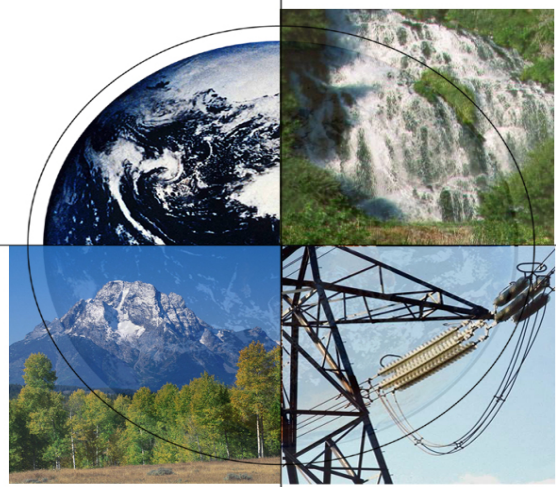
# DOE/NETL's Phase II Field Testing Program
## Updated Economic Analysis of Mercury Control via Activated Carbon Injection



*DOE/NETL's Mercury Control Technology R&D Program Review*

*December 12, 2007*
*Pittsburgh, PA*

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**Science Applications International Corporation**

# Disclaimer

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It should also be noted that the economic analyses represent “snapshots” in time based on the methodology used, assumptions made, and conditions that were specific to the time when DOE/NETL field testing occurred. Consequently, the economics presented are plant- and condition-specific and attempts to use this presentation as a tool to predict the performance of these mercury control technologies at other power plants should be conducted cautiously regardless of similarities in coal-rank and APCD configuration. In addition, the economics originate from relatively small datasets in many cases. As a result, the cost of mercury control could vary significantly with the inclusion of additional ACI performance data from current and future DOE/NETL field testing.

# Updated Economic Analysis of ACI

## *Purpose & Objectives*

## Purpose

- Develop *plant-specific* cost estimates for Hg control via:
  - Untreated ACI
  - Chemically-treated (or brominated) ACI
  - Conventional ACI with Sorbent Enhancement Additives (SEA)
- Gauge NETL's success in achieving cost target (25-50% below $60,000/lb)

## Objectives

- Discern the level of Hg capture that is attributable to ACI
- Incorporate the long-term (~30 days) field testing results
- Quantify the potential impacts of ACI on CUB reuse & disposal

***Economics represent "snapshots" in time based on the methodology used, assumptions made, and conditions present when DOE/NETL field testing occurred***

# Phase II Site Descriptions

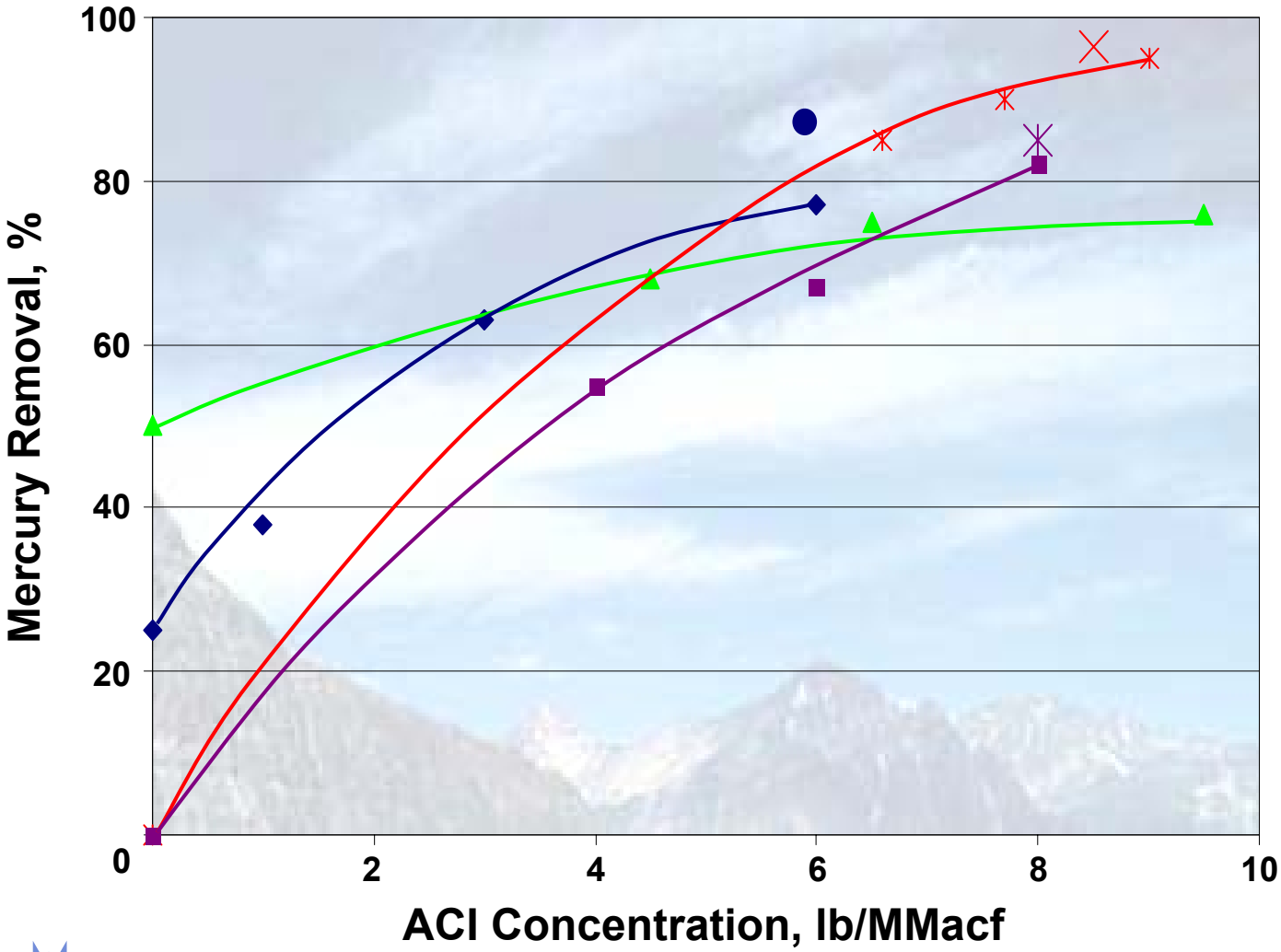
| Site | Holcomb Unit 1 | Meramec Unit 2 | Stanton Unit 10 | St. Clair Unit 1 | Leland Olds Unit 1 | Yates Unit 1 |
|---|---|---|---|---|---|---|
| Capacity, MW | 360 | 140 | 60 | 145 | 220 | 100 |
| Coal Rank | PRB | PRB | ND Lignite | 85:15 PRB/ Bituminous blend | ND Lignite | Bituminous |
| APCD Configuration | SDA/FF | CS-ESP | SDA/FF | CS-ESP | CS-ESP | CS-ESP & Wet FGD |
| $T_{ACI,}$ °F | 290 | 310 | 300 | 290 | 340 | 310 |
| Flue Gas Flow Rate, ACFM | 1,194,444 | 555,556 | 251,789 | 751,000 | 878,049 | 480,000 |
| Hg in Flue Gas, lb/hr | 0.0383 | 0.0128 | 0.0050 | 0.0087 | 0.0216 | 0.0071 |
| Co-benefit Hg Capture, lb/hr | 0.0142 (37%) | 0.0041 (32%) | 0.0000 (0%) | 0.0022 (25%) | 0.0039 (18%) | 0.0035 (50%) |
| Hg Control Technology | DARCO® Hg-LH | DARCO® Hg-LH | DARCO® Hg-LH | B-PAC™ | DARCO® Hg w/ $CaCl_2$ | Super HOK |

# Phase II Site Descriptions

| Site | Monroe Unit 4 | Lee Unit 1 | Stanton Unit 1 | Dave Johnston Unit 3 | Leland Olds Unit 1 | Portland Unit 1 |
|---|---|---|---|---|---|---|
| Capacity, MW | 785 | 79 | 150 | 240 | 220 | 170 |
| Coal Rank | 60:40 PRB/ Bituminous blend | Bituminous | PRB | PRB | ND Lignite | Bituminous |
| APCD Configuration | SCR & CS-ESP | CS-ESP | CS-ESP | CS-ESP | CS-ESP | CS-ESP |
| $T_{ACI}$, °F | 270 | 300 | 325 | 770 | 800 | 640 |
| Flue Gas Flow Rate, ACFM | 3,600,000 | 320,000 | 574,390 | 925,195 | 878,049 | 520,621 |
| Hg in Flue Gas, lb/hr | 0.0465 | 0.0032 | 0.0083 | 0.0193 | 0.0216 | 0.0159 |
| Co-benefit Hg Capture, lb/hr | 0.0116 (25%) | 0.0007 (21%) | 0.0012 (15%) | 0.0023 (12%) | 0.0039 (18%) | 0.0046 (29%) |
| Hg Control Technology | DARCO® Hg | B-PAC™ | B-PAC™ | Mer-Clean™ 8 | Mer-Clean™ 8 | Mer-Clean™ 8-21 |

# Phase II Parametric Data Curves

## *Bituminous Units*[a]




**Portland Unit 1**
Mer-Clean™ 8-21
CS-ESP

**Monroe Unit 4**
DARCO® Hg
SCR & CS-ESP

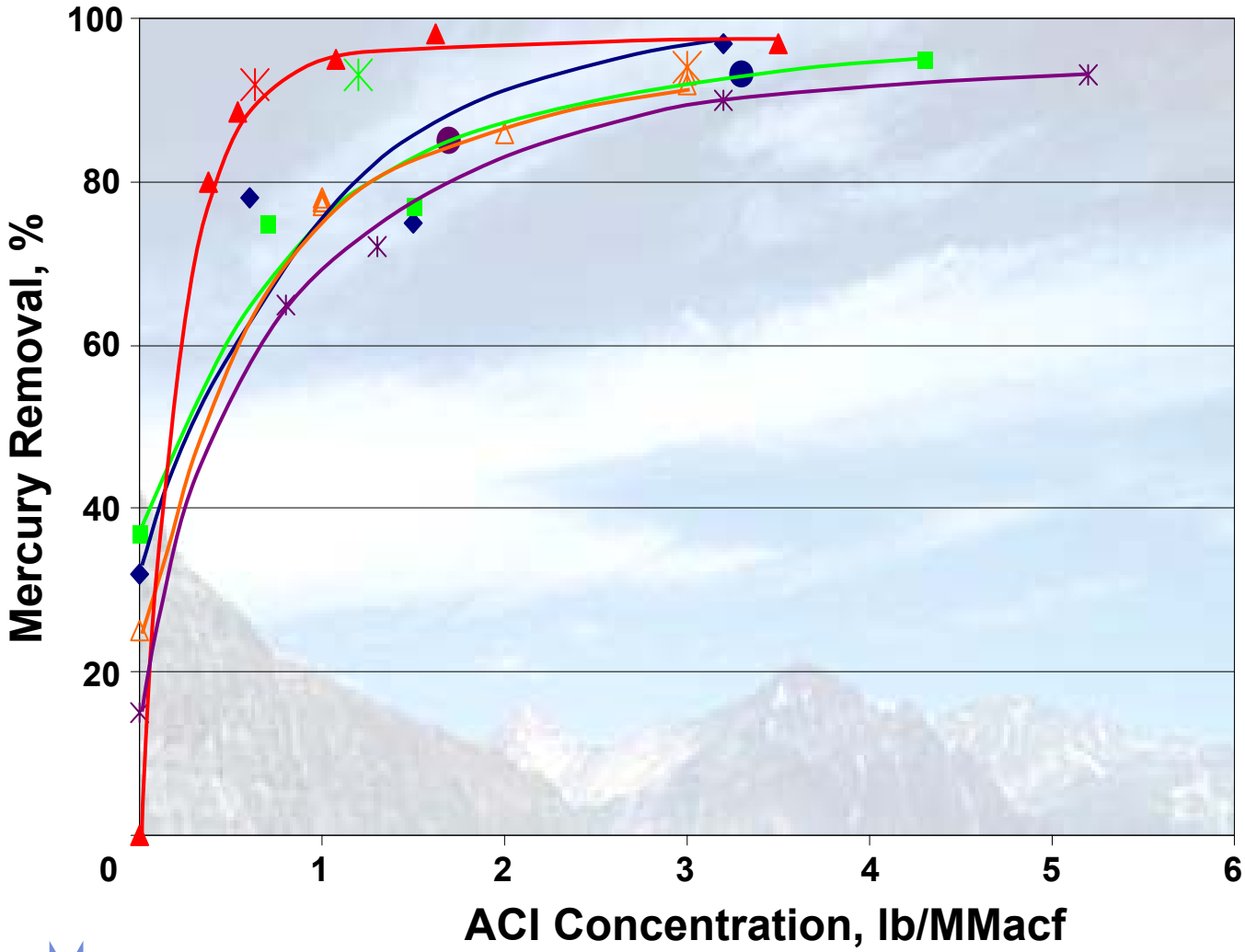
**Lee Unit 1**
B-PAC™
CS-ESP

**Plant Yates Unit 1**
Super HOK
CS-ESP & wet FGD

[a] Monroe typically burns a 60:40 PRB and bituminous coal blend

# Phase II Parametric Data Curves

## *PRB Subbituminous Units*[a]




**Dave Johnston Unit 3**
Mer-Clean™ 8
CS-ESP

**Meramec Unit 2**
DARCO® Hg-LH
CS-ESP

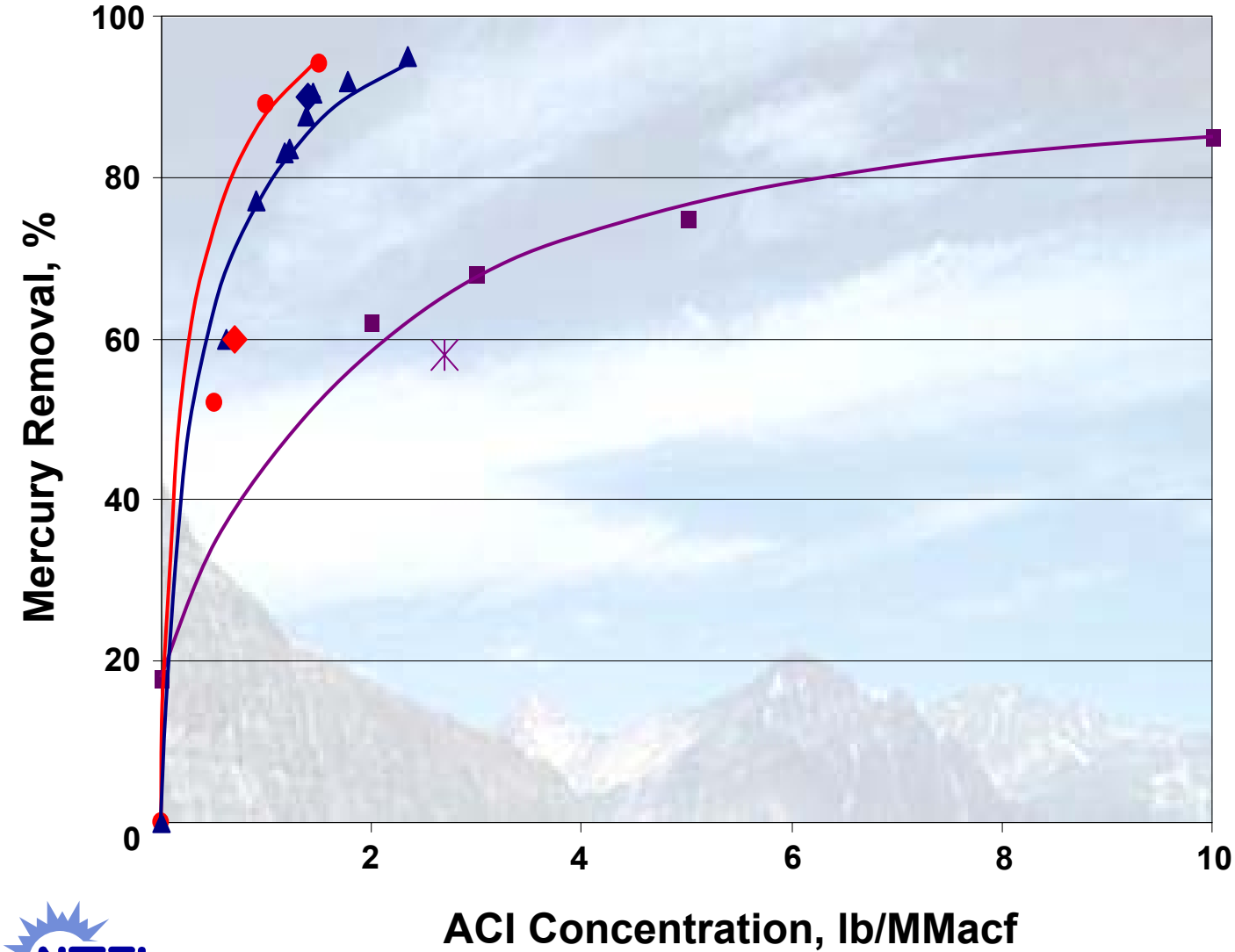
**St. Clair Unit 1**
B-PAC™
CS-ESP

**Holcomb Unit 1**
DARCO® Hg-LH
SDA/FF

**Stanton Unit 1**
B-PAC™
CS-ESP

[a] St. Clair typically burns a 85:15 PRB and bituminous coal blend

# Phase II Parametric Data Curves
## *ND Lignite Units*

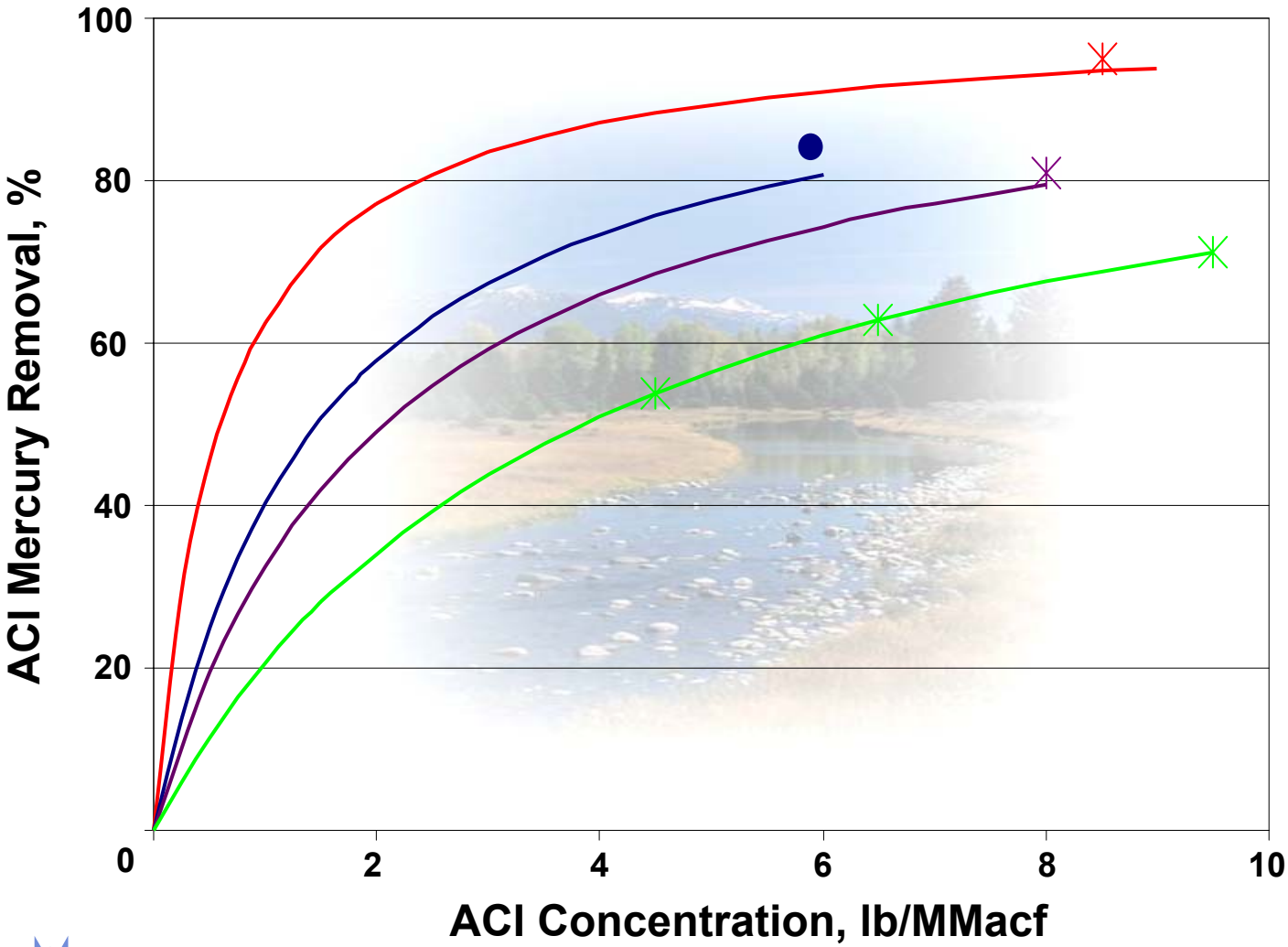



**Stanton Unit 10**
DARCO® Hg-LH
SDA/FF

**Leland Olds Unit 1**
Mer-Clean™ 8
CS-ESP

**Leland Olds Unit 1**
DARCO® Hg w/ $CaCl_2$
CS-ESP

# Phase II Adjusted Regression Curves
## *Bituminous Units*[a]




**Portland Unit 1**
Mer-Clean™ 8-21
CS-ESP

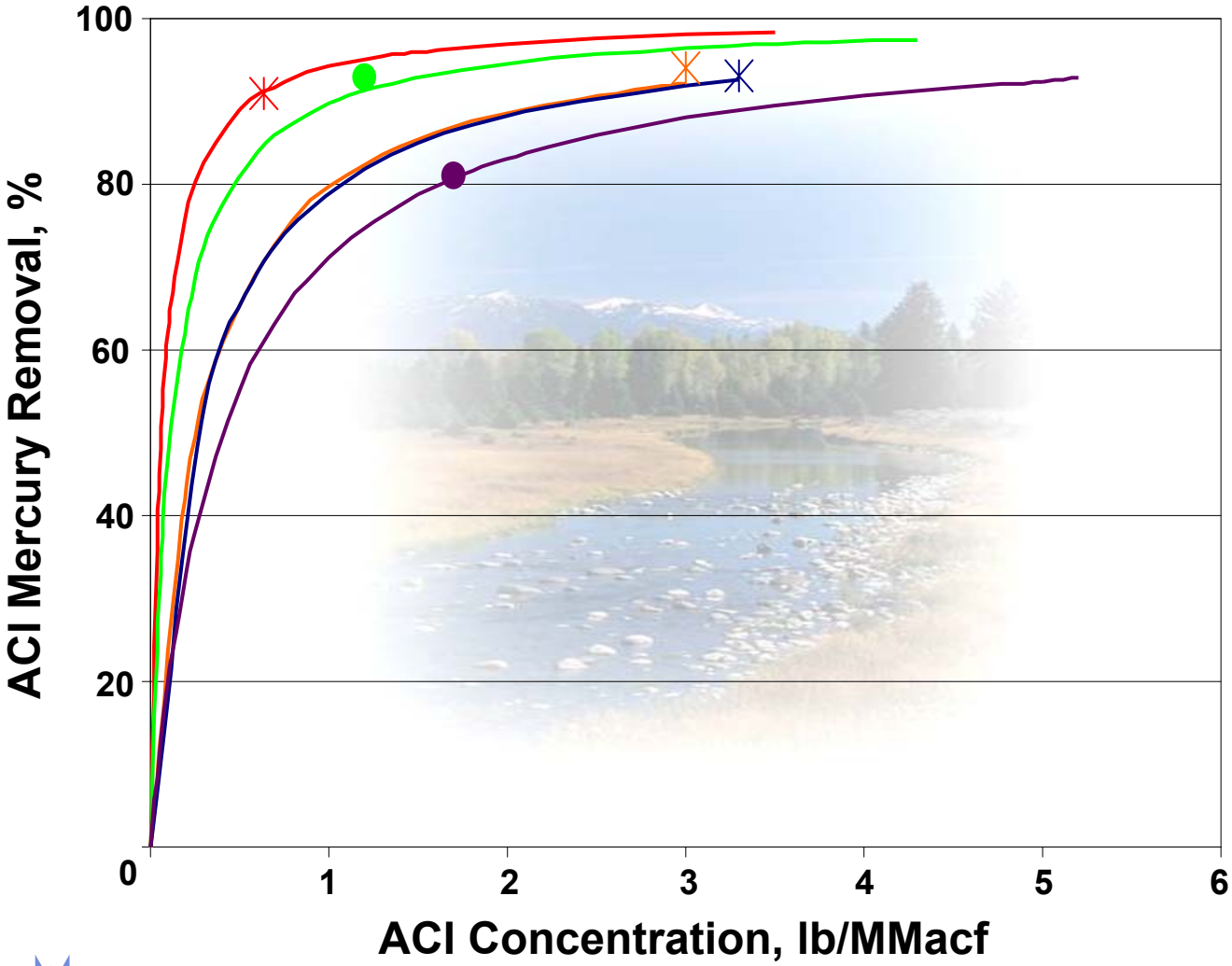
**Monroe Unit 4**
DARCO® Hg
SCR & CS-ESP

**Lee Unit 1**
B-PAC™
CS-ESP

**Plant Yates Unit 1**
Super HOK
CS-ESP & wet FGD

[a] Monroe typically burns a 60:40 PRB and bituminous coal blend

# Phase II Adjusted Regression Curves
## *PRB Subbituminous Units*[a]




**Dave Johnston Unit 3**
Mer-Clean™ 8
CS-ESP

**Holcomb Unit 1**
DARCO® Hg-LH
SDA/FF

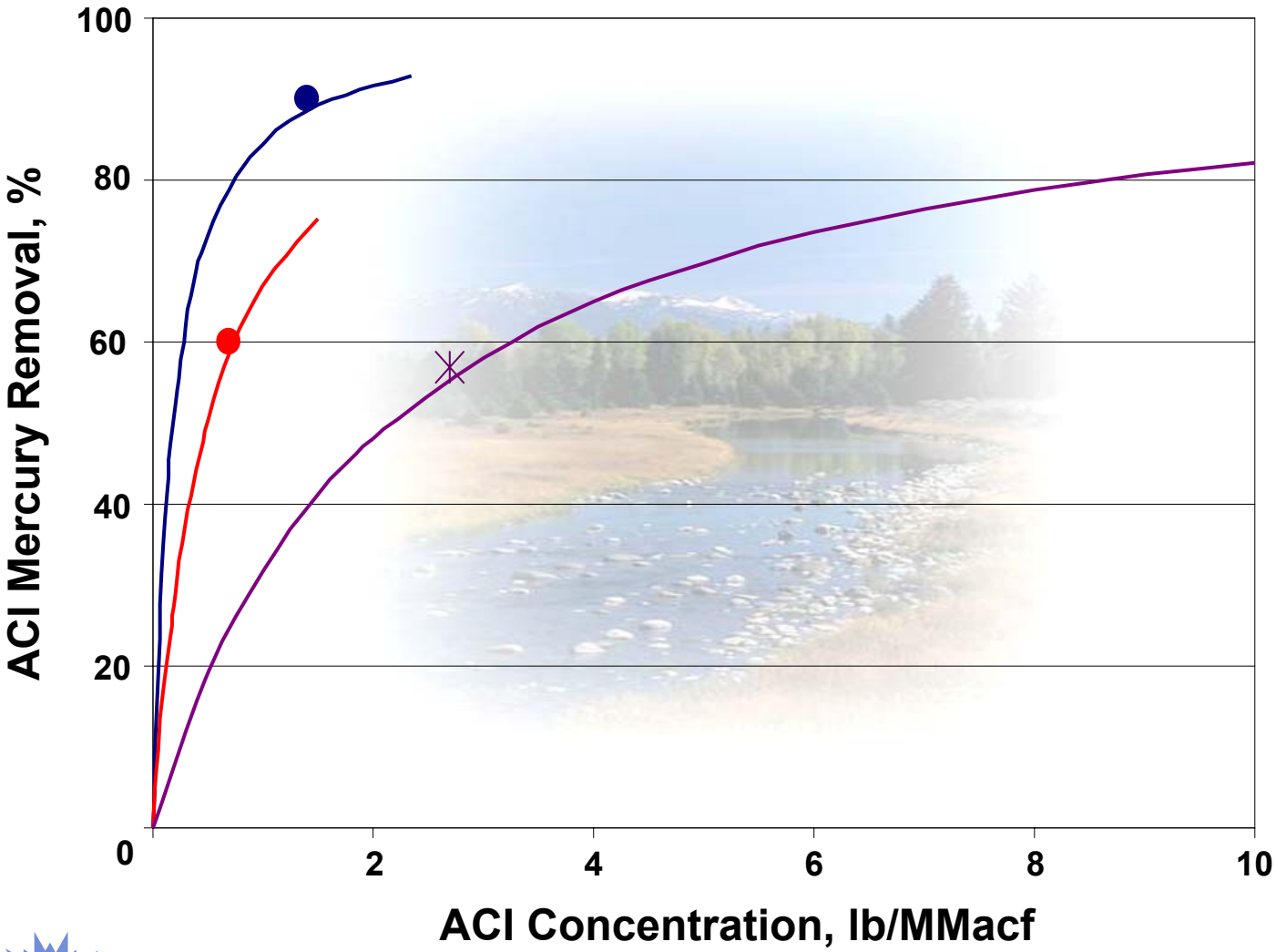
**St. Clair Unit 1**
B-PAC™
CS-ESP

**Meramec Unit 2**
DARCO® Hg-LH
CS-ESP

**Stanton Unit 1**
B-PAC™
CS-ESP

[a] St. Clair typically burns a 85:15 PRB and bituminous coal blend

# Phase II Adjusted Regression Curves
## *ND Lignite Units*

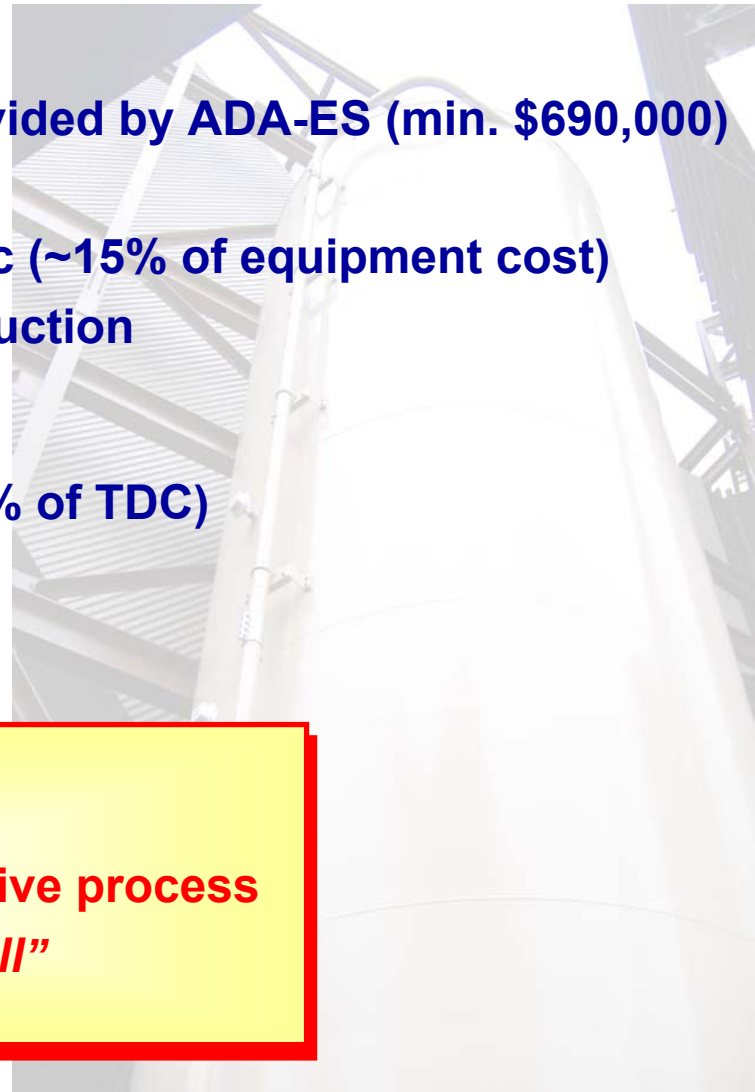



**Leland Olds Unit 1**
Mer-Clean™ 8
CS-ESP

**Stanton Unit 10**
DARCO® Hg-LH
SDA/FF

**Leland Olds Unit 1**
DARCO® Hg w/ $CaCl_2$
CS-ESP

# Capital Costs
## *Sorbent Storage and Injection System*



**Total Direct Cost (TDC)**

- Equipment cost based on estimates provided by ADA-ES (min. $690,000)
- Site Integration
- Cost of retrofit installation is site-specific (~15% of equipment cost)
- No adjustment for interest during construction

**Indirect Costs**

- General facilities & engineering fees (10% of TDC)
- Project contingency (15% of TDC)
- Process contingency (5% of TDC)

**Key Points**

Not a very capital-intensive process

*"One size fits all"*

# Annual Operating & Maintenance (O&M) Costs

- **Sorbent Consumption**
  - **ACI Concentration, Delivered Sorbent Price & Flue Gas Flow Rate**
- **Sorbent Disposal ($17/ton)**
- **SEA ($CaCl_2$) Consumption ($0.20/lb delivered)**
- **"Other" O&M Costs[a]**

## Potential CUB Impacts

- $17/ton for fly ash & SDA by-product disposal

**For Units with ESP**

- $18/ton for lost revenue from fly ash sales (assuming 100% reuse prior to ACI)

| Sorbent Name | Manufacturer | Description | Delivered Price ($/lb)[b] |
|---|---|---|---|
| Super HOK | RWE Rhinebraun | Untreated | 0.39 |
| DARCO® Hg | NORIT Americas | Untreated | 0.54 |
| DARCO® Hg-LH | NORIT Americas | Brominated | 0.95 |
| B-PAC™ | Sorbent Technologies | Brominated | 0.95 |
| Mer-Clean™ 8 and 8-21 | ALSTOM-PPL | Chemically-treated | 1.35 |

[a] Includes power consumption ($0.05/kW); operating labor (4 hrs/day @ $45/hr); ACI equipment maintenance (5% of uninstalled equipment cost); and spare parts ($10,000 annually).

[b] Includes $0.10/lb for transportation expenses.

# Cost Estimates for 70% ACI Mercury Control
## *Bituminous Units*

| | Portland Unit 1 | Monroe Unit 4 | Lee Unit 1 | Plant Yates Unit 1 |
|---|---|---|---|---|
| PAC / SEA | Mer-Clean™ 8-21 | DARCO® Hg | B-PAC™ | Super HOK |
| ACI Rate, lb/MMacf | 1.39 | 3.38 | 4.83 | 8.98 |
| Capital Cost, $ | $1,360,000 | $3,000,000 | $1,270,000 | $1,270,000 |
| Unit Capital, $/kW | $8.00 | $3.82 | $16.02 | $12.66 |
| **First-Year Annual O&M Costs (2006 $ - 80% capacity factor)** | | | | |
| PAC Consumption, $/yr | $410,000 | $2,760,000 | $617,000 | $707,000 |
| PAC Disposal, $/yr | $2,580 | $43,500 | $5,520 | $15,400 |
| Other, $/yr | $107,000 | $167,000 | $106,000 | $111,000 |
| Total O&M, $/yr | $520,000 | $2,970,000 | $729,000 | $833,000 |
| CUB Impacts[a], $/yr | $1,090,000 | $5,450,000 | $758,000 | $1,080,000 |
| **20-Year Levelized Cost *without* Byproduct Impacts (Current $)** | | | | |
| COE Increase, mills/kWh | 0.69 | 0.75 | 1.95 | 1.72 |
| $/lb Hg Removed | $14,900 | $24,000 | $87,200 | $69,500 |
| **20-Year Levelized Cost *with* Byproduct Impacts (Current $)** | | | | |
| COE Increase, mills/kWh | 1.84 | 1.99 | 3.66 | 3.66 |
| $/lb Hg Removed | $39,600 | $63,900 | $164,000 | $148,000 |

[a] For units equipped with CS-ESP, by-product impacts include the fly ash disposal cost ($17/ton) and lost revenue from fly ash sales ($18/ton) assuming 100% utilization. For the SDA/FF configuration, only the cost of SDA by-product disposal ($17/ton) is included.

# Cost Estimates for 80-90%[a] ACI Mercury Control

## *Bituminous Units*

| | Portland Unit 1 | Monroe Unit 4 | Lee Unit 1 |
|---|---|---|---|
| PAC / SEA | Mer-Clean™ 8-21 | DARCO® Hg | B-PAC™ |
| ACI Rate, lb/MMacf | 5.34 | 5.78 | 8.27 |
| Capital Cost, $ | $1,360,000 | $3,000,000 | $1,270,000 |
| Unit Capital, $/kW | $8.00 | $3.82 | $16.02 |
| **First-Year Annual O&M Costs (2006 $ - 80% capacity factor)** | | | |
| PAC Consumption, $/yr | $1,580,000 | $4,720,000 | $1,060,000 |
| PAC Disposal, $/yr | $9,940 | $74,300 | $9,460 |
| Other, $/yr | $111,000 | $165,000 | $106,000 |
| Total O&M, $/yr | $1,700,000 | $4,960,000 | $1,170,000 |
| CUB Impacts[b], $/yr | $1,090,000 | $5,450,000 | $758,000 |
| **20-Year Levelized Cost *without* Byproduct Impacts (Current $)** | | | |
| COE Increase, mills/kWh | 1.94 | 1.20 | 2.95 |
| $/lb Hg Removed | $32,300 | $33,800 | $103,000 |
| **20-Year Levelized Cost *with* Byproduct Impacts (Current $)** | | | |
| COE Increase, mills/kWh | 3.09 | 2.45 | 4.67 |
| $/lb Hg Removed | $51,500 | $68,800 | $163,000 |

[a] Cost estimates for 80% Hg control at the Monroe and Lee Stations, and 90% Hg control at Portland Station.

[b] For units equipped with CS-ESP, by-product impacts include the fly ash disposal cost ($17/ton) and lost revenue from fly ash sales ($18/ton) assuming 100% utilization. For the SDA/FF configuration, only the cost of SDA by-product disposal ($17/ton) is included.

# Cost Estimates for 70% ACI Mercury Control

## *Subbituminous Units*

| | DJ Unit 3 | Holcomb Unit 1 | St. Clair Unit 1 | Meramec Unit 2 | Stanton Unit 1 |
|---|---|---|---|---|---|
| PAC / SEA | Mer-Clean™ 8 | DARCO® Hg-LH | B-PAC™ | DARCO® Hg-LH | B-PAC™ |
| ACI Rate, lb/MMacf | 0.14 | 0.27 | 0.60 | 0.62 | 0.95 |
| Capital Cost, $ | $1,920,000 | $1,310,000 | $1,280,000 | $1,280,000 | $1,280,000 |
| Unit Capital, $/kW | $8.00 | $3.63 | $8.79 | $9.16 | $8.50 |
| **First-Year Annual O&M Costs (2006 $ - 80% capacity factor)** | | | | | |
| PAC Consumption, $/yr | $75,200 | $128,000 | $179,000 | $138,000 | $217,000 |
| PAC Disposal, $/yr | $474 | $1,140 | $1,600 | $1,230 | $1,940 |
| Other, $/yr | $122,000 | $105,000 | $105,000 | $105,000 | $105,000 |
| Total O&M, $/yr | $197,000 | $234,000 | $286,000 | $244,000 | $324,000 |
| CUB Impacts[a], $/yr | $1,730,000 | $1,430,000 | $792,000 | $1,060,000 | $566,000 |
| **20-Year Levelized Cost *without* Byproduct Impacts (Current $)** | | | | | |
| COE Increase, mills/kWh | 0.30 | 0.18 | 0.52 | 0.48 | 0.54 |
| $/lb Hg Removed | $5,970 | $3,910 | $16,300 | $11,100 | $16,500 |
| **20-Year Levelized Cost *with* Byproduct Impacts (Current $)** | | | | | |
| COE Increase, mills/kWh | 1.59 | 0.89 | 1.49 | 1.84 | 1.22 |
| $/lb Hg Removed | $32,100 | $19,000 | $47,200 | $42,400 | $36,900 |

[a] For units equipped with CS-ESP, by-product impacts include the fly ash disposal cost ($17/ton) and lost revenue from fly ash sales ($18/ton) assuming 100% utilization. For the SDA/FF configuration, only the cost of SDA by-product disposal ($17/ton) is included.

# Cost Estimates for 90% ACI Mercury Control

## *Subbituminous Units*

| | DJ Unit 3 | Holcomb Unit 1 | St. Clair Unit 1 | Meramec Unit 2 | Stanton Unit 1 |
|---|---|---|---|---|---|
| PAC / SEA | Mer-Clean™ 8 | DARCO® Hg-LH | B-PAC™ | DARCO® Hg-LH | B-PAC™ |
| ACI Rate, lb/MMacf | 0.55 | 1.03 | 2.31 | 2.40 | 3.65 |
| Capital Cost, $ | $1,920,000 | $1,310,000 | $1,280,000 | $1,280,000 | $1,280,000 |
| Unit Capital, $/kW | $8.00 | $3.63 | $8.79 | $9.16 | $8.50 |
| **First-Year Annual O&M Costs (2006 $ - 80% capacity factor)** | | | | | |
| PAC Consumption, $/yr | $291,000 | $493,000 | $692,000 | $532,000 | $837,000 |
| PAC Disposal, $/yr | $1,830 | $4,420 | $6,190 | $4,760 | $7,490 |
| Other, $/yr | $122,000 | $107,000 | $107,000 | $106,000 | $108,000 |
| Total O&M, $/yr | $414,000 | $605,000 | $805,000 | $643,000 | $953,000 |
| CUB Impacts[a], $/yr | $1,730,000 | $1,430,000 | $792,000 | $1,060,000 | $566,000 |
| **20-Year Levelized Cost *without* Byproduct Impacts (Current $)** | | | | | |
| COE Increase, mills/kWh | 0.46 | 0.37 | 1.16 | 0.99 | 1.29 |
| $/lb Hg Removed | $7,190 | $6,090 | $28,500 | $17,800 | $30,500 |
| **20-Year Levelized Cost *with* Byproduct Impacts (Current $)** | | | | | |
| COE Increase, mills/kWh | 1.75 | 1.08 | 2.13 | 2.35 | 1.97 |
| $/lb Hg Removed | $27,500 | $17,900 | $52,500 | $42,100 | $46,400 |

[a] For units equipped with CS-ESP, by-product impacts include the fly ash disposal cost ($17/ton) and lost revenue from fly ash sales ($18/ton) assuming 100% utilization. For the SDA/FF configuration, only the cost of SDA by-product disposal ($17/ton) is included.

# Cost Estimates for 70% ACI Mercury Control

## *ND Lignite Units*

| | Leland Olds Unit 1 | Stanton Unit 10 | Leland Olds Unit 1 |
|---|---|---|---|
| PAC / SEA | Mer-Clean™ 8 | DARCO® Hg-LH | DARCO® Hg & $CaCl_2$ |
| ACI Rate, lb/MMacf | 0.42 | 1.15 | 5.04 |
| Capital Cost, $ | $1,760,000 | $1,270,000 | $1,420,000 |
| Unit Capital, $/kW | $8.00 | $21.10 | $6.45 |
| **First-Year Annual O&M Costs (2006 $ - 80% capacity factor)** | | | |
| PAC Consumption, $/yr | $212,000 | $116,000 | $1,000,000 |
| PAC Disposal, $/yr | $1,330 | $1,040 | $15,800 |
| SEA Consumption, $/yr | N/A | N/A | $214,000 |
| Other, $/yr | $118,000 | $104,000 | $112,000 |
| Total O&M, $/yr | $331,000 | $221,000 | $1,350,000 |
| CUB Impacts[a], $/yr | $3,240,000 | $579,000 | $3,240,000 |
| **20-Year Levelized Cost *without* Byproduct Impacts (Current $)** | | | |
| COE Increase, mills/kWh | 0.42 | 1.05 | 1.21 |
| $/lb Hg Removed | $7,400 | $17,900 | $21,500 |
| **20-Year Levelized Cost *without* Byproduct Impacts (Current $)** | | | |
| COE Increase, mills/kWh | 3.05 | 2.78 | 3.84 |
| $/lb Hg Removed | $54,100 | $47,300 | $68,200 |

[a] For units equipped with CS-ESP, by-product impacts include the fly ash disposal cost ($17/ton) and lost revenue from fly ash sales ($18/ton) assuming 100% utilization. For the SDA/FF configuration, only the cost of SDA by-product disposal ($17/ton) is included.

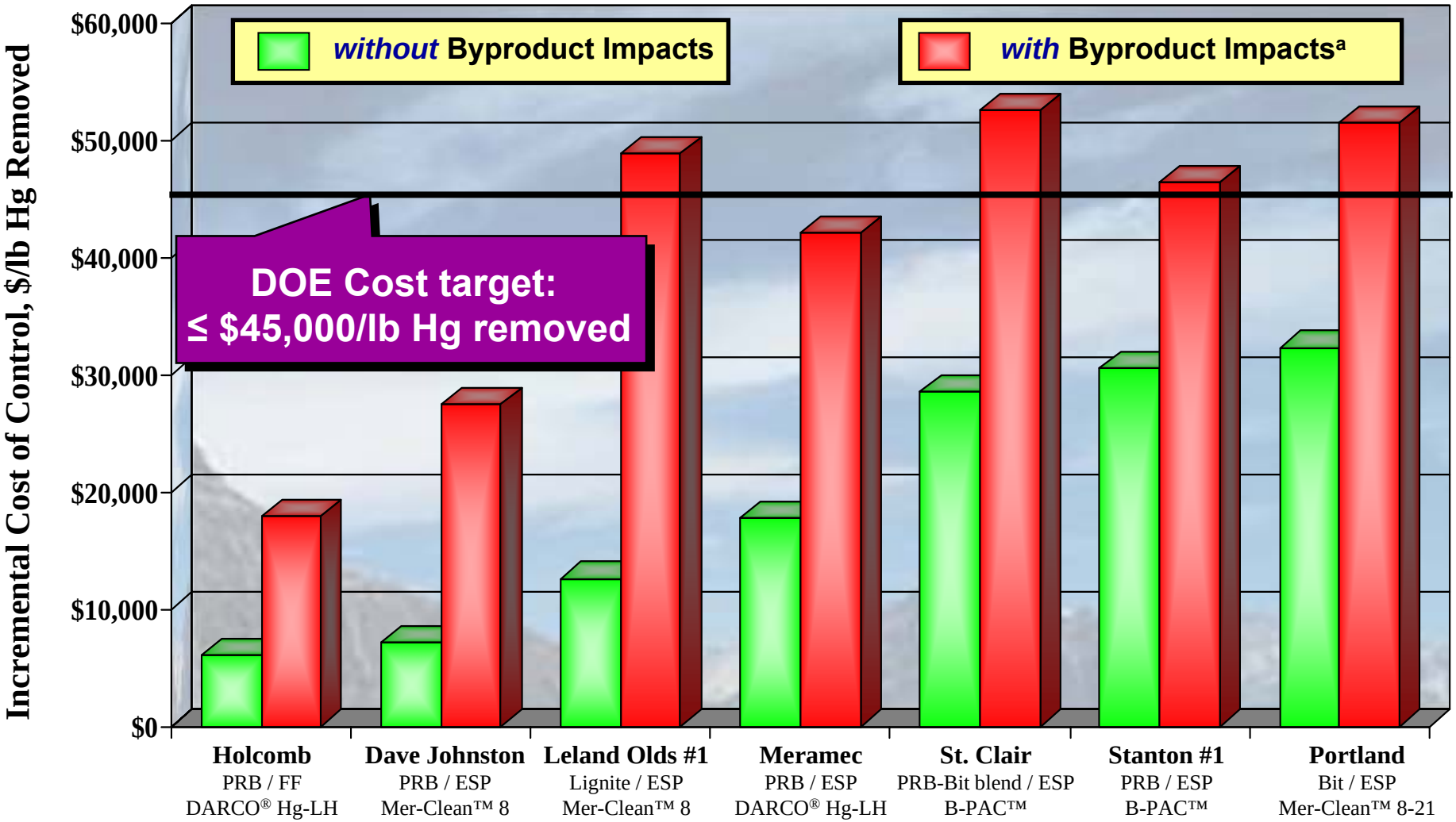
# Cost Estimates for 80-90%[a] ACI Mercury Control

## *ND Lignite Units*

| | Leland Olds Unit 1 | Stanton Unit 10 | Leland Olds Unit 1 |
|---|---|---|---|
| PAC / SEA | Mer-Clean™ 8 | DARCO® Hg-LH | DARCO® Hg & $CaCl_2$ |
| ACI Rate, lb/MMacf | 1.64 | 1.98 | 8.65 |
| Capital Cost, $ | $1,760,000 | $1,270,000 | $1,420,000 |
| Unit Capital, $/kW | $8.00 | $21.10 | $6.45 |
| **First-Year Annual O&M Costs (2006 $ - 80% capacity factor)** | | | |
| PAC Consumption, $/yr | $816,000 | $199,000 | $1,720,000 |
| PAC Disposal, $/yr | $5,140 | $1,780 | $27,100 |
| SEA Consumption, $/yr | N/A | N/A | $214,000 |
| Other, $/yr | $119,000 | $105,000 | $112,000 |
| Total O&M, $/yr | $940,000 | $305,000 | $2,080,000 |
| CUB Impacts[b], $/yr | $3,240,000 | $579,000 | $3,240,000 |
| **20-Year Levelized Cost *without* Byproduct Impacts (Current $)** | | | |
| COE Increase, mills/kWh | 0.91 | 1.30 | 1.81 |
| $/lb Hg Removed | $12,600 | $17,300 | $24,900 |
| **20-Year Levelized Cost *without* Byproduct Impacts (Current $)** | | | |
| COE Increase, mills/kWh | 3.54 | 3.03 | 4.44 |
| $/lb Hg Removed | $48,900 | $40,100 | $61,200 |

[a] Cost estimates for 80% Hg control at the Leland Olds and Stanton Stations, and 90% Hg control via Mer-Clean 8 injection at Leland Olds.
[b] For units equipped with CS-ESP, by-product impacts include the fly ash disposal cost ($17/ton) and lost revenue from fly ash sales ($18/ton) assuming 100% utilization. For the SDA/FF configuration, only the cost of SDA by-product disposal ($17/ton) is included.

# Incremental Cost of 90% ACI Mercury Control

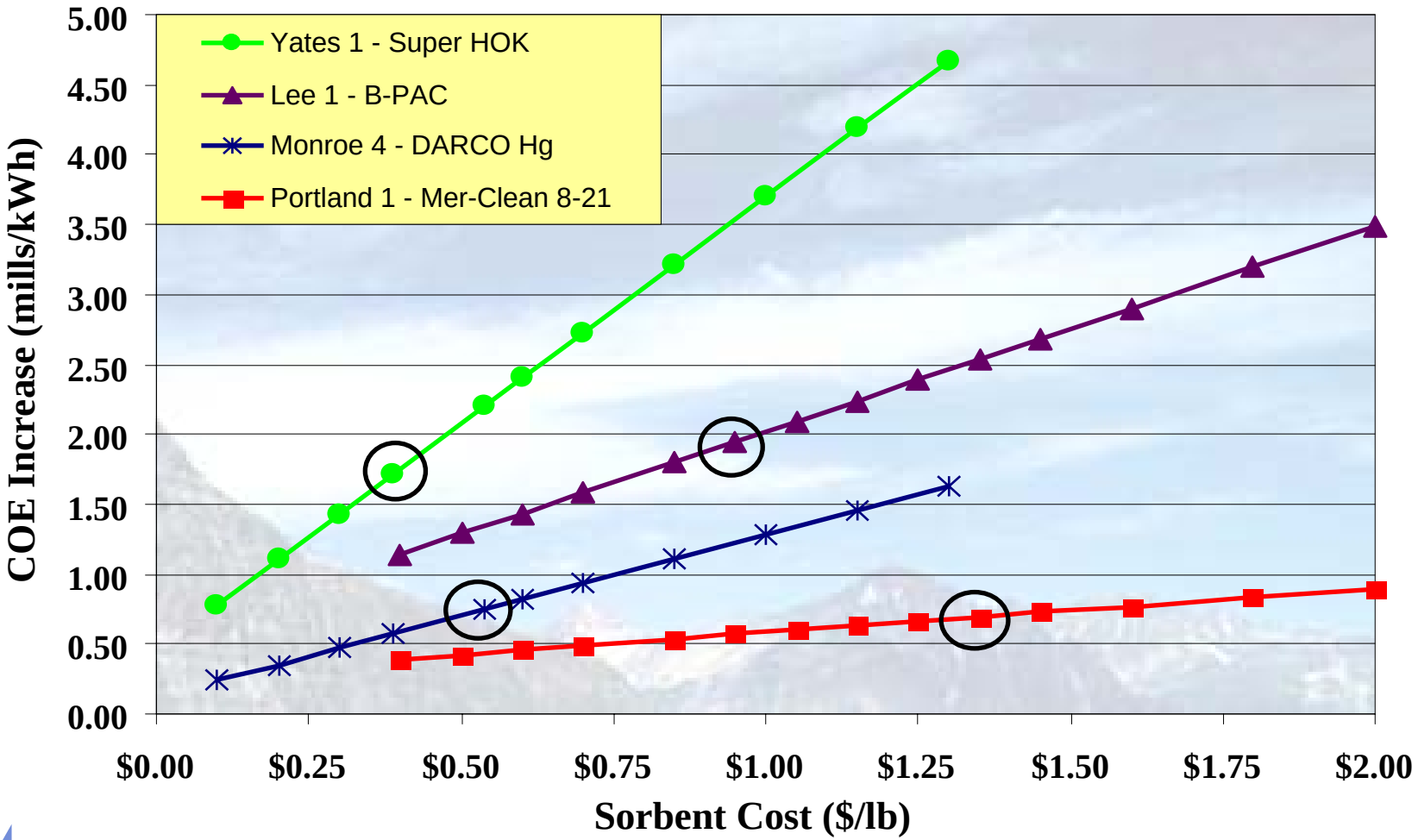



[a] For units equipped with an ESP, byproduct impacts include the fly ash disposal cost ($17/ton) and lost revenue from fly ash sales ($18/ton), assuming 100% utilization. For the SDA/FF configuration, only the cost of SDA byproduct disposal ($17/ton) is included.

***Source:*** *DOE/NETL's UPDATED Economic Analysis of Activated Carbon Injection, May 2007*
*http://www.netl.doe.gov/technologies/coalpower/ewr/mercury/pubs/Phase_II_UPDATED_Hg_Control_Economic_Analysis.pdf*

# Sensitivity of Incremental COE Increase[a] for 70% ACI Mercury Control to Variations in Sorbent Cost

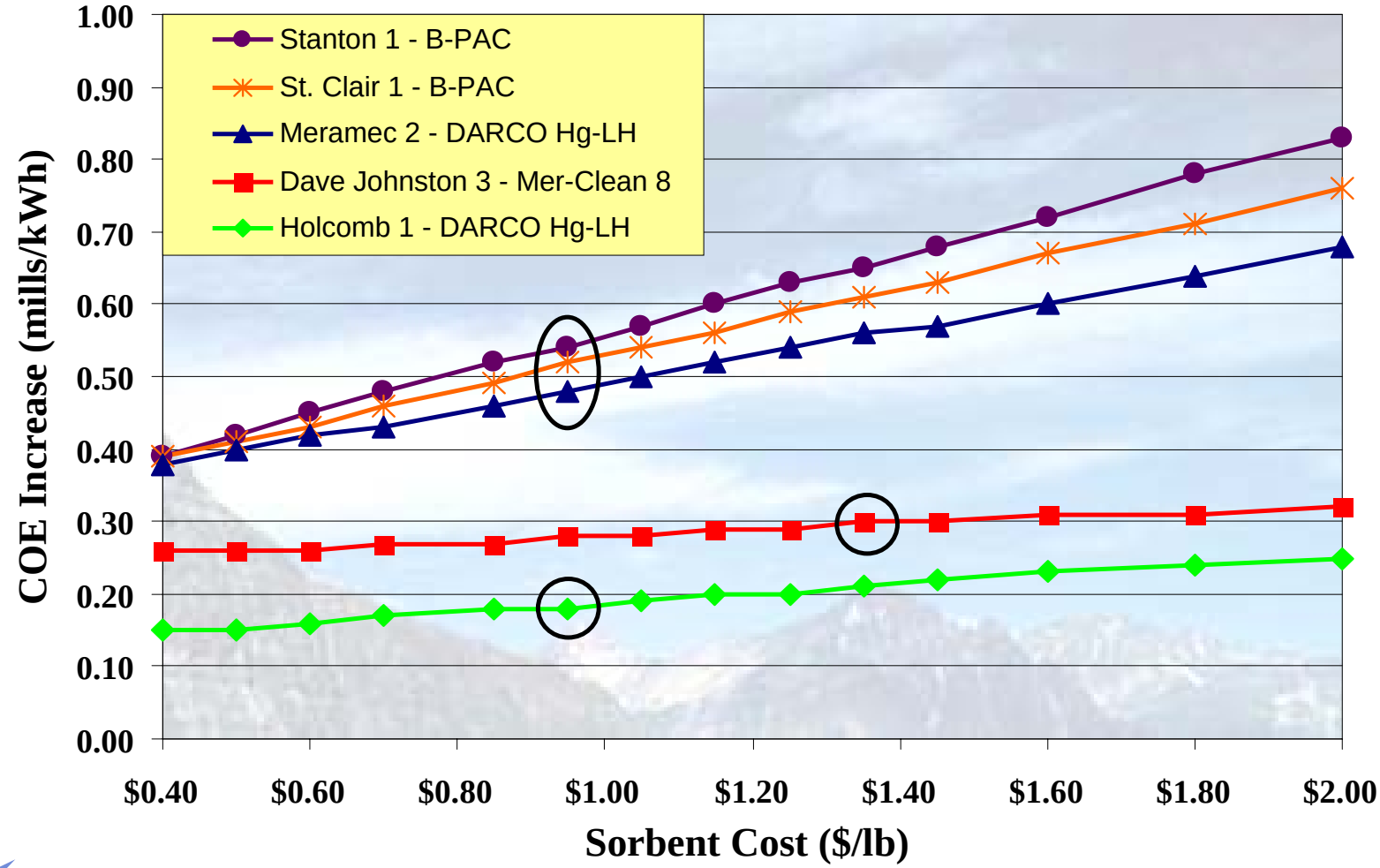
## *Bituminous Units*




[a] Economic data excludes CUB impacts.

# Sensitivity of Incremental COE Increase[a] for 70% ACI Mercury Control to Variations in Sorbent Cost

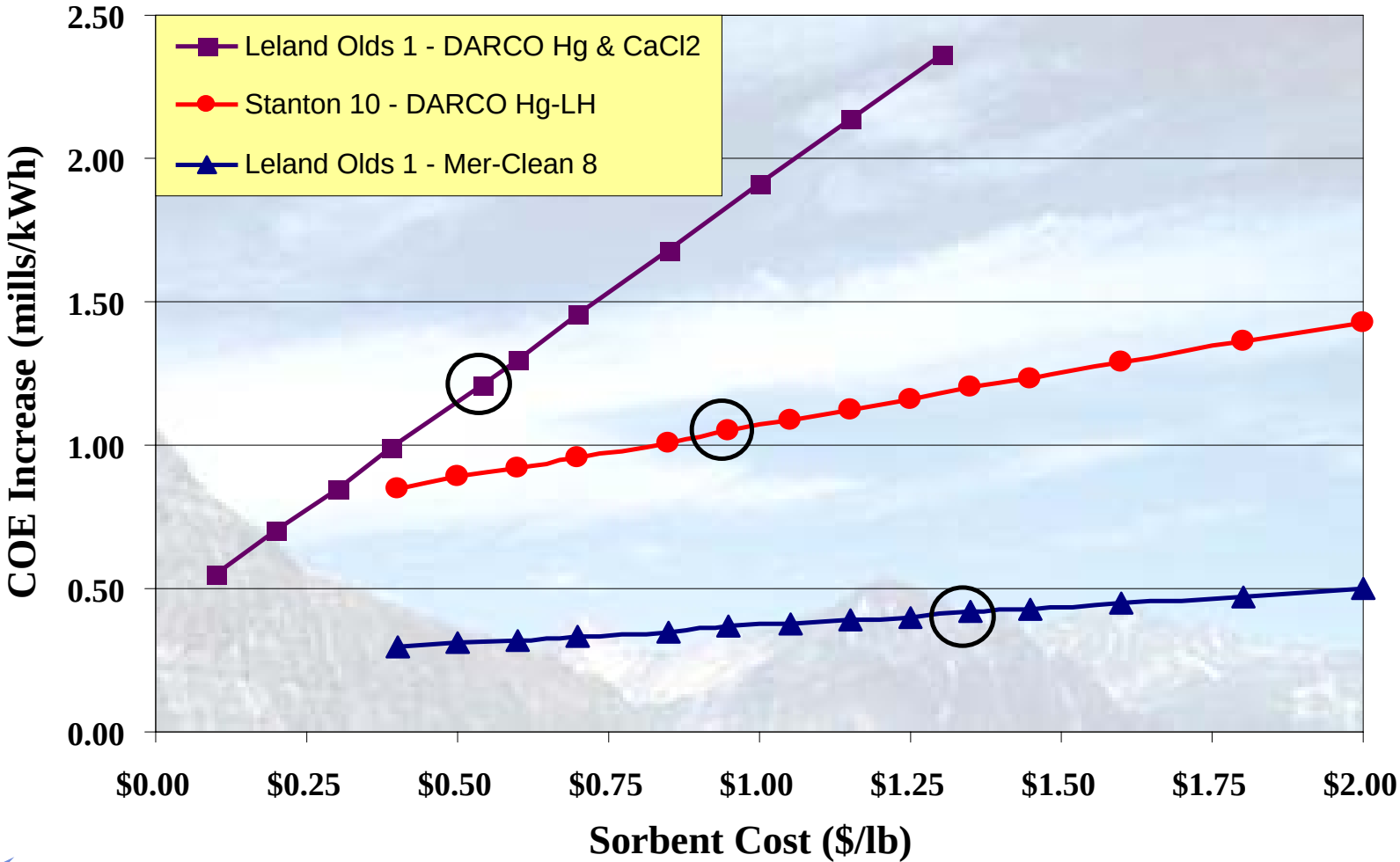
## *Subbituminous Units*




[a] Economic data excludes CUB impacts.

# Sensitivity of Incremental COE Increase[a] for 70% ACI Mercury Control to Variations in Sorbent Cost

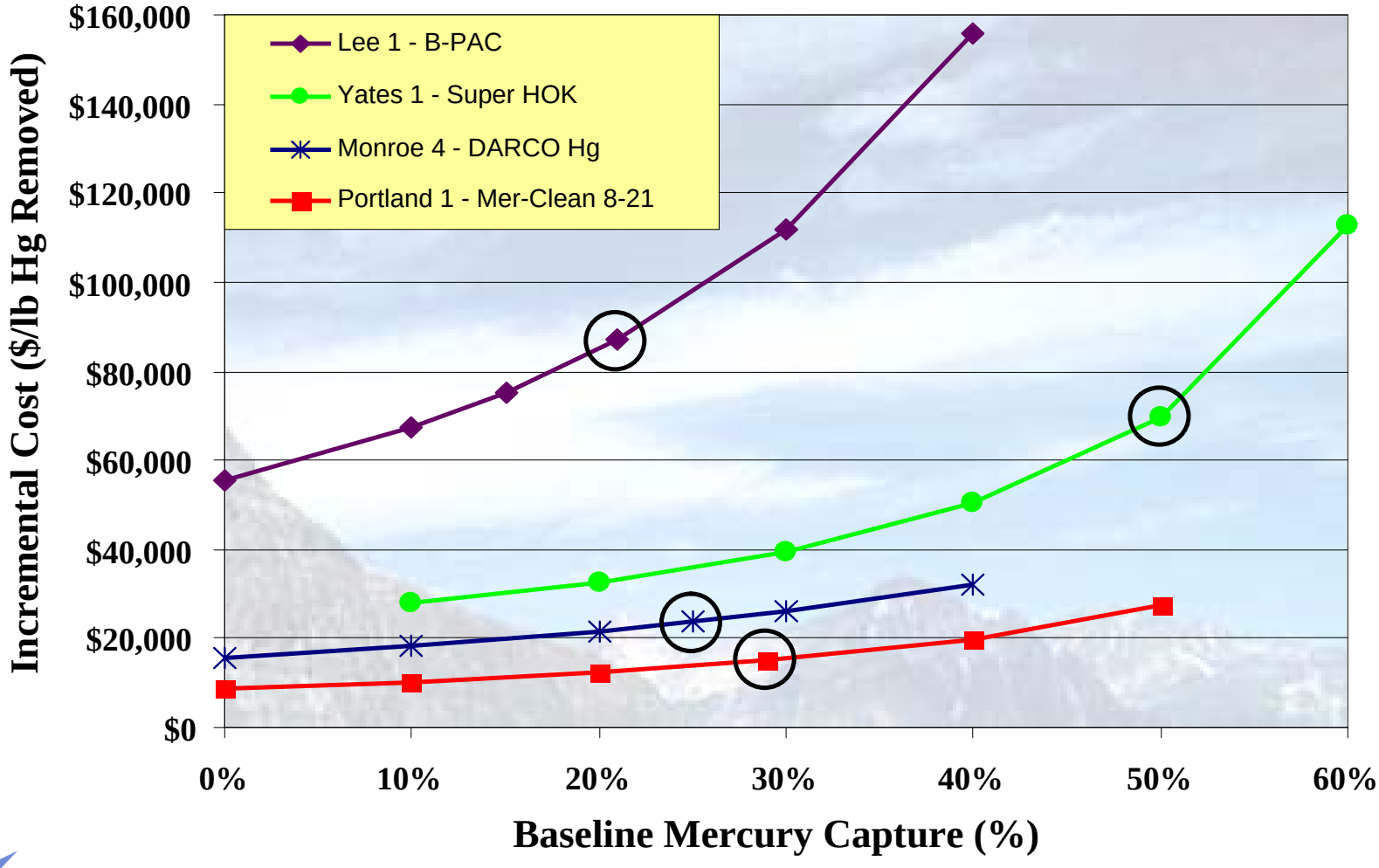
## *ND Lignite Units*




[a] Economic data excludes CUB impacts.

# Sensitivity of the Incremental Cost[a] of 70% ACI Mercury Control to Changes in Baseline Mercury Capture

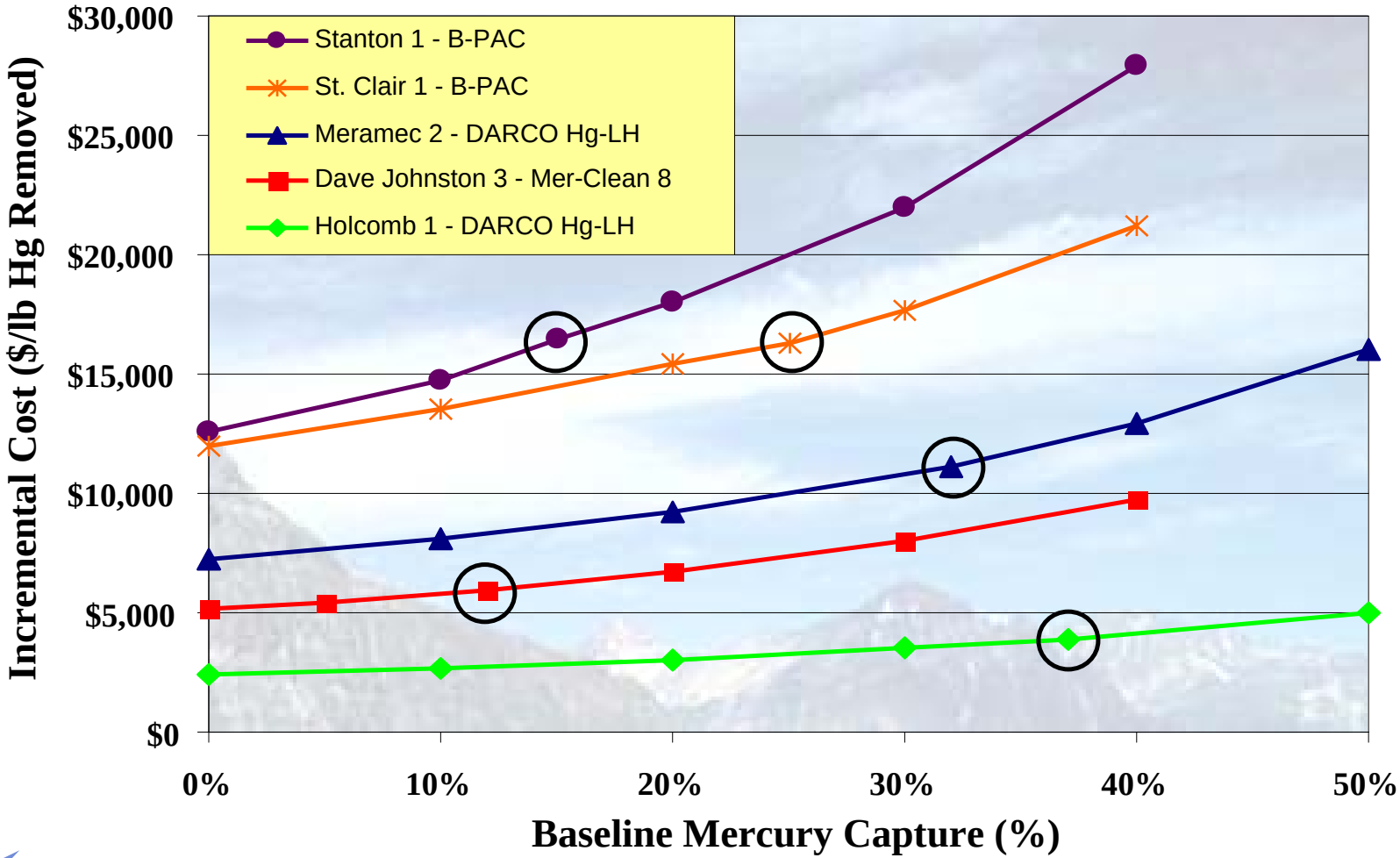
## *Bituminous Units*




[a] Economic data excludes CUB impacts.

# Sensitivity of the Incremental Cost[a] of 70% ACI Mercury Control to Changes in Baseline Mercury Capture

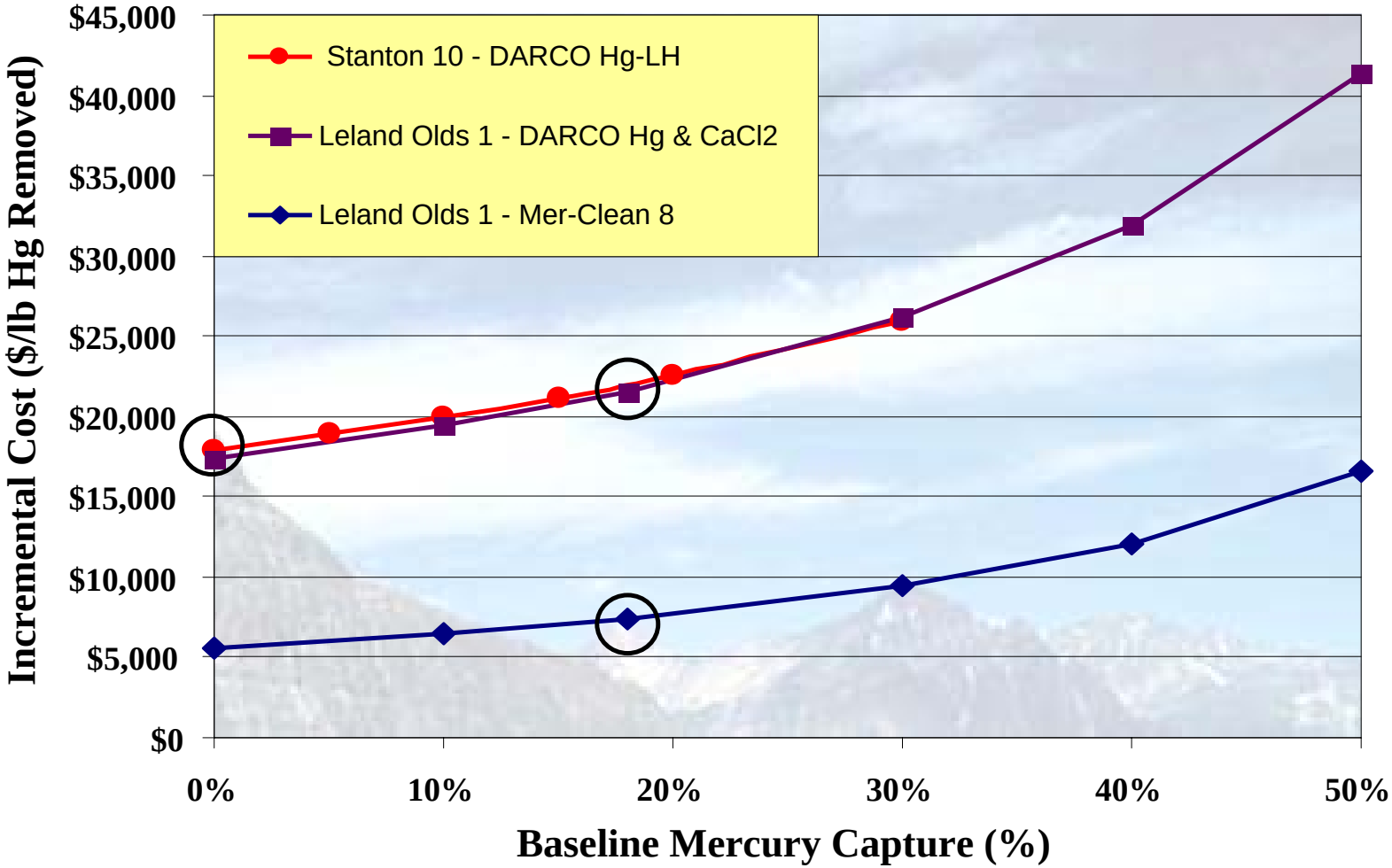
## *Subbituminous Units*




[a] Economic data excludes CUB impacts.

# Sensitivity of the Incremental Cost[a] of 70% ACI Mercury Control to Changes in Baseline Mercury Capture

## *ND Lignite Units*




[a] Economic data excludes CUB impacts.

# Preliminary Conclusions

- ***Estimated cost of Hg control on a $/lb removed basis continues to decline*** **under "no CUB impact" scenario**
- **Excluding CUB impacts, *economics of mercury control via ACI are dominated by PAC consumption costs*** **when FF retrofit is not required**
- ***< 2 mill/kWh increase in COE for 90% ACI Hg removal w/ treated ACI at bituminous, PRB, and lignite units***
- ***Incremental Cost of Mercury Control ($/lb Hg Removed)*** **can be influenced by a number of factors including:**
  - **Baseline mercury removal**
  - **Coal mercury content**

# Thank You!!!

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- AmerenUE; Basin Electric; Detroit Edison; Great River Energy; PacifiCorp; Progress Energy; Reliant Energy; Southern Company; Sunflower Electric