

TABLE 6-11b: (ENGLISH). CAPITAL COSTS OF LOW-ODOR CONVERSION (INCLUDING ESP UPGRADE TO CONTROL PM TO 0.044 GR/DSCF) FOR MODEL DCE RECOVERY FURNACES (EXCLUDING PULP PRODUCTION LOSSES)<sup>a</sup>

Model recovery furnaces	Pulp type	Black liquor firing rate, lb BLS/d	Equivalent ADTP/d	Gas flowrate-- ESP exit, acfm @ 8% O <sub>2</sub>	Downtime, d	Economizer expansion, demolition, \$	Concentrator, \$	Low-odor conversion, \$ (b)	ESP upgrade, \$ (c)	Wet to dry-bottom ESP conversion, \$ (d)	TCI, \$ (e)
RF-7a/7b	Bl	900,000	250	119,000	25	\$4,780,000	\$3,310,000	\$8,090,000	\$881,000	\$439,000	\$9,410,000
RF-8a/8b	Bl	1,500,000	420	198,000	25	\$6,500,000	\$4,500,000	\$11,000,000	\$1,200,000	\$596,000	\$12,800,000
RF-9a/9b	Bl	2,700,000	750	357,000	25	\$9,250,000	\$6,400,000	\$15,700,000	\$1,700,000	\$849,000	\$18,200,000
RF-7a/7b	Unbl	900,000	300	119,000	25	\$4,780,000	\$3,310,000	\$8,090,000	\$881,000	\$439,000	\$9,410,000
RF-8a/8b	Unbl	1,500,000	500	198,000	25	\$6,500,000	\$4,500,000	\$11,000,000	\$1,200,000	\$596,000	\$12,800,000
RF-9a/9b	Unbl	2,700,000	900	357,000	25	\$9,250,000	\$6,400,000	\$15,700,000	\$1,700,000	\$849,000	\$18,200,000

(a) All costs in \$1991

(b) Low-odor conversion cost = economizer expansion and DCE demolition cost + concentrator cost

Economizer expansion and DCE demolition cost =  $\$6,500,000 / [(1,500,000 \text{ lb BLS/d} / \text{model BLS firing rate}) \wedge 0.6]$

Concentrator cost =  $\$4,500,000 / [(1,500,000 \text{ lb BLS/d} / \text{model BLS firing rate}) \wedge 0.6]$

(c) ESP upgrade cost (to 0.044 gr/dscf) =  $\$1,292,000 / [(230,000 \text{ acfm} / \text{model gas flowrate}) \wedge 0.6] \times (361.3 \text{ } \$1991 / 357 \text{ } \$\text{May } 1993)$

(d) Wet-to dry-bottom ESP conversion cost =  $\$845,000 / [(357,000 \text{ acfm} / \text{model gas flowrate}) \wedge 0.6] \times (361.3 \text{ } \$1991 / 359.4 \text{ } \$\text{July } 1993)$

(e) TCI = low-odor conversion cost + ESP upgrade cost + wet-to dry-bottom ESP conversion cost

TABLE 6-12a (METRIC). CAPITAL COSTS OF LOW-ODOR CONVERSION (INCLUDING ESP UPGRADE TO CONTROL PM TO 0.10 G/DSCM) FOR MODEL DCE RECOVERY FURNACES (INCLUDING PULP PRODUCTION LOSSES) <sup>a</sup>

Model recovery furnaces	Pulp type	Black liquor firing rate, kg BLS/d	Equivalent ADMP/d	Gas flowrate-- ESP exit, m3/sec @ 8% O2	Downtime, d	Economizer expansion, demolition, \$	Concentrator, \$	Low-odor conversion, \$	ESP upgrade, \$	Wet-to dry-bottom ESP conversion, \$	TCI, \$	Pulp production losses, \$	TCI+ production losses, \$
RF-7a/7b	Bl	400,000	230	56.2	25	\$4,780,000	\$3,310,000	\$8,090,000	\$881,000	\$439,000	\$9,410,000	\$488,000	\$9,900,000
RF-8a/8b	Bl	700,000	380	93.4	25	\$6,500,000	\$4,500,000	\$11,000,000	\$1,200,000	\$596,000	\$12,800,000	\$820,000	\$13,600,000
RF-9a/9b	Bl	1,200,000	680	168	25	\$9,250,000	\$6,400,000	\$15,700,000	\$1,700,000	\$849,000	\$18,200,000	\$1,460,000	\$19,700,000
RF-7a/7b	Unbl	400,000	270	56.2	25	\$4,780,000	\$3,310,000	\$8,090,000	\$881,000	\$439,000	\$9,410,000	\$348,000	\$9,760,000
RF-8a/8b	Unbl	700,000	450	93.4	25	\$6,500,000	\$4,500,000	\$11,000,000	\$1,200,000	\$596,000	\$12,800,000	\$580,000	\$13,400,000
RF-9a/9b	Unbl	1,200,000	820	168	25	\$9,250,000	\$6,400,000	\$15,700,000	\$1,700,000	\$849,000	\$18,200,000	\$1,040,000	\$19,200,000

(a) Metric equivalents in this table were converted from the calculated English unit values given in Table 6-12b. Refer to Table 6-12b for footnotes, which include calculations.

TABLE 6-12b: (ENGLISH). CAPITAL COSTS OF LOW-ODOR CONVERSION (INCLUDING ESP UPGRADE TO CONTROL PM TO 0.044 GR/DSCF) FOR MODEL DCE RECOVERY FURNACES (INCLUDING PULP PRODUCTION LOSSES) <sup>a</sup>

Model recovery furnaces	Pulp type	Black liquor firing rate, lb BLS/d	Equivalent ADTP/d	Gas flowrate-- ESP exit, acfm @ 8% O <sub>2</sub>	Downtime, d	Economizer expansion, demolition, \$	Concentrator, \$	Low-odor conversion, \$ (b)	ESP upgrade, \$ (c)	Wet-to dry-bottom ESP conversion, \$ (d)	TCl, \$ (e)	Pulp production losses, \$ (f)	TCl+ production losses, \$
RF-7a/7b	BI	900,000	250	119,000	25	\$4,780,000	\$3,310,000	\$8,090,000	\$881,000	\$439,000	\$9,410,000	\$488,000	\$9,900,000
RF-8a/8b	BI	1,500,000	420	198,000	25	\$6,500,000	\$4,500,000	\$11,000,000	\$1,200,000	\$596,000	\$12,800,000	\$820,000	\$13,600,000
RF-9a/9b	BI	2,700,000	750	357,000	25	\$9,250,000	\$6,400,000	\$15,700,000	\$1,700,000	\$849,000	\$18,200,000	\$1,460,000	\$19,700,000
RF-7a/7b	Unbl	900,000	300	119,000	25	\$4,780,000	\$3,310,000	\$8,090,000	\$881,000	\$439,000	\$9,410,000	\$348,000	\$9,760,000
RF-8a/8b	Unbl	1,500,000	500	198,000	25	\$6,500,000	\$4,500,000	\$11,000,000	\$1,200,000	\$596,000	\$12,800,000	\$580,000	\$13,400,000
RF-9a/9b	Unbl	2,700,000	900	357,000	25	\$9,250,000	\$6,400,000	\$15,700,000	\$1,700,000	\$849,000	\$18,200,000	\$1,040,000	\$19,200,000

(a) All costs in \$1991

(b) Low-odor conversion cost = economizer expansion and DCE demolition cost + concentrator cost

Economizer expansion and DCE demolition cost = \$6,500,000/[(1,500,000 lb BLS/d)/(model BLS firing rate) ^ 0.6]

Concentrator cost = \$4,500,000/[(1,500,000 lb BLS/d)/(model BLS firing rate) ^ 0.6]

(c) ESP upgrade cost (to 0.044 gr/dscf) = \$1,292,000/[(230,000 acfm)/(model gas flowrate) ^ 0.6] x (361.3 \$/1991/357 \$/May 1993)

(d) Wet-to dry-bottom ESP conversion cost = \$845,000/[(357,000 acfm)/(model gas flowrate) ^ 0.6] x (361.3 \$/1991/359.4 \$/July 1993)

(e) TCl = low-odor conversion cost + ESP upgrade cost + wet-to dry-bottom ESP conversion cost

(f) Production losses = (25% gross profit margin) x (\$646/ton bleached pulp or \$384/ton unbleached pulp) x (136.2 \$/1991/124 \$/1989) x (25 d downtime-14 d scheduled downtime) x ADTP/d

TABLE 6-13a (METRIC). CAPITAL COSTS OF LOW-ODOR CONVERSION (INCLUDING ESP UPGRADE TO CONTROL PM TO 0.034 G/DSCM) FOR MODEL DCE RECOVERY FURNACES (EXCLUDING PULP PRODUCTION LOSSES)<sup>a</sup>

Model recovery furnaces	Pulp type	Black liquor firing rate, kg BLS/d	Equivalent ADMP/d	Gas flowrate--ESP exit, m3/sec @ 8% O2	Downtime, d	Economizer expansion, demolition, \$	Concentrator, \$	Low-odor conversion, \$	ESP upgrade, \$	Wet to dry-bottom ESP conversion, \$	TCI, \$
RF-7a/7b	Bl	400,000	230	56.2	25	\$4,780,000	\$3,310,000	\$8,090,000	\$1,270,000	\$439,000	\$9,800,000
RF-8a/8b	Bl	700,000	380	93.4	25	\$6,500,000	\$4,500,000	\$11,000,000	\$1,840,000	\$596,000	\$13,400,000
RF-9a/9b	Bl	1,200,000	680	168	25	\$9,250,000	\$6,400,000	\$15,700,000	\$2,860,000	\$849,000	\$19,400,000
RF-7a/7b	Unbl	400,000	270	56.2	25	\$4,780,000	\$3,310,000	\$8,090,000	\$1,270,000	\$439,000	\$9,800,000
RF-8a/8b	Unbl	700,000	450	93.4	25	\$6,500,000	\$4,500,000	\$11,000,000	\$1,840,000	\$596,000	\$13,400,000
RF-9a/9b	Unbl	1,200,000	820	168	25	\$9,250,000	\$6,400,000	\$15,700,000	\$2,860,000	\$849,000	\$19,400,000

(a) Metric equivalents in this table were converted from the calculated English unit values given in Table 6-13b. Refer to Table 6-13b for footnotes, which include calculations.



TABLE 6-14a (METRIC). CAPITAL COSTS OF LOW-ODOR CONVERSION (INCLUDING ESP UPGRADE TO CONTROL PM TO 0.034 G/DSCM) FOR MODEL DCE RECOVERY FURNACES (INCLUDING PULP PRODUCTION LOSSES)<sup>a</sup>

Model recovery furnaces	Pulp type	Black liquor firing rate, kg BLS/d	Equivalent ADMP/d	Gas flowrate-- ESP exit, m3/sec @ 8% O2	Downtime, d	Economizer expansion, demolition, \$	Concentrator, \$	Low-odor conversion, \$	ESP upgrade, \$	Wet to dry-bottom ESP conversion, \$	TCI, \$	Pulp production losses, \$	TCI+ production losses, \$
RF-7a/7b	Bl	400,000	230	56.2	25	\$4,780,000	\$3,310,000	\$8,090,000	\$1,270,000	\$439,000	\$9,800,000	\$488,000	\$10,300,000
RF-8a/8b	Bl	700,000	380	93.4	25	\$6,500,000	\$4,500,000	\$11,000,000	\$1,840,000	\$596,000	\$13,400,000	\$820,000	\$14,200,000
RF-9a/9b	Bl	1,200,000	680	168	25	\$9,250,000	\$6,400,000	\$15,700,000	\$2,860,000	\$849,000	\$19,400,000	\$1,460,000	\$20,900,000
RF-7a/7b	Unbl	400,000	270	56.2	25	\$4,780,000	\$3,310,000	\$8,090,000	\$1,270,000	\$439,000	\$9,800,000	\$348,000	\$10,100,000
RF-8a/8b	Unbl	700,000	450	93.4	25	\$6,500,000	\$4,500,000	\$11,000,000	\$1,840,000	\$596,000	\$13,400,000	\$580,000	\$14,000,000
RF-9a/9b	Unbl	1,200,000	820	168	25	\$9,250,000	\$6,400,000	\$15,700,000	\$2,860,000	\$849,000	\$19,400,000	\$1,040,000	\$20,400,000

(a) Metric equivalents in this table were converted from the calculated English unit values given in Table 6-14b. Refer to Table 6-14b for footnotes, which include calculations.

TABLE 6-14b: (ENGLISH). CAPITAL COSTS OF LOW-ODOR CONVERSION (INCLUDING ESP UPGRADE TO CONTROL PM TO 0.015 GR/DSCF) FOR MODEL DCE RECOVERY FURNACES (INCLUDING PULP PRODUCTION LOSSES)<sup>a</sup>

Model recovery furnaces	Pulp type	Black liquor firing rate, lb BLS/d	Equivalent ADTP/d	Gas flowrate-ESP exit, acfm @ 8% O <sub>2</sub>	Downtime, d	Economizer expansion, demolition, \$	Concentrator, \$	Low-odor conversion, \$ (b)	ESP upgrade, \$ (c)	Wet to dry-bottom ESP conversion, \$ (d)	TCI, \$ (e)	Pulp production losses, \$ (f)	TCI+ production losses, \$
RF-7a/7b	Bl	900,000	250	119,000	25	\$4,780,000	\$3,310,000	\$8,090,000	\$1,270,000	\$439,000	\$9,800,000	\$488,000	\$10,300,000
RF-8a/8b	Bl	1,500,000	420	198,000	25	\$6,500,000	\$4,500,000	\$11,000,000	\$1,840,000	\$596,000	\$13,400,000	\$820,000	\$14,200,000
RF-9a/9b	Bl	2,700,000	750	357,000	25	\$9,250,000	\$6,400,000	\$15,700,000	\$2,860,000	\$849,000	\$19,400,000	\$1,460,000	\$20,900,000
RF-7a/7b	Unbl	900,000	300	119,000	25	\$4,780,000	\$3,310,000	\$8,090,000	\$1,270,000	\$439,000	\$9,800,000	\$348,000	\$10,100,000
RF-8a/8b	Unbl	1,500,000	500	198,000	25	\$6,500,000	\$4,500,000	\$11,000,000	\$1,840,000	\$596,000	\$13,400,000	\$580,000	\$14,000,000
RF-9a/9b	Unbl	2,700,000	900	357,000	25	\$9,250,000	\$6,400,000	\$15,700,000	\$2,860,000	\$849,000	\$19,400,000	\$1,040,000	\$20,400,000

(a) All costs in \$1991

(b) Low-odor conversion cost = economizer expansion and DCE demolition cost + concentrator cost

Economizer expansion and DCE demolition cost =  $\$6,500,000 / [(1,500,000 \text{ lb BLS/d} / \text{model BLS firing rate}) \wedge 0.6]$

Concentrator cost =  $\$4,500,000 / [(1,500,000 \text{ lb BLS/d} / \text{model BLS firing rate}) \wedge 0.6]$

(c) ESP upgrade cost (to 0.015 gr/dscf) =  $\text{ESP upgrade cost (to } 0.044 \text{ gr/dscf)} + [(\text{increase in ESP plate area}) \times (\$39/\text{ft}^2 \text{ plate area})]$

(d) Wet to dry-bottom ESP conversion cost =  $\$845,000 / [(357,000 \text{ acfm} / \text{model gas flowrate}) \wedge 0.6] \times (\$361.3 / \$1991 / \$359.4 \text{ July } 1993)$

(e) TCI = low-odor conversion cost + ESP upgrade cost + wet to dry-bottom ESP conversion cost

(f) Production losses =  $(25\% \text{ gross profit margin}) \times (\$646/\text{ton bleached pulp or } \$384/\text{ton unbleached pulp}) \times (136.2 \text{ } \$1991 / 124 \text{ } \$1989) \times (25 \text{ d downtime} - 14 \text{ d scheduled downtime}) \times \text{ADTP/d}$

TABLE 6-15a (METRIC). MODEL DCE RECOVERY FURNACE/ESP DESIGN PARAMETERS

Model furnace/ESP design parameters	Model Recovery Furnaces					
	RF-7a	RF-7b	RF-8a	RF-8b	RF-9a	RF-9b
Black liquor firing rate, kg BLS/d	400,000	400,000	700,000	700,000	1,200,000	1,200,000
Equivalent ADMP/d						
Bleached pulp	230	230	380	380	680	680
Unbleached pulp	270	270	450	450	820	820
Gas flow rate--ESP exit, m3/sec	56.2	56.2	93.4	93.4	168	168
ESP SCA, m2/(m3/sec)						
Baseline	66	85	66	85	66	85
PM controls--0.10 g/dscm	105	105	105	105	105	105
PM controls--0.034 g/dscm	121	121	121	121	121	121
ESP plate area, m2						
Baseline	3,688	4,794	6,129	7,967	11,024	14,331
PM controls--0.10 g/dscm	5,900	5,900	9,806	9,806	17,638	17,638
PM controls--0.034 g/dscm	6,822	6,822	11,338	11,338	20,394	20,394
Operating days per year	351	351	351	351	351	351
Operating hours per year	8,424	8,424	8,424	8,424	8,424	8,424

(a) Metric equivalents in this table were converted from the calculated English unit values given in Table 6-15b.



TABLE 6-15b (ENGLISH). MODEL DCE RECOVERY FURNACE/ESP DESIGN PARAMETERS

Model furnace/ESP design parameters	Model Recovery Furnaces					
	RF-7a	RF-7b	RF-8a	RF-8b	RF-9a	RF-9b
Black liquor firing rate, lb BLS/d	900,000	900,000	1,500,000	1,500,000	2,700,000	2,700,000
Equivalent ADTP/d						
Bleached pulp	250	250	420	420	750	750
Unbleached pulp	300	300	500	500	900	900
Gas flow rate--ESP exit, acfm	119,000	119,000	198,000	198,000	357,000	357,000
Exhaust gas temperature, degrees F	320	320	320	320	320	320
Moisture content--ESP exit, %	32	32	32	32	32	32
ESP SCA, ft2/1,000 acfm						
Baseline	333	433	333	433	333	433
PM controls--0.044 gr/dscf	533	533	533	533	533	533
PM controls--0.015 gr/dscf	617	617	617	617	617	617
ESP plate area, ft2						
Baseline	39,667	51,567	66,000	85,800	119,000	154,700
PM controls--0.044 gr/dscf	63,467	63,467	105,600	105,600	190,400	190,400
PM controls--0.015 gr/dscf	73,383	73,383	122,100	122,100	220,150	220,150
Operating days per year	351	351	351	351	351	351
Operating hours per year	8,424	8,424	8,424	8,424	8,424	8,424

TABLE 6-16. SCENARIO 1: ANNUAL COSTS OF LOW-ODOR CONVERSION (INCLUDING ESP UPGRADE TO CONTROL PM TO 0.10 G/DSCM [0.044 GR/DSCF]) FOR MODEL DCE RECOVERY FURNACES (EXCLUDING ANNUALIZED PULP PRODUCTION LOSSES)<sup>a</sup>

Costs	Model Recovery Furnaces					
	RF-7a	RF-7b	RF-8a	RF-8b	RF-9a	RF-9b
Total Capital Investment (TCI)	\$9,410,000	\$9,410,000	\$12,800,000	\$12,800,000	\$18,200,000	\$18,200,000
Direct Annual Costs (DAC)						
Steam production credits (b)						
Natural gas	(\$758,000)	(\$758,000)	(\$1,260,000)	(\$1,260,000)	(\$2,270,000)	(\$2,270,000)
Fuel oil	(\$1,190,000)	(\$1,190,000)	(\$1,990,000)	(\$1,990,000)	(\$3,580,000)	(\$3,580,000)
BLO operating cost savings (c)	(\$103,000)	(\$103,000)	(\$172,000)	(\$172,000)	(\$309,000)	(\$309,000)
Concentrator steam costs (d)	\$57,800	\$57,800	\$96,300	\$96,300	\$173,000	\$173,000
ESP operating electricity costs (e)	\$23,300	\$11,700	\$38,800	\$19,400	\$70,000	\$35,000
Total DAC						
Natural gas	(\$780,000)	(\$792,000)	(\$1,300,000)	(\$1,320,000)	(\$2,340,000)	(\$2,370,000)
Fuel oil	(\$1,210,000)	(\$1,220,000)	(\$2,030,000)	(\$2,050,000)	(\$3,650,000)	(\$3,680,000)
Indirect Annual Costs (IAC)						
Administrative, taxes, and insurance (f)						
Low-odor conversion	\$324,000	\$324,000	\$440,000	\$440,000	\$628,000	\$628,000
ESP upgrade	\$35,200	\$35,200	\$48,000	\$48,000	\$68,000	\$68,000
Wet- to dry-bottom ESP conversion	\$17,600	\$17,600	\$23,800	\$23,800	\$34,000	\$34,000
Total	\$377,000	\$377,000	\$512,000	\$512,000	\$730,000	\$730,000
Capital recovery (g)						
Low-odor conversion	\$764,000	\$764,000	\$1,040,000	\$1,040,000	\$1,480,000	\$1,480,000
ESP upgrade	\$103,000	\$103,000	\$140,000	\$140,000	\$199,000	\$199,000
Wet- to dry-bottom ESP conversion	\$51,300	\$51,300	\$69,700	\$69,700	\$99,200	\$99,200
Total	\$918,000	\$918,000	\$1,250,000	\$1,250,000	\$1,780,000	\$1,780,000
Total IAC	\$1,300,000	\$1,300,000	\$1,760,000	\$1,760,000	\$2,510,000	\$2,510,000
Total Annual Costs						
Natural gas	\$520,000	\$508,000	\$460,000	\$440,000	\$170,000	\$140,000
Fuel oil	\$90,000	\$80,000	(\$270,000)	(\$290,000)	(\$1,140,000)	(\$1,170,000)

(a) All costs in \$1991. Numbers in parentheses represent cost savings.

(b) Steam production credit calculations (either natural gas or fuel oil):

Natural gas credit = (model BLS firing rate) x (8,000 Btu/lb) x (1 d/24 hr) x (66%-56% thermal efficiency)/(85% power boiler efficiency) x (1 ft<sup>3</sup>/1,024 Btu) x (8,424 hr/yr) x (\$3.48/1,000 ft<sup>3</sup>)

Fuel oil credit = (model BLS firing rate) x (6,000 Btu/lb) x (1 d/24 hr) x (66%-56% thermal efficiency)/(85% power boiler efficiency) x (1 gal/144,000 Btu) x (8,424 hr/yr) x (\$0.77/gal)

(c) BLO operating cost savings = \$251,900/yr x (model BLS firing rate/2,200,000 lb BLS/d)

(d) Concentrator steam costs = \$54,000/yr x (model BLS firing rate/2,400,000 lb BLS/d)

(e) ESP operating electricity cost = 0.00194 x increase in ESP plate area x 8,424 hr/yr x \$0.06/kWh

(f) Administrative, taxes, and insurance = 0.04 x TCI

(g) For low-odor conversion, capital recovery cost = 0.0944 x TCI (based on 20-yr remaining service life and 7% interest)

For ESP upgrade and wet- to dry-bottom ESP conversion, capital recovery cost = 0.1169 x TCI (based on 13.5-yr ESP life and 7% interest)

TABLE 6-17. SCENARIO 2: ANNUAL COSTS OF LOW-ODOR CONVERSION (INCLUDING ESP UPGRADE TO CONTROL PM TO 0.10 G/DSCM [0.044 GR/DSCF]) FOR MODEL DCE RECOVERY FURNACES (INCLUDING BLEACHED PULP PRODUCTION LOSSES)<sup>a</sup>

Costs	Model Recovery Furnaces					
	RF-7a	RF-7b	RF-8a	RF-8b	RF-9a	RF-9b
Total Capital Investment (TCI)	\$9,900,000	\$9,900,000	\$13,600,000	\$13,600,000	\$19,700,000	\$19,700,000
Direct Annual Costs (DAC)						
Steam production credits (b)						
Natural gas	(\$758,000)	(\$758,000)	(\$1,260,000)	(\$1,260,000)	(\$2,270,000)	(\$2,270,000)
Fuel oil	(\$1,190,000)	(\$1,190,000)	(\$1,990,000)	(\$1,990,000)	(\$3,580,000)	(\$3,580,000)
BLO operating cost savings (c)	(\$103,000)	(\$103,000)	(\$172,000)	(\$172,000)	(\$309,000)	(\$309,000)
Concentrator steam costs (d)	\$57,800	\$57,800	\$96,300	\$96,300	\$173,000	\$173,000
ESP operating electricity costs (d)	\$23,300	\$11,700	\$38,800	\$19,400	\$70,000	\$35,000
Total DAC						
Natural gas	(\$780,000)	(\$792,000)	(\$1,300,000)	(\$1,320,000)	(\$2,340,000)	(\$2,370,000)
Fuel oil	(\$1,210,000)	(\$1,220,000)	(\$2,030,000)	(\$2,050,000)	(\$3,650,000)	(\$3,680,000)
Indirect Annual Costs (IAC)						
Administrative, taxes, and insurance (e)						
Low-odor conversion	324,000	324,000	440,000	440,000	628,000	628,000
ESP upgrade	35,200	35,200	48,000	48,000	68,000	68,000
Wet- to dry-bottom ESP conversion	17,600	17,600	23,800	23,800	34,000	34,000
Total	\$377,000	\$377,000	\$512,000	\$512,000	\$730,000	\$730,000
Capital recovery (f)						
Low-odor conversion	\$764,000	\$764,000	\$1,040,000	\$1,040,000	\$1,480,000	\$1,480,000
ESP upgrade	\$103,000	\$103,000	\$140,000	\$140,000	\$199,000	\$199,000
Wet- to dry-bottom ESP conversion	\$51,300	\$51,300	\$69,700	\$69,700	\$99,200	\$99,200
Production losses	\$46,100	\$46,100	\$77,400	\$77,400	\$138,000	\$138,000
Total	\$964,000	\$964,000	\$1,330,000	\$1,330,000	\$1,920,000	\$1,920,000
Total IAC	\$1,340,000	\$1,340,000	\$1,840,000	\$1,840,000	\$2,650,000	\$2,650,000
Total Annual Costs						
Natural gas	\$560,000	\$548,000	\$540,000	\$520,000	\$310,000	\$280,000
Fuel oil	\$130,000	\$120,000	(\$190,000)	(\$210,000)	(\$1,000,000)	(\$1,030,000)

- (a) All costs in \$1991. Numbers in parentheses represent cost savings.  
(b) Steam production credit calculations (either natural gas or fuel oil):  
    Natural gas credit = (model BLS firing rate) x (6,000 Btu/lb) x (1 d/24 hr) x (66%-56% thermal efficiency)/(85% power boiler efficiency) x (1 ft<sup>3</sup>/1,024 Btu) x (8,424 hr/yr) x (\$3.48/1,000 ft<sup>3</sup>)  
    Fuel oil credit = (model BLS firing rate) x (6,000 Btu/lb) x (1 d/24 hr) x (66%-56% thermal efficiency)/(85% power boiler efficiency) x (1 gal/144,000 Btu) x (8,424 hr/yr) x (\$0.77/gal)  
(c) BLO operating cost savings = \$251,900/yr x (model BLS firing rate/2,200,000 lb BLS/d)  
(d) Concentrator steam costs = \$54,000/yr x (model BLS firing rate/2,400,000 lb BLS/d)  
(e) ESP operating electricity cost = 0.00194 x increase in ESP plate area x 8,424 hr/yr x \$0.06/kWh  
(f) Administrative, taxes, and insurance = 0.04 x TCI  
(g) For low-odor conversion, capital recovery cost = 0.0944 x TCI (based on 20-yr remaining service life and 7% interest)  
    For ESP upgrade and wet- to dry-bottom ESP conversion, capital recovery cost = 0.1169 x TCI (based on 13.5-yr ESP life and 7% interest)

TABLE 6-18. SCENARIO 3: ANNUAL COSTS OF LOW-ODOR CONVERSION (INCLUDING ESP UPGRADE TO CONTROL PM TO 0.10 G/DSCM [0.044 GR/DSCF]) FOR MODEL DCE RECOVERY FURNACES (INCLUDING UNBLEACHED PULP PRODUCTION LOSSES)<sup>a</sup>

Costs	Model Recovery Furnaces					
	RF-7a	RF-7b	RF-8a	RF-8b	RF-9a	RF-9b
Total Capital Investment (TCI)	\$9,760,000	\$9,760,000	\$13,400,000	\$13,400,000	\$19,200,000	\$19,200,000
Direct Annual Costs (DAC)						
Steam production credits (b)						
Natural gas	(\$758,000)	(\$758,000)	(\$1,260,000)	(\$1,260,000)	(\$2,270,000)	(\$2,270,000)
Fuel oil	(\$1,190,000)	(\$1,190,000)	(\$1,990,000)	(\$1,990,000)	(\$3,580,000)	(\$3,580,000)
BLO operating cost savings (c)	(\$103,000)	(\$103,000)	(\$172,000)	(\$172,000)	(\$309,000)	(\$309,000)
Concentrator steam costs (d)	\$57,800	\$57,800	\$96,300	\$96,300	\$173,000	\$173,000
ESP operating electricity costs (e)	\$23,300	\$11,700	\$38,800	\$19,400	\$70,000	\$35,000
Total DAC						
Natural gas	(\$780,000)	(\$792,000)	(\$1,300,000)	(\$1,320,000)	(\$2,340,000)	(\$2,370,000)
Fuel oil	(\$1,210,000)	(\$1,220,000)	(\$2,030,000)	(\$2,050,000)	(\$3,650,000)	(\$3,680,000)
Indirect Annual Costs (IAC)						
Administrative, taxes, and insurance (f)						
Low-odor conversion	324,000	324,000	440,000	440,000	628,000	628,000
ESP upgrade	35,200	35,200	48,000	48,000	68,000	68,000
Wet- to dry-bottom ESP conversion	17,600	17,600	23,800	23,800	34,000	34,000
Total	377,000	377,000	512,000	512,000	730,000	730,000
Capital recovery (g)						
Low-odor conversion-	\$764,000	\$764,000	\$1,040,000	\$1,040,000	\$1,480,000	\$1,480,000
ESP upgrade	\$103,000	\$103,000	\$140,000	\$140,000	\$199,000	\$199,000
Wet- to dry-bottom ESP conversion	\$51,300	\$51,300	\$69,700	\$69,700	\$99,200	\$99,200
Production losses	\$32,900	\$32,900	\$54,800	\$54,800	\$98,200	\$98,200
Total	951,000	951,000	1,300,000	1,300,000	1,880,000	1,880,000
Total IAC	\$1,330,000	\$1,330,000	\$1,820,000	\$1,820,000	\$2,610,000	\$2,610,000
Total Annual Costs						
Natural gas	\$550,000	\$538,000	\$520,000	\$500,000	\$270,000	\$240,000
Fuel oil	\$120,000	\$110,000	(\$210,000)	(\$230,000)	(\$1,040,000)	(\$1,070,000)

(a) All costs in \$1991. Numbers in parentheses represent cost savings.

(b) Steam production credit calculations (either natural gas or fuel oil):

Natural gas credit = (model BLS firing rate) x (6,000 Btu/lb) x (1 d/24 hr) x (66%-56% thermal efficiency)/(85% power boiler efficiency) x (1 ft<sup>3</sup>/1,024 Btu) x (8,424 hr/yr) x (\$3.48/1,000 ft<sup>3</sup>)

Fuel oil credit = (model BLS firing rate) x (6,000 Btu/lb) x (1 d/24 hr) x (66%-56% thermal efficiency)/(85% power boiler efficiency) x (1 gal/144,000 Btu) x (8,424 hr/yr) x (\$0.77/gal)

(c) BLO operating cost savings = \$251,900/yr x (model BLS firing rate/2,200,000 lb BLS/d)

(d) Concentrator steam costs = \$54,000/yr x (model BLS firing rate/2,400,000 lb BLS/d)

(e) ESP operating electricity cost = 0.00194 x increase in ESP plate area x 8,424 hr/yr x \$0.06/kWh

(f) Administrative, taxes, and insurance = 0.04 x TCI

(g) For low-odor conversion, capital recovery cost = 0.0944 x TCI (based on 20-yr remaining service life and 7% interest)

For ESP upgrade and wet- to dry-bottom ESP conversion, capital recovery cost = 0.1169 x TCI (based on 13.5-yr ESP life and 7% interest)

TABLE 6-19. SCENARIO 1: ANNUAL COSTS OF LOW-ODOR CONVERSION (INCLUDING ESP UPGRADE TO CONTROL PM TO 0.034 G/DSCM [0.015 GR/DSCF]) FOR MODEL DCE RECOVERY FURNACES (EXCLUDING ANNUALIZED PULP PRODUCTION LOSSES)<sup>a</sup>

Costs	Model Recovery Furnaces					
	RF-7a	RF-7b	RF-8a	RF-8b	RF-9a	RF-9b
Total Capital Investment (TCI)	\$9,800,000	\$9,800,000	\$13,400,000	\$13,400,000	\$19,400,000	\$19,400,000
Direct Annual Costs (DAC)						
Steam production credits (b)						
Natural gas	(\$758,000)	(\$758,000)	(\$1,263,000)	(\$1,260,000)	(\$2,270,000)	(\$2,270,000)
Fuel oil	(\$1,190,000)	(\$1,190,000)	(\$1,990,000)	(\$1,990,000)	(\$3,580,000)	(\$3,580,000)
BLO operating cost savings (c)	(\$103,000)	(\$103,000)	(\$172,000)	(\$172,000)	(\$309,000)	(\$309,000)
Concentrator steam costs (d)	\$57,800	\$57,800	\$96,300	\$96,300	\$173,000	\$173,000
ESP operating electricity costs (e)	\$33,100	\$21,400	\$55,000	\$35,600	\$99,200	\$64,200
Total DAC						
Natural gas	(\$770,000)	(\$782,000)	(\$1,280,000)	(\$1,300,000)	(\$2,310,000)	(\$2,340,000)
Fuel oil	(\$1,200,000)	(\$1,210,000)	(\$2,010,000)	(\$2,030,000)	(\$3,620,000)	(\$3,650,000)
Indirect Annual Costs (IAC)						
Administrative, taxes, and insurance (f)						
Low-odor conversion	324,000	324,000	440,000	440,000	628,000	628,000
ESP upgrade	50,800	50,800	73,600	73,600	114,000	114,000
Wet- to dry-bottom ESP conversion	17,600	17,600	23,800	23,800	34,000	34,000
Total	392,000	392,000	537,000	537,000	776,000	776,000
Capital recovery (g)						
Low-odor conversion	\$764,000	\$764,000	\$1,040,000	\$1,040,000	\$1,480,000	\$1,480,000
ESP upgrade	\$148,000	\$148,000	\$215,000	\$215,000	\$334,000	\$334,000
Wet- to dry-bottom ESP conversion	\$51,300	\$51,300	\$69,700	\$69,700	\$99,200	\$99,200
Total	963,000	963,000	1,320,000	1,320,000	1,910,000	1,910,000
Total IAC	\$1,360,000	\$1,360,000	\$1,860,000	\$1,860,000	\$2,690,000	\$2,690,000
Total Annual Costs						
Natural gas	\$590,000	\$578,000	\$580,000	\$560,000	\$380,000	\$350,000
Fuel oil	\$160,000	\$150,000	(\$150,000)	(\$170,000)	(\$930,000)	(\$960,000)

(a) All costs in \$1991. Numbers in parentheses represent cost savings.

(b) Steam production credit calculations (either natural gas or fuel oil):

Natural gas credit = (model BLS firing rate) x (6,000 Btu/lb) x (1 d/24 hr) x (66%-56% thermal efficiency)/(85% power boiler efficiency) x (1 ft<sup>3</sup>/1,024 Btu) x (8,424 hr/yr) x (\$3.48/1,000 ft<sup>3</sup>)

Fuel oil credit = (model BLS firing rate) x (6,000 Btu/lb) x (1 d/24 hr) x (66%-56% thermal efficiency)/(85% power boiler efficiency) x (1 gal/144,000 Btu) x (8,424 hr/yr) x (\$0.77/gal)

(c) BLO operating cost savings = \$251,900/yr x (model BLS firing rate/2,200,000 lb BLS/d)

(d) Concentrator steam costs = \$54,000/yr x (model BLS firing rate/2,400,000 lb BLS/d)

(e) ESP operating electricity cost = 0.00194 x increase in ESP plate area x 8,424 hr/yr x \$0.06/kWh

(f) Administrative, taxes, and insurance = 0.04 x TCI

(g) For low-odor conversion, capital recovery cost = 0.0944 x TCI (based on 20-yr remaining service life and 7% interest)

For ESP upgrade and wet- to dry-bottom ESP conversion, capital recovery cost = 0.1169 x TCI (based on 13.5-yr ESP life and 7% interest)

TABLE 6-20. SCENARIO 2: ANNUAL COSTS OF LOW-ODOR CONVERSION (INCLUDING ESP UPGRADE TO CONTROL PM TO 0.034 G/DSCM [0.015 GR/DSCF]) FOR MODEL DCE RECOVERY FURNACES (INCLUDING BLEACHED PULP PRODUCTION LOSSES)<sup>a</sup>

Costs	Model Recovery Furnaces					
	RF-7a	RF-7b	RF-8a	RF-8b	RF-9a	RF-9b
Total Capital Investment (TCI)	\$10,300,000	\$10,300,000	\$14,200,000	\$14,200,000	\$20,900,000	\$20,900,000
Direct Annual Costs (DAC)						
Steam production credits (b)						
Natural gas	(\$758,000)	(\$758,000)	(\$1,260,000)	(\$1,260,000)	(\$2,270,000)	(\$2,270,000)
Fuel oil	(\$1,190,000)	(\$1,190,000)	(\$1,990,000)	(\$1,990,000)	(\$3,580,000)	(\$3,580,000)
BLO operating cost savings (c)	(\$103,000)	(\$103,000)	(\$172,000)	(\$172,000)	(\$309,000)	(\$309,000)
Concentrator steam costs (d)	\$57,800	\$57,800	\$96,300	\$96,300	\$173,000	\$173,000
ESP operating electricity costs (d)	\$33,100	\$21,400	\$55,000	\$35,600	\$99,200	\$64,200
Total DAC						
Natural gas	(\$770,000)	(\$782,000)	(\$1,280,000)	(\$1,300,000)	(\$2,310,000)	(\$2,340,000)
Fuel oil	(\$1,200,000)	(\$1,210,000)	(\$2,010,000)	(\$2,030,000)	(\$3,620,000)	(\$3,650,000)
Indirect Annual Costs (IAC)						
Administrative, taxes, and insurance (e)						
Low-odor conversion	324,000	324,000	440,000	440,000	628,000	628,000
ESP upgrade	50,800	50,800	73,600	73,600	114,000	114,000
Wet- to dry-bottom ESP conversion	17,600	17,600	23,800	23,800	34,000	34,000
Total	392,000	392,000	537,000	537,000	776,000	776,000
Capital recovery (f)						
Low-odor conversion	\$764,000	\$764,000	\$1,040,000	\$1,040,000	\$1,480,000	\$1,480,000
ESP upgrade	\$148,000	\$148,000	\$215,000	\$215,000	\$334,000	\$334,000
Wet- to dry-bottom ESP conversion	\$51,300	\$51,300	\$69,700	\$69,700	\$99,200	\$99,200
Production losses	\$46,100	\$46,100	\$77,400	\$77,400	\$138,000	\$138,000
Total	1,010,000	1,010,000	1,400,000	1,400,000	2,050,000	2,050,000
Total IAC	\$1,400,000	\$1,400,000	\$1,940,000	\$1,940,000	\$2,830,000	\$2,830,000
Total Annual Costs						
Natural gas	\$630,000	\$618,000	\$660,000	\$640,000	\$520,000	\$490,000
Fuel oil	\$200,000	\$190,000	(\$70,000)	(\$90,000)	(\$790,000)	(\$820,000)

(a) All costs in \$1991. Numbers in parentheses represent cost savings.

(b) Steam production credit calculations (either natural gas or fuel oil):

Natural gas credit = (model BLS firing rate) x (6,000 Btu/lb) x (1 d/24 hr) x (66%-56% thermal efficiency)/(85% power boiler efficiency) x (1 ft<sup>3</sup>/1,024 Btu) x (8,424 hr/yr) x (\$3.48/1,000 ft<sup>3</sup>)

Fuel oil credit = (model BLS firing rate) x (6,000 Btu/lb) x (1 d/24 hr) x (66%-56% thermal efficiency)/(85% power boiler efficiency) x (1 gal/144,000 Btu) x (8,424 hr/yr) x (\$0.77/gal)

(c) BLO operating cost savings = \$251,900/yr x (model BLS firing rate/2,200,000 lb BLS/d)

(d) Concentrator steam costs = \$54,000/yr x (model BLS firing rate/2,400,000 lb BLS/d)

(e) ESP operating electricity cost = 0.00194 x increase in ESP plate area x 8,424 hr/yr x \$0.06/kWh

(f) Administrative, taxes, and insurance = 0.04 x TCI

(g) For low-odor conversion and production losses, capital recovery cost = 0.0944 x TCI (based on 20-yr remaining service life and 7% interest)  
For ESP upgrade and wet- to dry-bottom ESP conversion, capital recovery cost = 0.1169 x TCI (based on 13.5-yr ESP life and 7% interest)

TABLE 6-21. SCENARIO 3: ANNUAL COSTS OF LOW-ODOR CONVERSION (INCLUDING ESP UPGRADE TO CONTROL PM TO 0.034 G/DSCM [0.015 GR/DSCF]) FOR MODEL DCE RECOVERY FURNACES (INCLUDING UNBLEACHED PULP PRODUCTION LOSSES)<sup>a</sup>

Costs	Model Recovery Furnaces					
	RF-7a	RF-7b	RF-8a	RF-8b	RF-9a	RF-9b
Total Capital Investment (TCI)	\$10,100,000	\$10,100,000	\$14,000,000	\$14,000,000	\$20,400,000	\$20,400,000
Direct Annual Costs (DAC)						
Steam production credits (b)						
Natural gas	(\$758,000)	(\$758,000)	(\$1,260,000)	(\$1,260,000)	(\$2,270,000)	(\$2,270,000)
Fuel oil	(\$1,190,000)	(\$1,190,000)	(\$1,990,000)	(\$1,990,000)	(\$3,580,000)	(\$3,580,000)
BLO operating cost savings (c)	(\$103,000)	(\$103,000)	(\$172,000)	(\$172,000)	(\$309,000)	(\$309,000)
Concentrator steam costs (d)	\$57,800	\$57,800	\$96,300	\$96,300	\$173,000	\$173,000
ESP operating electricity costs (e)	\$33,100	\$21,400	\$55,000	\$35,600	\$99,200	\$64,200
Total DAC						
Natural gas	(\$770,000)	(\$782,000)	(\$1,280,000)	(\$1,300,000)	(\$2,310,000)	(\$2,340,000)
Fuel oil	(\$1,200,000)	(\$1,210,000)	(\$2,010,000)	(\$2,030,000)	(\$3,620,000)	(\$3,650,000)
Indirect Annual Costs (IAC)						
Administrative, taxes, and insurance (f)						
Low-odor conversion	324,000	324,000	440,000	440,000	628,000	628,000
ESP upgrade	50,800	50,800	73,600	73,600	114,000	114,000
Wet- to dry-bottom ESP conversion	17,600	17,600	23,800	23,800	34,000	34,000
Total	392,000	392,000	537,000	537,000	776,000	776,000
Capital recovery (g)						
Low-odor conversion	\$764,000	\$764,000	\$1,040,000	\$1,040,000	\$1,480,000	\$1,480,000
ESP upgrade	\$148,000	\$148,000	\$215,000	\$215,000	\$334,000	\$334,000
Wet- to dry-bottom ESP conversion	\$51,300	\$51,300	\$69,700	\$69,700	\$99,200	\$99,200
Production losses	\$32,900	\$32,900	\$54,800	\$54,800	\$98,200	\$98,200
Total	996,000	996,000	1,380,000	1,380,000	2,010,000	2,010,000
Total IAC	\$1,390,000	\$1,390,000	\$1,920,000	\$1,920,000	\$2,790,000	\$2,790,000
Total Annual Costs						
Natural gas	\$620,000	\$608,000	\$640,000	\$620,000	\$480,000	\$450,000
Fuel oil	\$190,000	\$180,000	(\$90,000)	(\$110,000)	(\$830,000)	(\$860,000)

(a) All costs in \$1991. Numbers in parentheses represent cost savings.

(b) Steam production credit calculations (either natural gas or fuel oil):  
 Natural gas credit = (model BLS firing rate) x (6,000 Btu/lb) x (1 d/24 hr) x (66%-56% thermal efficiency)/(85% power boiler efficiency) x (1 ft<sup>3</sup>/1,024 Btu) x (8,424 hr/yr) x (\$3.48/1,000 ft<sup>3</sup>)  
 Fuel oil credit = (model BLS firing rate) x (6,000 Btu/lb) x (1 d/24 hr) x (66%-56% thermal efficiency)/(85% power boiler efficiency) x (1 gal/144,000 Btu) x (8,424 hr/yr) x (\$0.77/gal)

(c) BLO operating cost savings = \$251,900/yr x (model BLS firing rate/2,200,000 lb BLS/d)

(d) Concentrator steam costs = \$54,000/yr x (model BLS firing rate/2,400,000 lb BLS/d)

(e) ESP operating electricity cost = 0.00194 x increase in ESP plate area x 8,424 hr/yr x \$0.06/kWh

(f) Administrative, taxes, and insurance = 0.04 x TCI

(g) For low-odor conversion and production losses, capital recovery cost = 0.0944 x TCI (based on 20-yr remaining service life and 7% interest)  
 For ESP upgrade and wet- to dry-bottom ESP conversion, capital recovery cost = 0.1169 x TCI (based on 13.5-yr ESP life and 7% interest)

TABLE 6-22a (METRIC). GAS AND LIQUID STREAM PARAMETERS FOR RECOVERY FURNACE MODEL PROCESS UNITS<sup>a</sup>

Parameters	Model NDCE/Converted DCE Recovery Furnaces				Model DCE Recovery Furnaces		
	RF-1/4/8	RF-2/5/9	RF-3/6	RF-7	RF-7	RF-8	RF-9
<b>Gas Stream Properties:</b>							
<b>ESP Outlet:</b>							
Flow rate, m <sup>3</sup> /sec	93	168	243	56	56	93	168
Temperature, °C	199	199	199	199	160	160	160
Moisture content, %	26	26	26	26	32	32	32
<b>Out of Quench:</b>							
Flow rate, m <sup>3</sup> /sec	76	136	197	45	48	80	144
Temperature, °C	72	72	72	72	74	74	74
Moisture content, %	33	33	33	33	37	37	37
Density, kg/m <sup>3</sup>	0.8946	0.8946	0.8946	0.8946	0.8762	0.8762	0.8762
Molecular weight, g/gmole	25.3	25.3	25.3	25.3	25.0	25.0	25.0
Viscosity, kg/m-hr	0.0617	0.0617	0.0617	0.0617	0.0607	0.0607	0.0607
HCl concentration, ppmv	9.7	9.7	9.7	9.7	9.2	9.2	9.2
HCl emissions, kg/d	82	147	212	49	49	82	147
<b>Out of Absorber:</b>							
HCl concentration, ppmv	5	5	5	5	5	5	5
<b>Liquid Stream Properties:</b>							
HCl concentration in entering liquid, gmole HCl per gmole pollutant-free liquid	0	0	0	0	0	0	0
Density, kg/m <sup>3</sup>	999	999	999	999	999	999	999
Molecular weight, g/gmole	18	18	18	18	18	18	18
<b>Pollutant Properties:</b>							
Diffusivity of HCl in air, m <sup>2</sup> /hr	0.0673	0.0673	0.0673	0.0673	0.0673	0.0673	0.0673
Diffusivity of HCl in water, m <sup>2</sup> /hr	9.4E-6	9.4E-6	9.4E-6	9.4E-6	9.4E-6	9.4E-6	9.4E-6

<sup>a</sup>Metric equivalents in this table were converted from the calculated English unit values given in Table 6-22b.



TABLE 6-22b (ENGLISH). GAS AND LIQUID STREAM PARAMETERS FOR RECOVERY FURNACE MODEL PROCESS UNITS

Parameters	Model NDCE/Converted DCE Recovery Furnaces				Model DCE Recovery Furnaces		
	RF-1/4/8	RF-2/5/9	RF-3/6	RF-7	RF-7	RF-8	RF-9
<u>Gas Stream Properties:</u>							
ESP Outlet:							
Flow rate, acfm	198,000	357,000	515,000	119,000	119,000	198,000	357,000
Temperature, °F	390	390	390	390	320	320	320
Moisture content, %	26	26	26	26	32	32	32
Out of Quench <sup>a</sup> :							
Flow rate, acfm	161,000	289,000	417,000	96,500	102,000	170,000	307,000
Temperature, °F	161	161	161	161	165	165	165
Moisture content, %	33	33	33	33	37	37	37
Density, lb/ft <sup>3</sup>	0.05587	0.05587	0.05587	0.05587	0.05470	0.05470	0.05470
Molecular weight, lb/lbmole	25.3	25.3	25.3	25.3	25.0	25.0	25.0
Viscosity, lb/ft-hr	0.0415	0.0415	0.0415	0.0415	0.0408	0.0408	0.0408
HCl concentration, ppmv	9.7	9.7	9.7	9.7	9.2	9.2	9.2
HCl emissions, lb/d	180	324	468	108	108	180	324
Out of Absorber:							
HCl concentration, ppmv	5	5	5	5	5	5	5
<u>Liquid Stream Properties:</u>							
HCl concentration in entering liquid, lbmole HCl per lbmole pollutant-free liquid	0	0	0	0	0	0	0
Density, lb/ft <sup>3</sup>	62.4	62.4	62.4	62.4	62.4	62.4	62.4
Molecular weight, lb/lbmole	18	18	18	18	18	18	18
<u>Pollutant Properties:</u>							
Diffusivity of HCl in air, ft <sup>2</sup> /hr	0.725	0.725	0.725	0.725	0.725	0.725	0.725
Diffusivity of HCl in water, ft <sup>2</sup> /hr	1.02E-4	1.02E-4	1.02E-4	1.02E-4	1.02E-4	1.02E-4	1.02E-4

<sup>a</sup>To simplify the packed-bed scrubber design analysis, it was assumed that the gas stream exiting the ESP was cooled to saturation with water sprays.

TABLE 6-23a (METRIC). PACKED-BED SCRUBBER DESIGN AND OPERATING PARAMETERS<sup>a</sup>

Packed-Bed Scrubber Parameters	Model NDCE/Converted DCE Recovery Furnaces				Model DCE Recovery Furnaces		
	RF-1/4/8	RF-2/5/9	RF-3/6	RF-7	RF-7	RF-8	RF-9
<u>Packed-Bed Scrubber Design Parameters:</u>							
Cross-sectional area, m <sup>2</sup>	36	64	93	21	22	37	67
Vessel diameter, m	6.7	9.0	11	5.2	5.4	6.9	9.3
Packing height, m	0.47	0.47	0.47	0.47	0.43	0.43	0.43
Tower height, m	8.4	11	13	6.8	6.9	8.5	11
Surface area, m <sup>2</sup>	249	433	615	155	161	259	452
Pressure drop, mm Hg	2.4	2.4	2.4	2.4	2.2	2.2	2.2
<u>Auxiliary Equipment:</u>							
Stack height, m	30.5	30.5	30.5	30.5	30.5	30.5	30.5
Stack diameter, m	3.1	4.1	5.0	2.4	2.5	3.2	4.3
Fan impeller diameter, m	2.7	3.6	4.1	2.2	2.3	2.8	3.7
Fan motor efficiency, fraction	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Pump motor efficiency, fraction	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Power for fan, kW	34.4	62.3	89.5	20.6	20.2	33.6	60.7
Power for pump, kW	28.1	50.6	73.1	16.9	17.7	29.5	53.1
Wastewater flow rate, L/min	6.25	11.2	16.2	3.75	3.21	5.36	9.65
Caustic addition (dry NaOH), kg/hr	25.6	46.1	66.6	15.4	13.2	22.0	39.6
<u>Column Operation:</u>							
Minimum wetting rate, m <sup>2</sup> /hr	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Fraction of flooding gas velocity	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Operating hours per year							
Equipment	8,424	8,424	8,424	8,424	8,424	8,424	8,424
Labor	8,760	8,760	8,760	8,760	8,760	8,760	8,760
Operating labor requirement, hr/d	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Maintenance labor requirement, hr/d	1.5	1.5	1.5	1.5	1.5	1.5	1.5

<sup>a</sup>Metric equivalents in this table were converted from the calculated English unit values given in Table 6-23b.

TABLE 6-23b (ENGLISH). PACKED-BED SCRUBBER DESIGN AND OPERATING PARAMETERS

Packed-Bed Scrubber Parameters	Model NDCE/Converted DCE Recovery Furnaces				Model DCE Recovery Furnaces		
	RF-1/4/8	RF-2/5/9	RF-3/6	RF-7	RF-7	RF-8	RF-9
<b><u>Packed-Bed Scrubber Design Parameters:</u></b>							
Cross-sectional area, ft <sup>2</sup>	384	690	998	231	242	403	725
Vessel diameter, ft	22.1	29.6	35.6	17.1	17.6	22.7	30.4
Packing height, ft	1.54	1.54	1.54	1.53	1.41	1.41	1.41
Tower height, ft	27.5	35.2	41.3	22.4	22.7	27.9	35.8
Surface area, ft <sup>2</sup>	2,679	4,657	6,624	1,672	1,735	2,791	4,864
Pressure drop, in H <sub>2</sub> O	1.3	1.3	1.3	1.3	1.2	1.2	1.2
<b><u>Auxiliary Equipment:</u></b>							
Stack height, ft	100	100	100	100	100	100	100
Stack diameter, ft	10.1	13.6	16.3	7.8	8.1	10.4	14.0
Fan impeller diameter, in	105	140	160	85	90	110	145
Fan motor efficiency, fraction	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Pump motor efficiency, fraction	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Power for fan, kW	34.4	62.3	89.5	20.6	20.2	33.6	60.7
Power for pump, kW	28.1	50.6	73.1	16.9	17.7	29.5	53.1
Wastewater flow rate, gpm	1.651	2.971	4.291	0.990	0.849	1.415	2.548
Caustic addition (dry NaOH), lb/hr	56.5	102	147	33.9	29.1	48.4	87.2
<b><u>Column Operation:</u></b>							
Minimum wetting rate, ft <sup>2</sup> /hr	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Fraction of flooding gas velocity	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Operating hours per year							
Equipment	8,424	8,424	8,424	8,424	8,424	8,424	8,424
Labor	8,760	8,760	8,760	8,760	8,760	8,760	8,760
Operating labor requirement, hr/d	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Maintenance labor requirement, hr/d	1.5	1.5	1.5	1.5	1.5	1.5	1.5

TABLE 6-24a (METRIC). UNIT COSTS FOR PACKED-BED SCRUBBER<sup>a</sup>

Parameters	Value
Operator wage rate, \$/hr	15.64
Water cost, \$/m <sup>3</sup>	0.05
Electricity, \$/kWh	0.06
Wastewater disposal, \$/m <sup>3</sup>	1.0
Caustic (dry NaOH), \$/Mg	441
Packing material, \$/m <sup>3</sup>	706

<sup>a</sup>Metric equivalents in this table were converted from the calculated English unit values given in Table 6-24b.

TABLE 6-24b (ENGLISH). UNIT COSTS FOR PACKED-BED SCRUBBER<sup>a, b</sup>

Parameters	Value
Operator wage rate, \$/hr	15.64
Water cost, \$/1,000 gal	0.2
Electricity, \$/kWh	0.06
Wastewater disposal, \$/1,000 gal	3.8
Caustic (dry NaOH), \$/ton	400
Packing material, \$/ft <sup>3</sup>	20

<sup>a</sup>OAQPS Control Cost Manual

<sup>b</sup>Medical Waste Incinerators--Background Information for Proposed Standards and Guidelines: Model Plant Description and Cost Report for New and Existing Facilities. U. S. Environmental Protection Agency. Research Triangle Park, NC. Publication No. EPA-453/R-94-044a. July 1994. p. 62.

TABLE 6 - 25. PACKED-BED SCRUBBER CAPITAL COSTS FOR MODEL RECOVERY FURNACES<sup>a</sup>

Costs	Model NDCE/Converted DCE Recovery Furnaces				Model DCE Recovery Furnaces			
	RF-1/4/8	RF-2/5/9	RF-3/6	RF-7	RF-7	RF-7	RF-8	RF-9
Equipment Costs <sup>b</sup> :								
Tower	\$308,139	\$535,566	\$761,709	\$192,226	\$199,517	\$320,931	\$559,395	
Packing	\$11,810	\$21,196	\$30,685	\$7,084	\$6,809	\$11,366	\$20,409	
Pump	\$27,888	\$50,112	\$72,480	\$16,776	\$17,575	\$29,268	\$52,653	
Fan	\$35,639	\$53,007	\$63,733	\$26,624	\$28,809	\$38,001	\$55,637	
Fan motor	\$2,414	\$3,935	\$5,297	\$1,583	\$1,557	\$2,367	\$3,848	
Stack	\$36,394	\$48,868	\$58,695	\$28,214	\$29,075	\$37,505	\$50,360	
Total Equipment Cost (TEC):	\$422,283	\$712,685	\$992,598	\$272,507	\$283,343	\$439,438	\$742,303	
Purchased Equipment Cost (PEC) <sup>c</sup> :	\$498,294	\$840,968	\$1,171,266	\$321,559	\$334,344	\$518,536	\$875,918	
Total Capital Investment (TCI) <sup>d</sup> :	\$1,100,000	\$1,850,000	\$2,580,000	\$707,000	\$736,000	\$1,140,000	\$1,930,000	

<sup>a</sup>All costs in \$1991

<sup>b</sup>Equipment cost equations:

FRP tower = 115 x surface area of column

Packing = volume of packing x (\$20/ft<sup>3</sup> of packing)

Pump = liquid flow rate x (\$16/gpm)

Fan = 57.9 x (fan impeller diameter)<sup>1.38</sup>

Fan motor = 104 x (E<sub>fan</sub>/0.746)<sup>0.821</sup>

Stack = 36 x stack diameter x stack height

<sup>c</sup>Purchased equipment cost = 1.18 x (TEC)

<sup>d</sup>Total capital investment = 2.2 x (PEC)

TABLE 6-26. PACKED-BED SCRUBBER ANNUAL COSTS FOR MODEL RECOVERY FURNACES<sup>a</sup>

Costs	Model NDCE/Converted DCE Recovery Furnaces				Model DCE Recovery Furnaces			
	RF-1/4/8	RF-2/5/9	RF-3/6	RF-7	RF-7	RF-7	RF-8	RF-9
Total Capital Investment (TCD):	\$1,100,000	\$1,850,000	\$2,580,000	\$707,000	\$736,000	\$1,140,000	\$1,930,000	
Direct Annual Costs (DAC):								
Operating labor <sup>b</sup> :								
Operator	\$8,563	\$8,563	\$8,563	\$8,563	\$8,563	\$8,563	\$8,563	\$8,563
Supervisor	\$1,284	\$1,284	\$1,284	\$1,284	\$1,284	\$1,284	\$1,284	\$1,284
Maintenance <sup>c</sup> :								
Labor	\$9,419	\$9,419	\$9,419	\$9,419	\$9,419	\$9,419	\$9,419	\$9,419
Material	\$9,419	\$9,419	\$9,419	\$9,419	\$9,419	\$9,419	\$9,419	\$9,419
Utilities <sup>d</sup> :								
Electricity (fan and pump)	\$31,598	\$57,062	\$82,216	\$18,949	\$19,150	\$31,888	\$57,515	\$7,515
Water	\$7,803	\$14,069	\$20,297	\$4,690	\$3,481	\$5,793	\$10,444	\$10,444
Caustic <sup>e</sup> :	\$95,145	\$171,262	\$247,378	\$57,087	\$48,957	\$81,596	\$146,872	\$146,872
Wastewater disposal <sup>f</sup> :	\$3,170	\$5,706	\$8,242	\$1,902	\$1,631	\$2,719	\$4,894	\$4,894
Total DAC:	\$166,401	\$276,784	\$386,818	\$111,313	\$101,904	\$150,681	\$248,410	\$248,410
Indirect Annual Costs (IAC):								
Overhead <sup>g</sup> :	\$17,211	\$17,211	\$17,211	\$17,211	\$17,211	\$17,211	\$17,211	\$17,211
Admin., taxes and insurance <sup>h</sup> :	\$43,850	\$74,005	\$103,071	\$28,297	\$29,422	\$45,631	\$77,081	\$77,081
Capital recovery <sup>i</sup> :	\$120,368	\$203,144	\$282,931	\$77,676	\$80,764	\$125,258	\$211,587	\$211,587
Total IAC:	\$181,429	\$294,360	\$403,213	\$123,184	\$127,397	\$188,100	\$305,879	\$305,879
Total Annual Costs (TAC):	\$348,000	\$571,000	\$790,000	\$234,000	\$229,000	\$339,000	\$554,000	\$554,000

<sup>a</sup>All costs in \$1991

<sup>b</sup>Operator labor = 1.5 hr/d x 365 d/yr x \$15.64/hr; supervisor labor = 15% of operator labor cost

<sup>c</sup>Maintenance labor = 1.5 hr/d x 365 d/yr x (1.1 x \$15.64/hr); maintenance materials = 100% of maintenance labor cost

<sup>d</sup>Electricity (fan and pump) =  $(E_{fan} + E_{pump}) \times 8,424 \text{ hr/yr} \times \$0.06/\text{kWh}$

<sup>e</sup>Water = [wastewater flow rate + (water vapor out of quench - water vapor out of ESP)] (gpm) x 60 min/hr x 8.424 hr/yr x \$0.20/gal H<sub>2</sub>O

<sup>f</sup>Caustic = caustic addition (lb/hr) x 8.424 hr/yr x 1 ton/2,000 lb x \$400/ton caustic

<sup>g</sup>Wastewater disposal = wastewater flow rate (gpm) x 60 min/hr x 8.424 hr/yr x \$3.80/1,000 gal wastewater

<sup>h</sup>Overhead = 0.6 x (maintenance cost + operating labor cost)

<sup>i</sup>Administrative, taxes, and insurance = 0.04 x TCI

<sup>j</sup>Capital recovery = 0.1098 x TCI (based on 15-yr scrubber life and 7% interest)

TABLE 6-27a (METRIC). MODEL BLACK LIQUOR OXIDATION UNIT DESIGN PARAMETERS<sup>a</sup>

Design parameters	Model BLO units		
	BLO-1	BLO-2	BLO-3
Black liquor firing rate, kg BLS/d	400,000	700,000	1,200,000
Equivalent ADMP/d			
Bleached pulp	230	380	680
Unbleached pulp	270	450	820
Vent gas flowrate, m <sup>3</sup> /sec @ 54 degrees C	4.2	8.5	12.7
Operating days per year			
Equipment	351	351	351
Labor	365	365	365
Operating hours per year			
Equipment	8,424	8,424	8,424
Labor	8,760	8,760	8,760

(a) Metric equivalents in this table were converted from the calculated English unit values given in Table 6-27b.

TABLE 6r.27b (ENGLISH). MODEL BLACK LIQUOR OXIDATION UNIT DESIGN PARAMETERS<sup>a</sup>

Design parameters	Model BLO units		
	BLO-1	BLO-2	BLO-3
Black liquor firing rate, lb BLS/d	900,000	1,500,000	2,700,000
Equivalent ADTP/d			
Bleached pulp	250	420	750
Unbleached pulp	300	500	900
Vent gas flowrate, acfm @ 130 degrees F	8,900	18,000	26,900
Operating days per year			
Equipment	351	351	351
Labor	365	365	365
Operating hours per year			
Equipment	8,424	8,424	8,424
Labor	8,760	8,760	8,760