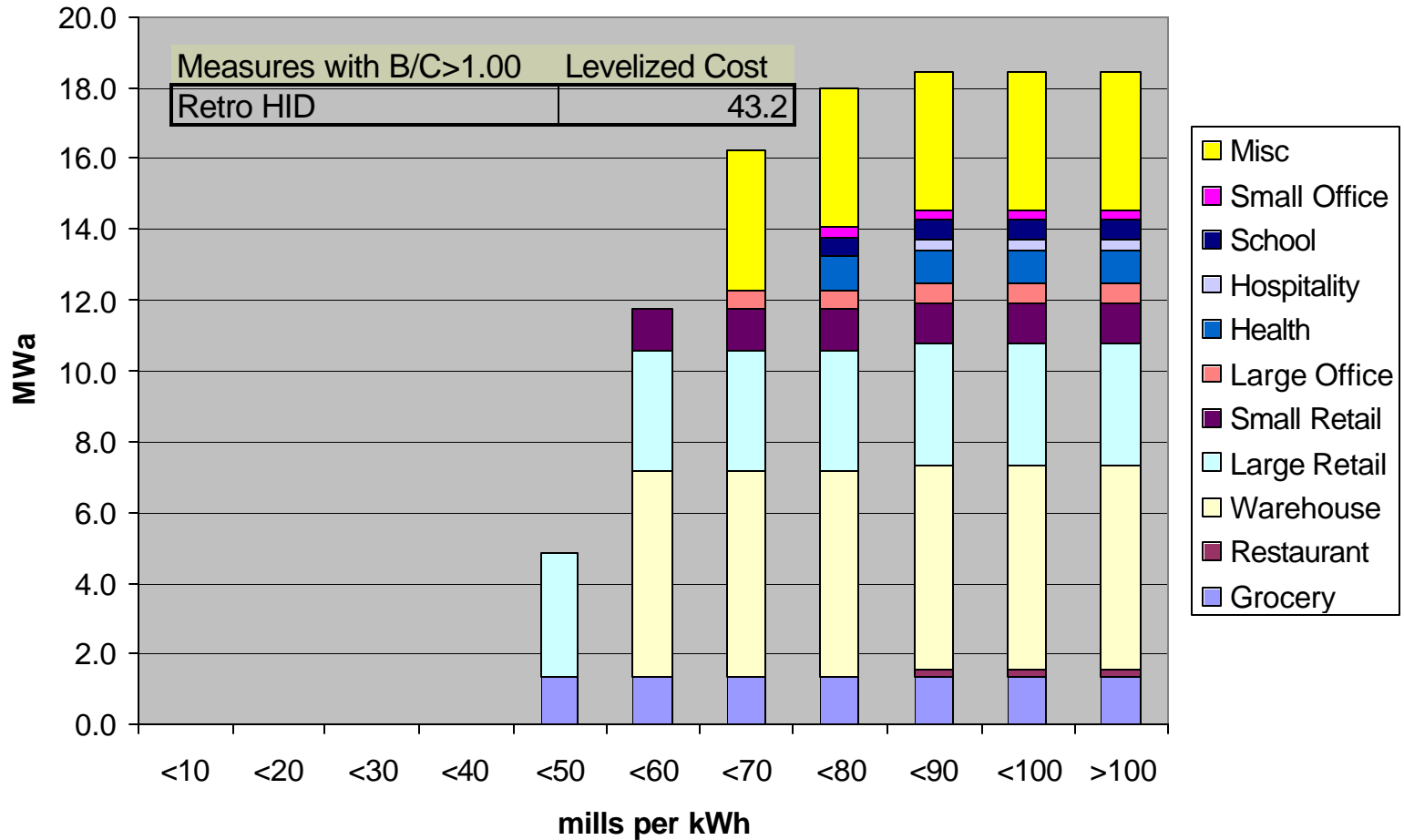
# HID Results

- Cost-Effective Both TRC and Power System
  - All Mercury Vapor conversions
  - Metal Halide to Linear Fluorescent (T5 & HPT8)
- Not Cost-effective
  - Schools & Small Offices
- Sometimes cost-effective
  - Conversions to CFL reflectors
  - Standard Metal Halide to Pulse Start Metal Halide
- MH to CFL Reflector is cost-effective to power system, but not to customer

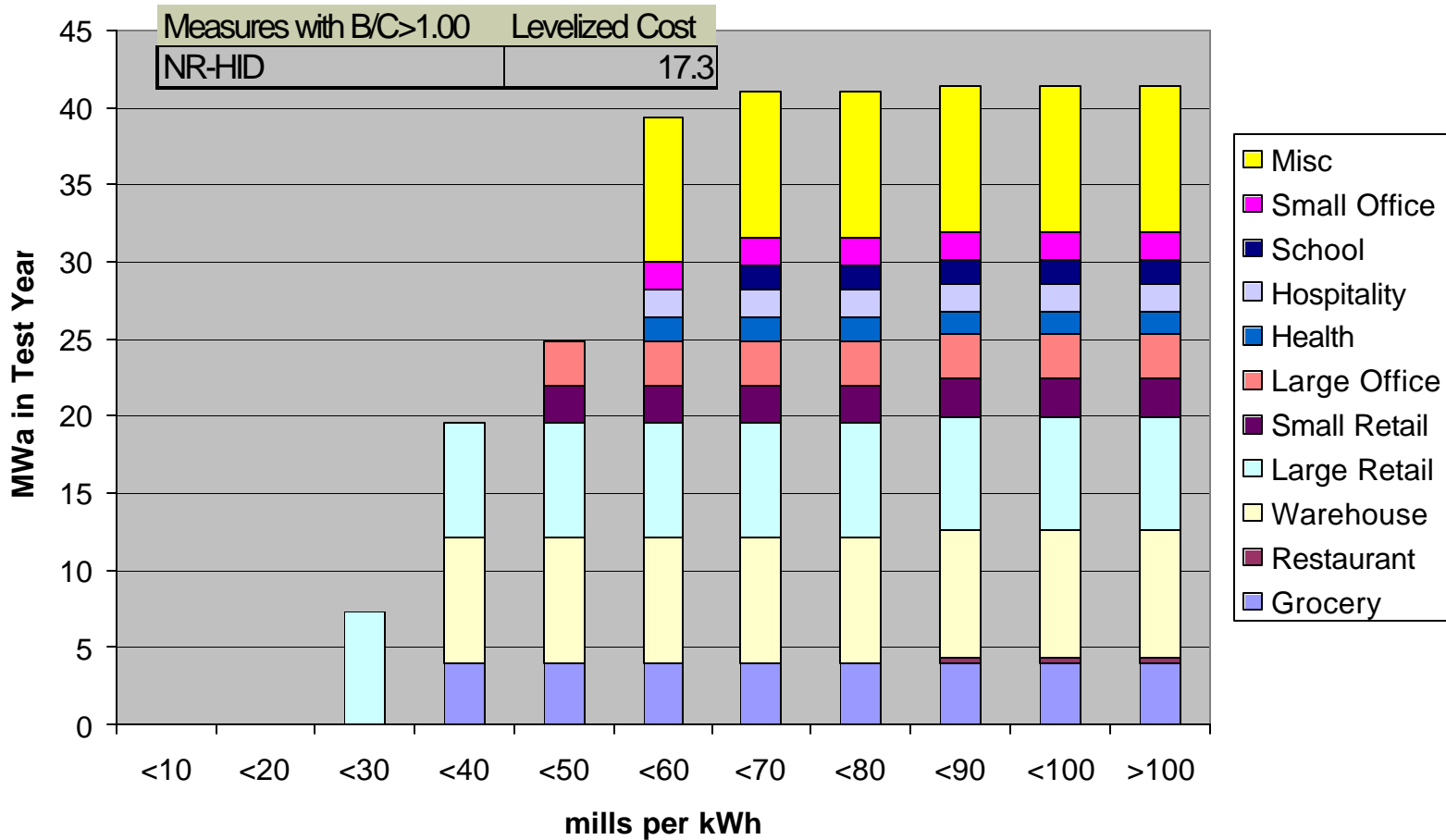
### Cost-Effective HID Measures - 2002 Stock



### Cost of Retrofit Savings by Activity Type - HID Systems



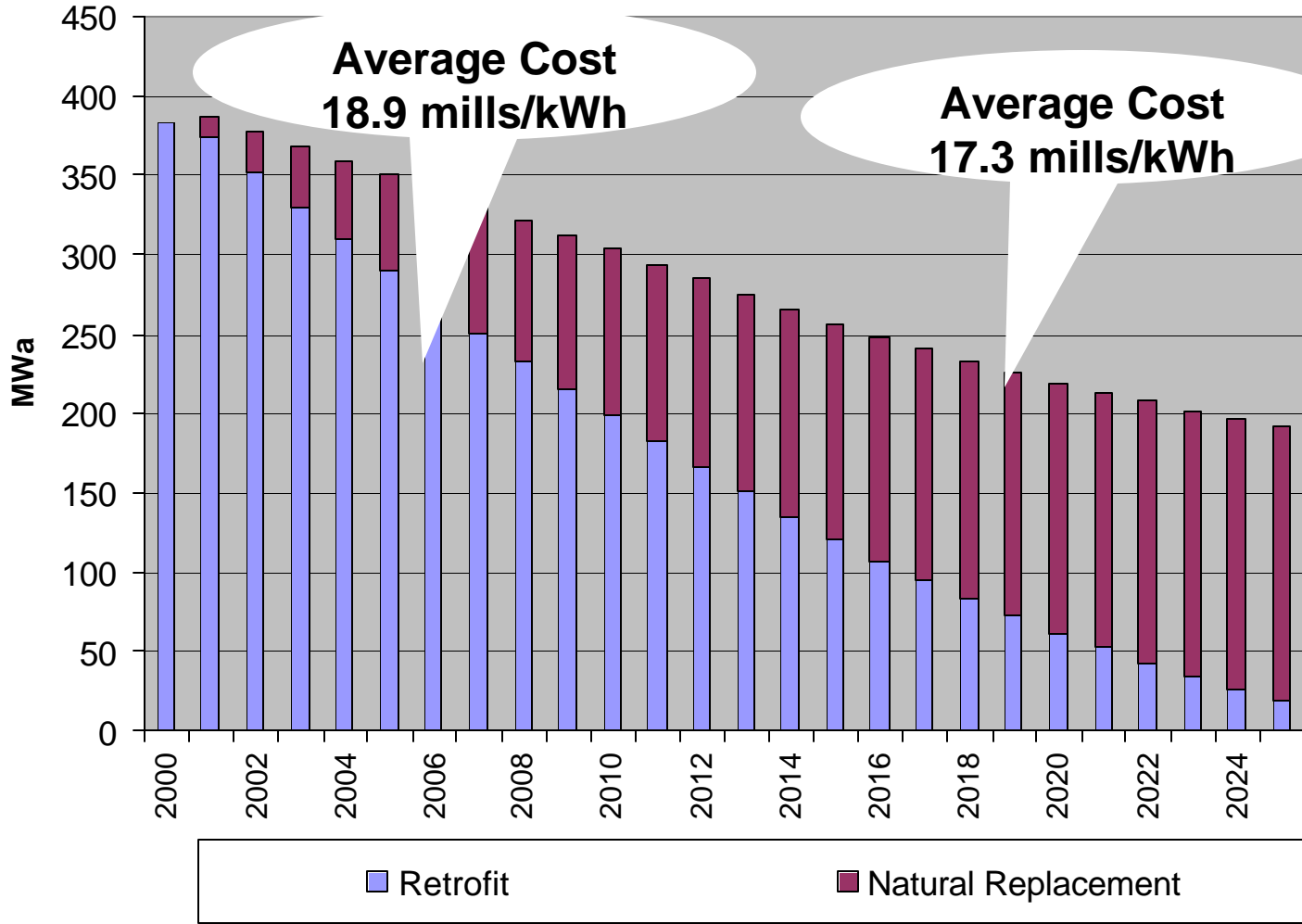
### Cost of Natural Replacement Savings - HID Lighting



## Final Step: All Retrofit Measures Together

- 11 Fluorescent Measures
- Six Incandescent Measures
- Five HID Measures
- Ten Activity Types
- New and Replacement Scenarios

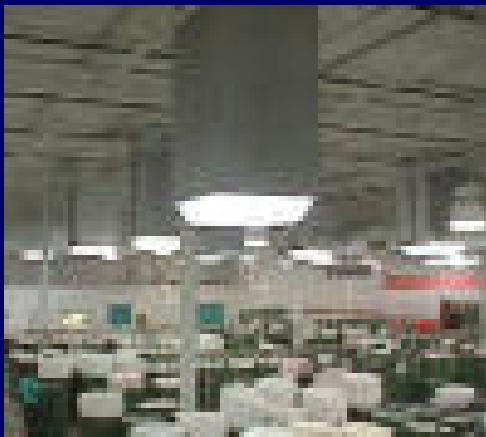
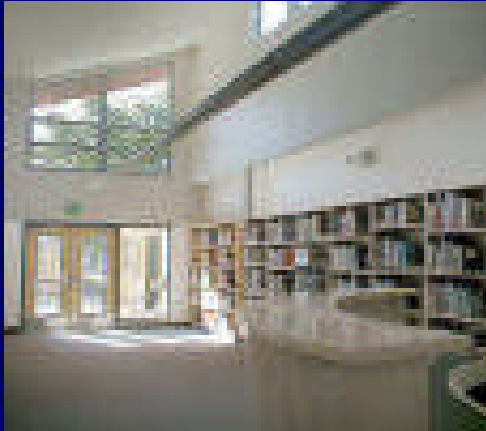
## All Cost-Effective Lighting Measures on 2002 Stock



# All Measures Together

Measures with B/C > 1.00	Levelized Cost
Retro FLUOR	23.3
Reto INC	9.4
Retro HID	43.2
NR-FLUOR	35.3
NR-INC	17.0
NR-HID	17.3

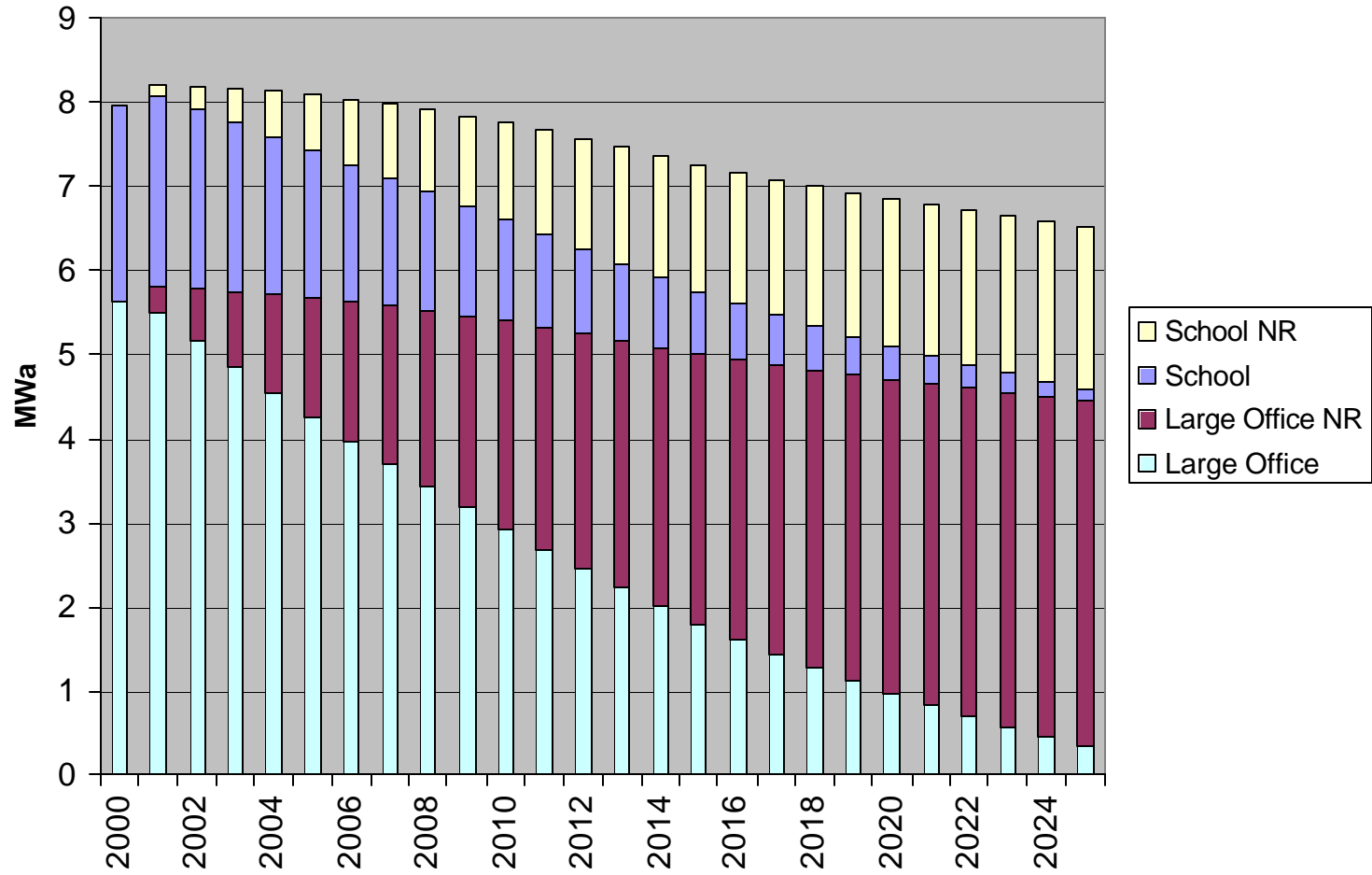
# Day Lighting



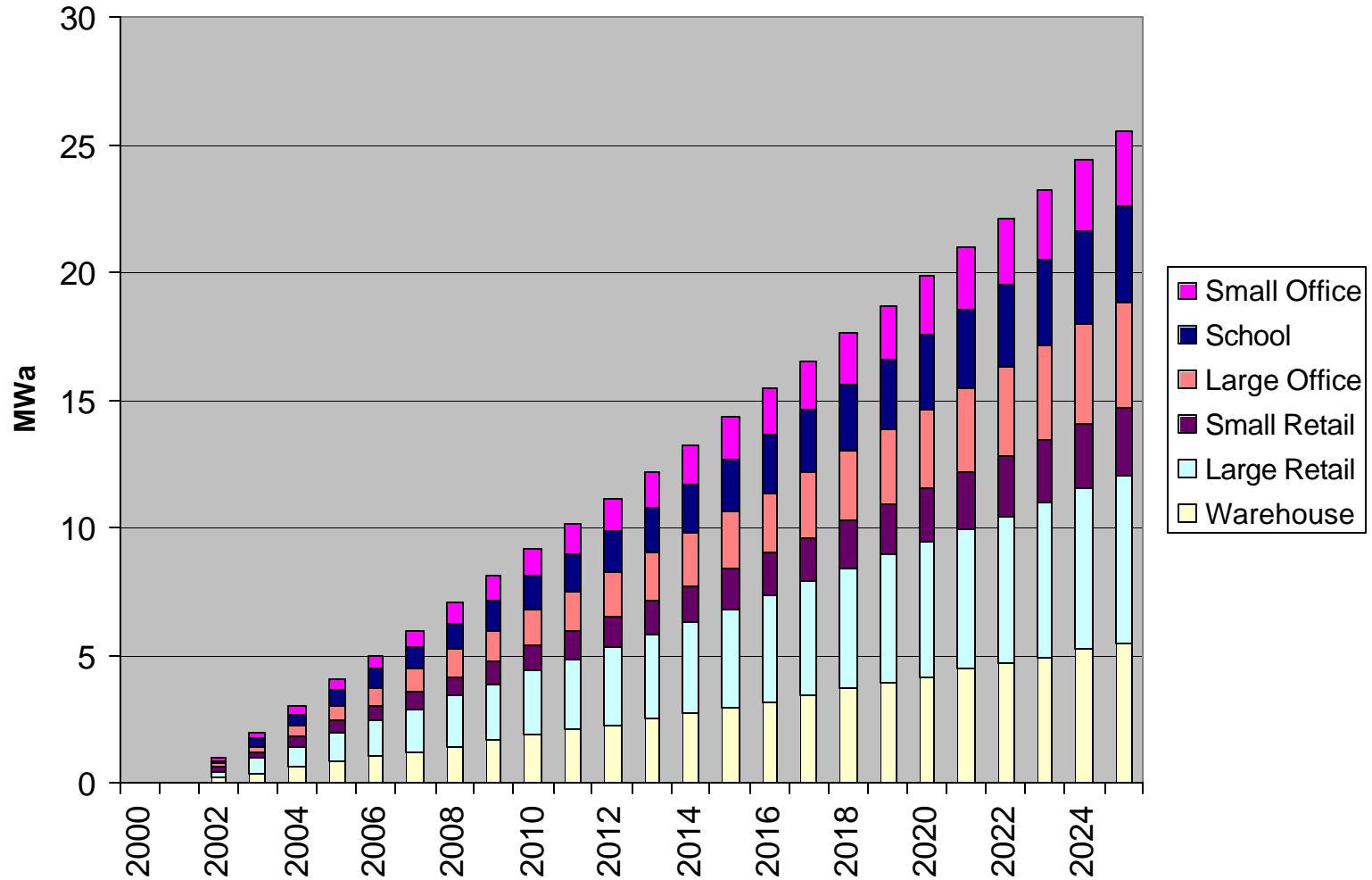
# First Cut Estimates

- Based on reduced LPD from previous measures
- Retrofit potential in Office and School
- New building potential Warehouse, One-story Retail, Office and School
- Costs not yet evaluated

## Daylighting Controls



## Day Lighting Potential in New Buildings



# Next Up:



“So quick bright things....”

- The Bard
- A Midsummer Night's Dream