Electronic Supplementary Material (ESI) for Sustainable Energy & Fuels.

Supplementary Information for

Enhanced Carbon Dioxide Removal from Coupled Direct Air Capture-Bioenergy Systems

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Figures S1 - S5
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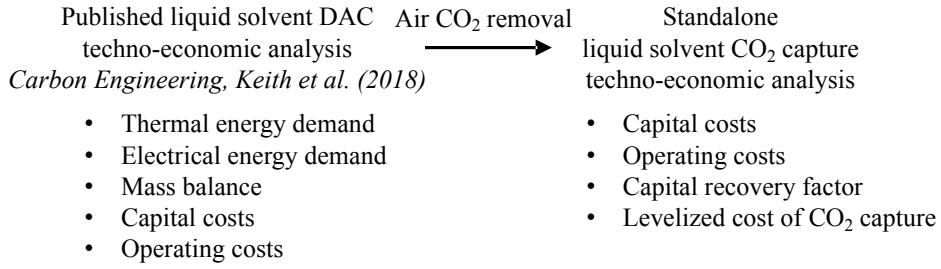
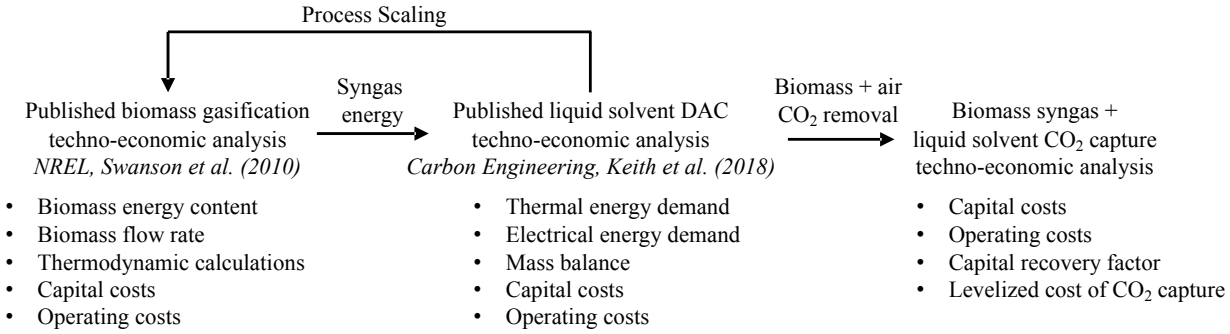
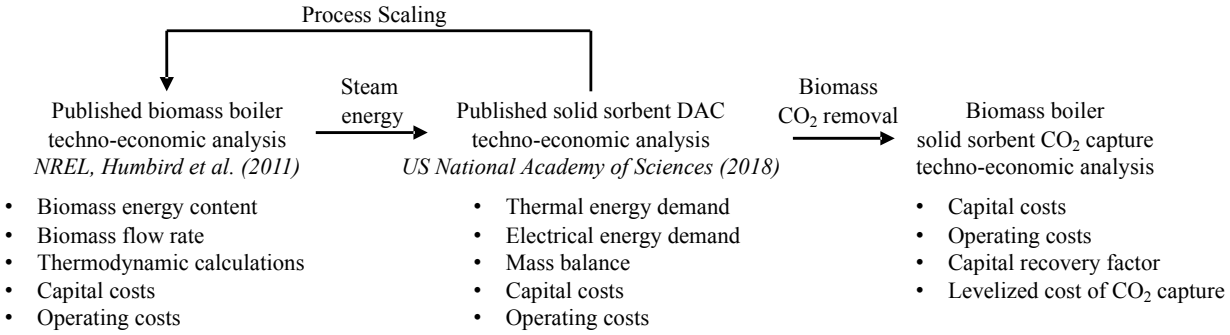
A Natural Gas + Liquid Solvent (NG + LS-DAC)



B Biomass Gasification + Liquid Solvent (BG + LS-DAC)



C Biomass Boiler + Solid Sorbent without direct air capture (BB + SS-CC)



D Biomass Boiler + Solid Sorbent with direct air capture (BB + SS-DAC)

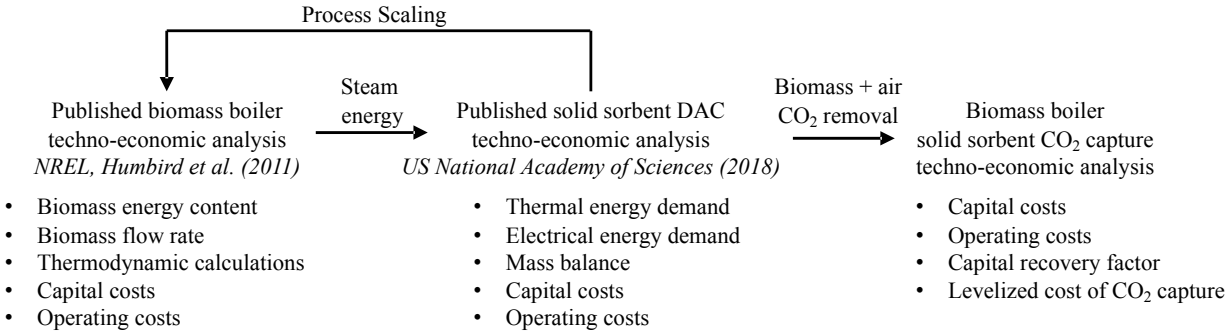


Figure S1. Approaches taken to design, model, and analyze the four CO_2 removal systems

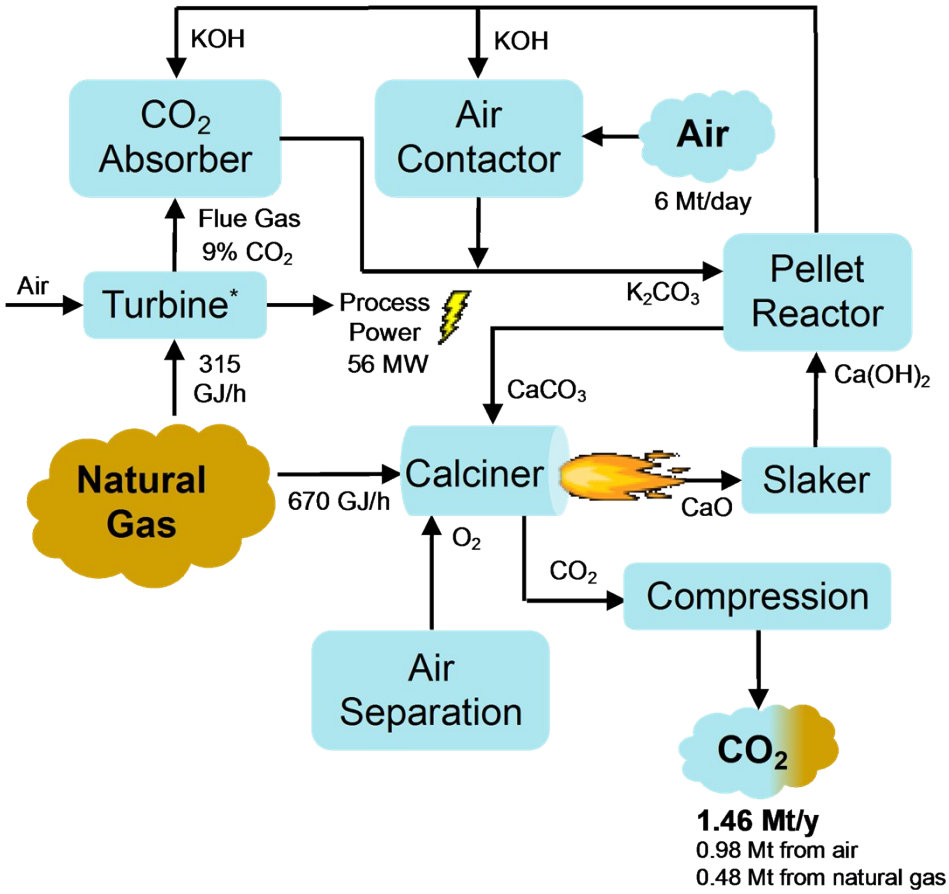


Figure S2. A generalized process flow diagram of the Natural Gas plus Liquid Solvent DAC system (NG + LS-DAC) adapted from Carbon Engineering. Turbine* includes a gas turbogenerator and a heat recovery steam generator.

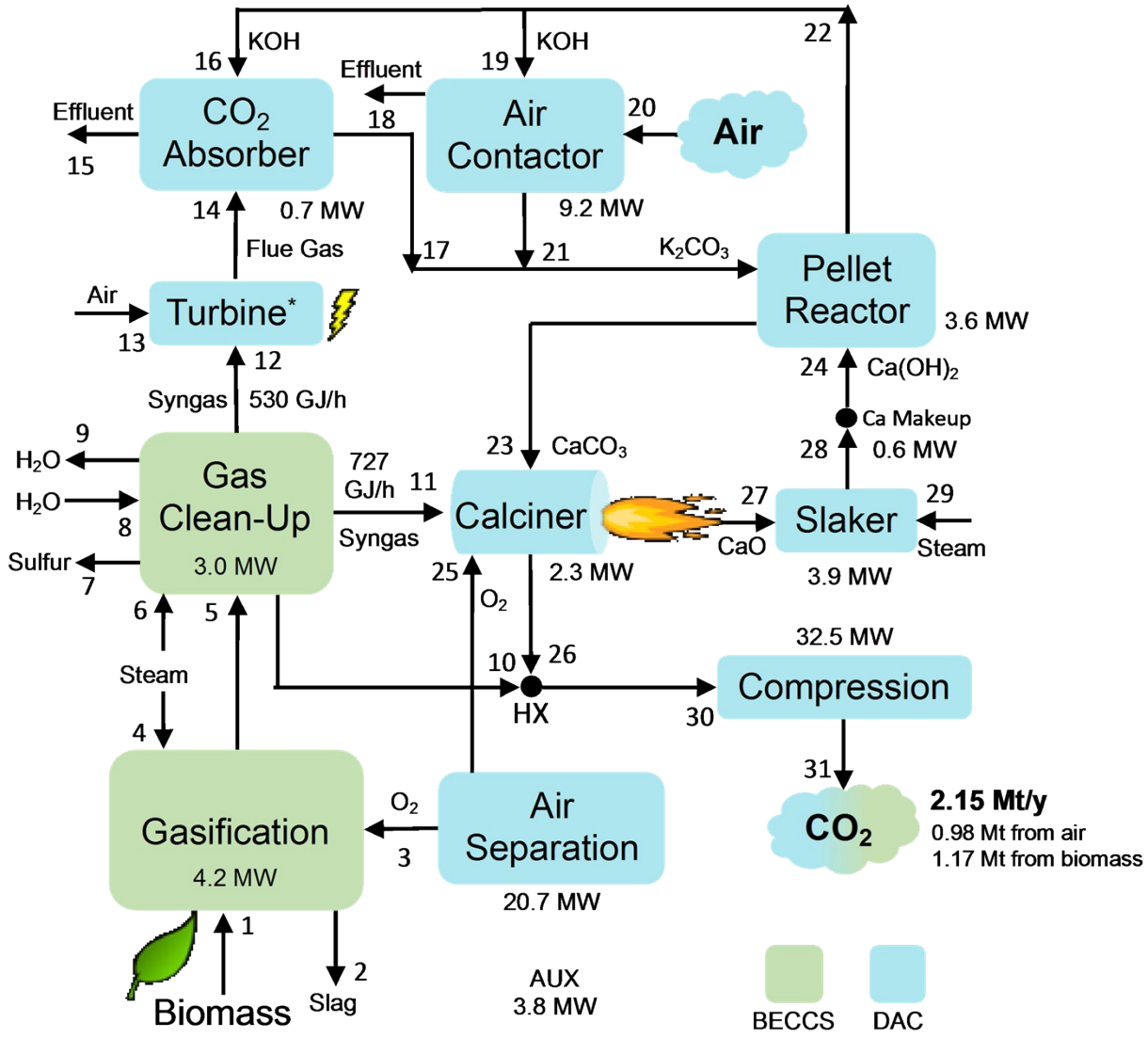


Figure S3. A generalized process flow diagram of the Biomass Gasification + Liquid Solvent Direct Air Capture (BG + LS-DAC) system. Only major streams shown, with minor make-up streams not shown. Turbine* includes a gas turbogenerator and a heat recovery steam system. Preprocessing (drying) and several minor streams are not shown for the gasification subsystem. Calciner includes heat exchange between hot flue gas and incoming $CaCO_3$, as well as water knockout. Air separation includes oxygen pre-heating. Power demanded by major process areas shown.

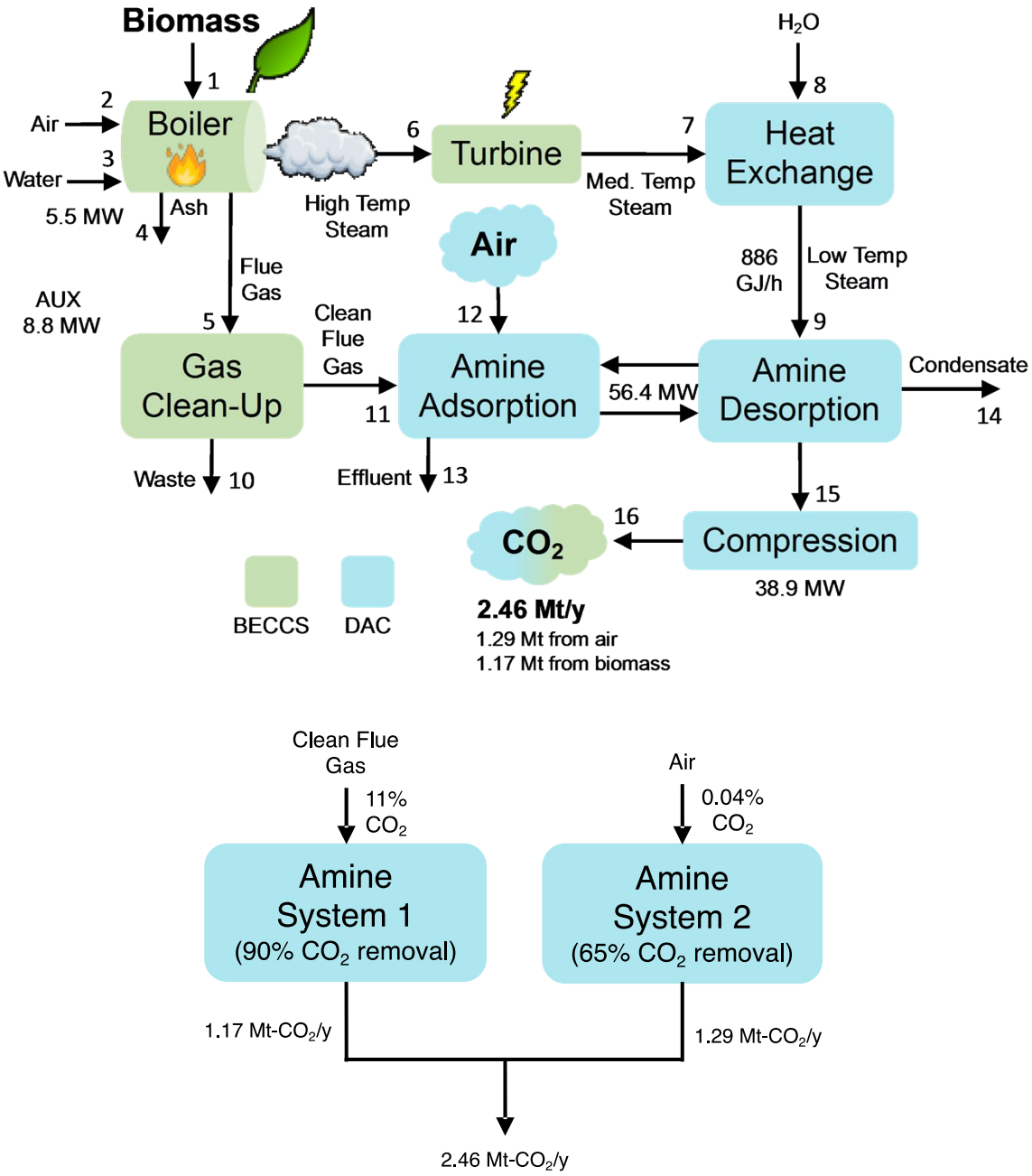


Figure S4. A generalized process flow diagram of the Biomass Boiler plus Solid Sorbent Direct Air Capture (BB + SS-DAC) system**.** Only major streams shown, with most make-up streams not shown. Power demanded by major process areas shown.

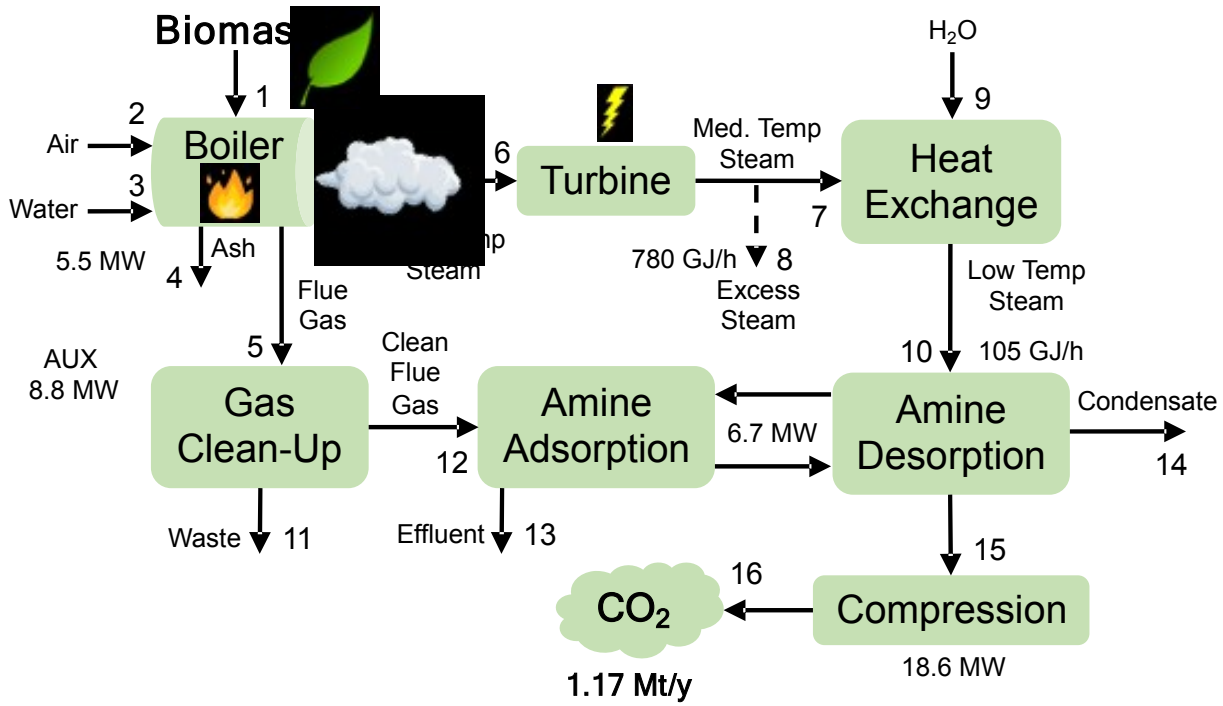


Figure S5. A generalized process flow diagram of the Biomass Boiler plus Solid Sorbent Carbon Capture (BB + SS-CC) system**.** Only major streams shown, with most make-up streams not shown. Power demanded by major process areas shown.

Table S1. An overview of the four CO_2 removal systems analyzed in this study

System	Acronym	Feedstock for Combustion	CO_2 Capture Technology	Flue Gas CO_2 Capture?	Direct Air CO_2 Capture?
Natural Gas plus Liquid Solvent Direct Air Capture	NG + LS-DAC	Natural Gas	Liquid Alkaline Solvent	Yes	Yes
Biomass Gasification plus Liquid Solvent Direct Air Capture	BG + LS-DAC	Biomass	Liquid Alkaline Solvent	Yes	Yes
Biomass Boiler plus Solid Sorbent Carbon Capture	BB + SS-CC	Biomass	Solid Amine Sorbent	Yes	No
Biomass Boiler plus Solid Sorbent Direct Air Capture	BB + SS-DAC	Biomass	Solid Amine Sorbent	Yes	Yes

Table S2. Capital recovery factors (CRF) with varying weighted average costs of capital (i) and project life (years)

Capital Recovery Factor (CRF) Values						
Weighted Average Cost of Capital (i)	Project Life (years) (N)					
	5	10	15	20	25	30
1%	21%	11%	7%	6%	5%	4%
5%	23%	13%	10%	8%	7%	7%
10%	26%	16%	13%	12%	11%	11%
15%	30%	20%	17%	16%	15%	15%
20%	33%	24%	21%	21%	20%	20%

Table S3. Itemized capital costs and scaling factors for the NG + LS-DAC system

Equipment Name	Original installed cost	Reference	Year of quote	Scaling Value	Units	Scaling exponent	Scaling stream	New value	Size ratio	Scaled installation cost	Index base year (2016)	Index project year (2016)	Installed cost in project year
Air contactor	$ 132,800,000	*(10)*	2016	1.45	Mt-CO2/y	0.80	CO2 Capacity	1.45	1	$ 132,800,000	541.7	541.7	$ 132,800,000
Pellet reactor	$ 94,800,000	*(10)*	2016	1.45	Mt-CO2/y	0.80	CO2 Capacity	1.45	1	$ 94,800,000	541.7	541.7	$ 94,800,000
Calciner-slaker	$ 63,600,000	*(10)*	2016	1.45	Mt-CO2/y	0.80	CO2 Capacity	1.45	1	$ 63,600,000	541.7	541.7	$ 63,600,000
Air separation unit	$ 46,700,000	*(10)*	2016	1.45	Mt-CO2/y	0.80	CO2 Capacity	1.45	1	$ 46,700,000	541.7	541.7	$ 46,700,000
CO2 compressor	$ 15,500,000	*(10)*	2016	1.45	Mt-CO2/y	0.80	CO2 Capacity	1.45	1	$ 15,500,000	541.7	541.7	$ 15,500,000
Steam turbine	$ 5,800,000	*(10)*	2016	1.45	Mt-CO2/y	0.80	CO2 Capacity	1.45	1	$ 5,800,000	541.7	541.7	$ 5,800,000
Power plant	$ 26,700,000	*(10)*	2016	1.45	Mt-CO2/y	0.80	CO2 Capacity	1.45	1	$ 26,700,000	541.7	541.7	$ 26,700,000
Fines filter	$ 24,800,000	*(10)*	2016	1.45	Mt-CO2/y	0.80	CO2 Capacity	1.45	1	$ 24,800,000	541.7	541.7	$ 24,800,000
Other equipment	$ 77,000,000	*(10)*	2016	1.45	Mt-CO2/y	0.80	CO2 Capacity	1.45	1	$ 77,000,000	541.7	541.7	$ 77,000,000
Buildings	$ 5,800,000	*(10)*	2016	1.45	Mt-CO2/y	0.80	CO2 Capacity	1.45	1	$ 5,800,000	541.7	541.7	$ 5,800,000
Transformer	$ 16,700,000	*(10)*	2016	1.45	Mt-CO2/y	0.80	CO2 Capacity	1.45	1	$ 16,700,000	541.7	541.7	$ 16,700,000
Indirect costs		*(10)*											$ 180,800,000
Contingency		*(10)*											$ 86,800,000
												Total Direct Costs:	$ 510,200,000
												Total Indirect Costs:	$ 267,600,000
												Total Capital Costs:	$ 777,800,000
												Capital Intensity ($/t-CO2-year)	$ 793

Table S4. A summary of results from the Natural Gas plus Liquid Solvent Direct Air Capture (NG + LS-DAC) techno-economic analysis showing levelized costs of CO_2 removal with a natural gas cost of $3.5/GJ and CRF values of 7.5% and 12.5%. These results compare nicely with those determined in Keith et al.'s techno-economic analysis of Carbon Engineering's baseline process.

Natural Gas + Liquid Solvent Direct Air Capture NG + LS-DAC Economic Summary		
Direct air CO2 capacity (Mt-CO2/y)		0.98
Biogenic CO2 capacity (Mt-CO2/y)		0.00
Total capacity (Mt-CO2/y)		0.98
Specific biogenic CO2 capacity (t-CO2/t-biomass)		N/A
Natural gas cost ($/GJ)	$	3.50
Equipment Costs (2016$)		**Installed Capital Cost**
Air contactor	$	132,800,000
Pellet reactor	$	94,800,000
Calciner-slaker	$	63,600,000
Air separation unit	$	46,700,000
CO2 compressor	$	15,500,000
Steam turbine	$	5,800,000
Power plant	$	26,700,000
Fines filter	$	24,800,000
Other equipment	$	77,000,000
Buildings	$	5,800,000
Transformer	$	16,700,000
Indirect costs	$	180,800,000
Contingency	$	86,800,000
Total Installed Capital	$	777,800,000
Capital Intensity ($/t-CO2-year)	$	793
Levelized Capital Cost (CRF 7.5%) ($/t-CO2)	**$**	**66**
Levelized Capital Cost (CRF 12.5%) ($/t-CO2)	**$**	**110**
Operating Costs (2016$)		**Annual Cost ($/y)**
Natural gas	$	30,252,835
Non-energy O&M	$	29,433,600
Electricity to grid	$	-
Net Operating Costs	$	59,686,435
Net Operating Costs ($/t-CO2)	**$**	**61**
Total Costs (CRF 7.5%) ($/t-CO2)	**$**	**127**
Total Costs (CRF 12.5%) ($/t-CO2)	**$**	**171**

Table S5. Mass balance of the BG + LS-DAC system

Stream	Approx. Temp (C)	Mass flow (t/day)	Biomass	H2O	CO	H2	CO2	O2	N2	KOH	K2CO3	Ca(OH)2	CaCO3	CaO	H2S	S	Slag
1	90	2556	2300	256	0	0	0	0	0	0	0	0	0	0	0	0	0
2	50	131	0	0	0	0	0	0	0	0	0	0	0	0	0	0	131
3	149	856	0	0	0	0	0	805	0	0	0	0	0	0	0	0	0
4	200	1104	0	1104	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1300	4399	0	1137	1676	141	1362	0	0	0	0	0	0	0	0	0	0
6	190	633	0	633	0	0	0	0	0	0	0	0	0	0	0	0	0
7	50	8	0	5	0	0	0	0	0	0	0	0	0	0	0	4	0
8	30	115	0	115	0	0	0	0	0	0	0	0	0	0	0	0	0
9	40	1726	0	1550	25		147		0	0	0	0	0	0	1	0	0
10	53	2032	0	29	5	0	1976	0	18	0	0	0	0	0	0	0	0
11	52	799	0	30	661	102	9	0	0	0	0	0	0	0	0	0	0
12	52	583	0	22	481	75	7	0	0	0	0	0	0	0	0	0	0
13	25	3761	0	0	0	0	0	873	2836	0	0	0	0	0	0	0	0
14	90	4294	0	694	0	0	764	0	2836	0	0	0	0	0	0	0	0
15	25	3607	0	0	0	0	76	0	0	0	0	0	0	0	0	0	0
16	21	17370	0	15617	0	0	0	0	0	1752	0	0	0	0	0	0	0
17	31	18057	0	15899	0	0	0	0	0	0	2158	0	0	0	0	0	0
18	21	6021307	0	59035	0	0	922	1385520	4575830	0	0	0	0	0	0	0	0
19	21	68065	0	61198	0	0	0	0	0	6866	0	0	0	0	0	0	0
20	21	6024000	0	59035	0	0	3614	1385520	4575830	0	0	0	0	0	0	0	0
21	31	70758	0	62300	0	0	0	0	0	0	8458	0	0	0	0	0	0
22	21	84573	0	76816	0	0	0	0	0	7757	0	0	0	0	0	0	0
23	21	6913	0	0	0	0	0	0	0	0	0	0	6913	0	0	0	0
24	21	20277	0	15161	0	0	0	0	0	0	0	5116	0	0	0	0	0
25	674	1197	0	0	0	0	0	1197	0	0	0	0	0	0	0	0	0
26	900	4876	0	952	0	0	3924	0	0	0	0	0	0	0	0	0	0
27	674	3794	0	0	0	0	0	0	0	0	0	0	0	3794	0	0	0
28	300	19423	0	15161	0	0	0	0	0	0	0	4262	0	0	0	0	0
29	253	16198	0	16198	0	0	0	0	0	0	0	0	0	0	0	0	0
30	30	6439	0	0	0	0	6246	0	193	0	0	0	0	0	0	0	0
31	40	6439	0	0	0	0	6246	0	193	0	0	0	0	0	0	0	0

Overall Mass Balance			
	Mass in	Mass out	% diff
Gasification	4515	4530	-0.33%
Syngas Cleaning	5146	5149	-0.06%
Turbine	4344	4294	1.16%
CO2 Absorber	21664	21664	0.00%
Air Contactor	6092065	6092065	0.00%
Pellet reactor	91035	91486	-0.50%
Calciner	8910	8670	2.69%
Slaker	19992	19423	2.85%
Total	6247670	6247280	0.01%

Table S6. Itemized capital costs and scaling factors for the BG + LS-DAC system

Equipment	Original installed cost	Reference	Year of quote	Scaling stream	Scaling value	Units	Scaling exponent	New value	Size ratio	Scaled installed cost	Cost index base year	Cost index project year (2016)	Installed cost in project year
Preprocessing	$ 22,700,000	*(15)*	2007	Biomass feed	2000	dry tonne/day	0.80	2300	1.15	$ 25,385,407	525.4	541.7	$ 26,172,963
Gasification	$ 67,800,000	*(15)*	2007	Biomass feed	2000	dry tonne/day	0.80	2300	1.15	$ 75,820,731	525.4	541.7	$ 78,172,992
Syngas cleaning	$ 33,500,000	*(15)*	2007	Biomass feed	2000	dry tonne/day	0.80	2300	1.15	$ 37,463,045	525.4	541.7	$ 38,625,298
Power Plant	$ 45,564,672	*(15)*	2007	Power Generation	36	MW	0.80	85	2.4	$ 90,497,884	525.4	541.7	$ 93,305,489
Air contactor	$ 132,800,000	*(10)*	2016	CO2 capacity	0.98	Mt-CO2/y	0.80	0.98	1	$ 132,800,000	541.7	541.7	$ 132,800,000
Pellet reactor	$ 94,800,000	*(10)*	2016	CO2 to pellets	1.13	Mt-CO2/y	0.80	1.23	1.08	$ 101,176,251	541.7	541.7	$ 101,176,251
Calciner-slaker	$ 63,600,000	*(10)*	2016	Total CO2 capacity	1.45	Mt-CO2/y	0.80	2.15	1.48	$ 86,921,315	541.7	541.7	$ 86,921,315
Air separation unit	$ 46,700,000	*(10)*	2016	O2 demand	1284	tonne/day	0.80	2002	1.56	$ 66,626,224	541.7	541.7	$ 66,626,224
CO2 compressor	$ 15,500,000	*(10)*	2016	Total CO2 capacity	1.45	Mt-CO2/y	0.80	2.15	1.48	$ 21,183,654	541.7	541.7	$ 21,183,654
Fines filter	$ 24,800,000	*(10)*	2016	CO2 to pellets	1.13	Mt-CO2/y	0.80	1.23	1.08	$ 26,468,049	541.7	541.7	$ 26,468,049
Other equipment	$ 77,000,000	*(10)*	2016	Total CO2 capacity	1.45	Mt-CO2/y	0.80	2.15	1.48	$ 105,234,925	541.7	541.7	$ 105,234,925
Buildings	$ 5,800,000	*(10)*	2016	Total CO2 capacity	1.45	Mt-CO2/y	0.80	2.15	1.48	$ 7,926,787	541.7	541.7	$ 7,926,787
Transformer	$ 16,700,000	*(10)*	2016	Power Generation	55.80	MW	0.80	84.60	1.52	$ 23,297,066	541.7	541.7	$ 23,297,066
Indirect costs		*(10)*											$ 286,300,100
Contingency													$ 218,842,222
												Total Direct Costs:	$ 807,911,012
												Total Indirect Costs:	$ 505,142,322
												Total Capital Costs:	$ 1,313,053,334
												Capital Intensity ($/t-CO2-year)	$ 611

Table S7. A summary of results from the Biomass Gasification plus Liquid Solvent Direct Air Capture (BG + LS-DAC) techno-economic analysis showing levelized costs of CO_2 removal with a biomass cost of $70/dry short ton and CRF values of 7.5% and 12.5%.

Biomass Gasification + Liquid Solvent Direct Air Capture BG + LS-DAC Economic Summary		
Direct air CO2 capacity (Mt-CO2/y)		0.98
Biogenic CO2 capacity (Mt-CO2/y)		1.17
Total capacity (Mt-CO2/y)		2.15
Specific biogenic CO2 capacity (t-CO2/t-biomass)		1.55
Biomass cost ($/short t-biomass)	$	70
Equipment Costs (2016$)		**Installed Capital Cost**
Preprocessing	$	26,172,963
Gasification	$	78,172,992
Syngas cleaning	$	38,625,298
Power Plant	$	93,305,489
Air contactor	$	132,800,000
Pellet reactor	$	101,176,251
Calciner-slaker	$	86,921,315
Air separation unit	$	66,626,224
CO2 compressor	$	21,183,654
Fines filter	$	26,468,049
Other equipment	$	105,234,925
Buildings	$	7,926,787
Transformer	$	23,297,066
Indirect costs	$	286,300,100
Contingency	$	218,842,222
Total Installed Capital	$	1,313,053,334
Capital Intensity ($/t-CO2-year)	$	611
Levelized Capital Cost (CRF 7.5%) ($/t-CO2)	**$**	**51**
Levelized Capital Cost (CRF 12.5%) ($/t-CO2)	**$**	**85**
Operating Costs (2016$)		**Annual Cost ($/y)**
Biomass feedstock	$	58,299,522
Non-energy O&M Costs	$	62,967,699
Electricity to grid	$	-
Net Operating Costs	$	121,267,221
Net Operating Costs ($/t-CO2)	**$**	**56**
Total Costs (w/ CRF 7.5%) ($/t-CO2)	**$**	**107**
Total Costs (w/ CRF 12.5%) ($/t-CO2)	**$**	**141**

Table S8. Mass balance of the BB + SS-DAC system

Stream	Approx. Temp (C)	Mass flow (t/day)	Biomass	H2O	CO2	O2	N2	Ash	S
1	47	3067	2300	624	0	0	0	138	5
2	192	21795	0	0	0	5056	16434	0	0
3	114	9279	0	9279	0	0	0	0	0
4	25	138	0	0	0	0	0	138	0
5	278	23418	0	1035	3971	1973	16434	0	5
6	454	9279	0	9279	0	0	0	0	0
7	230	9279	0	9279	0	0	0	0	0
8	25	53526	0	53526	0	0	0	0	0
9	100	62804	0	62804	0	0	0	0	0
10	25	1040	0	1035	0	0	0	0	5
11	60	22378	0	0	3971	1973	16434	0	0
12	25	10214528	0	100102	6129	2349342	7758956	0	0
13	30	10229201	0	100102	2625	2351315	7775158	0	0
14	40	62804	0	62804	0	0	0	0	0
15	30	7705	0	0	7474	0	231	0	0
16	40	7705	0	0	7474	0	231	0	0

Overall Mass Balance			
	Mass in	Mass out	% diff
Boiler	34140	32835	3.82%
Turbine	9279	9279	0.00%
Heat Exchange	62804	62804	0.00%
Gas Clean-Up	23418	23418	0.00%
Amine System	10299710	10299710	0.00%
Total	10429351	10428046	0.01%

Table S9. Itemized capital costs and scaling factors for the BB + SS-DAC system

Equipment Name	Original installed price	Reference	Year of quote	Scaling stream	Scaling Value	Units	Scaling exponent	New value	Size ratio	Scaled installed cost	Index base year	Index project year (2016)	Installed cost in project year
Preprocessing	$ 24,155,013	*(16)*	2009	Biomass Feed	2000	dry tonne/day	0.8	2300	1.15	$ 27,012,548	521.9	541.7	$ 28,037,358
Boiler	$ 48,652,589	*(16)*	2010	High Quality Steam Production	235	tonne/h	0.8	387	1.65	$ 72,508,866	550.8	541.7	$ 71,310,917
Turbine/generator	$ 16,145,591	*(16)*	2010	Power Production	41	MW	0.8	109.6	2.67	$ 35,453,254	550.8	541.7	$ 34,867,515
Boiler accessories + gas cleaning	$ 1,161,393	*(16)*	2010	Biomass Feed	622	dry tonne/day	0.8	2300	3.70	$ 3,305,273	550.8	541.7	$ 3,250,665
Cooling tower system/HX	$ 2,186,673	*(16)*	2010	High Quality Steam Production	235	tonne/h	0.8	387	1.65	$ 3,258,885	550.8	541.7	$ 3,205,043
Blower	$ 21,000,000	*(5)*	2016	Gas Flow Rate	10.2	Mt-gas/day	0.8	10.2	1.00	$ 21,033,213	541.7	541.7	$ 21,033,213
Vacuum pump	$ 26,000,000	*(5)*	2016	CO2 Capacity	1	Mt-CO2/y	0.8	2.46	2.46	$ 53,340,397	541.7	541.7	$ 53,340,397
Contactor	$ 13,000,000	*(5)*	2016	CO2 Capacity	1	Mt-CO2/y	0.8	2.46	2.46	$ 26,670,198	541.7	541.7	$ 26,670,198
Compressor	$ 15,500,000	*(10)*	2016	CO2 Capacity	1.45	Mt-CO2/y	0.8	2.46	1.69	$ 23,559,576	541.7	541.7	$ 23,559,576
Indirect costs		*(10)*											$ 94,005,682
Contingency													$ 107,784,169
												Total Direct Costs:	$ 265,274,882
												Total Indirect Costs:	$ 201,789,851
												Total Capital Costs:	$ 467,064,733
												Capital Intensity ($/t-CO2-year)	$ 190

Table S10. A summary of results from the Biomass Boiler plus Solid Sorbent Direct Air Capture (BB + SS-DAC) techno-economic analysis showing levelized costs of CO_2 removal with a biomass cost of $70/dry short ton and CRF values of 7.5% and 12.5%.

Biomass Boiler + Solid Sorbent with Direct Air Capture BB + SS-DAC Economic Summary		
Direct air CO2 capacity (Mt-CO2/y)		1.28
Biogenic CO2 capacity (Mt-CO2/y)		1.17
Total capacity (Mt-CO2/y)		2.46
Specific biogenic CO2 capacity (t-CO2/t-biomass)		1.55
Biomass cost ($/short t-biomass)	$	70
Electricity cost ($/kWh)	$	0.05
Equipment Costs (2016$)		**Installed Capital Cost**
Preprocessing	$	28,037,358
Boiler	$	71,310,917
Turbine/generator	$	34,867,515
Boiler accessories + gas cleaning	$	3,250,665
Cooling tower system	$	3,205,043
Blower	$	21,033,213
Vacuum pump	$	53,340,397
Contactor	$	26,670,198
Compressor	$	23,559,576
Indirect costs	$	94,005,682
Contingency	$	107,784,169
Total Installed Capital	$	467,064,733
Capital Intensity ($/t-CO2-year)	$	190
Levelized Capital Cost (CRF 7.5%) ($/t-CO2)	**$**	**16**
Levelized Capital Cost (CRF 12.5%) ($/t-CO2)	**$**	**26**
Operating Costs (2016$)		**Annual Cost ($/y)**
Biomass feestock	$	58,299,522
Sorbent material (6-month life span)	$	188,743,957
Non-energy O&M	$	42,993,151
Electricity to grid	$	-
Process steam byproduct	$	-
Net Operating Costs	$	290,036,631
Net Operating Costs ($/t-CO2)	**$**	**118**
Total Costs (CRF 7.5%) ($/t-CO2)	**$**	**134**
Total Costs (CRF 12.5%) ($/t-CO2)	**$**	**145**

Table S11. Mass balance of the BB + SS-CC system

Stream	Approx. Temp (C)	Mass flow (t/day)	Biomass	H2O	CO2	O2	N2	Ash	S
1	47	3067	2300	624	0	0	0	138	5
2	192	21795	0	0	0	5056	16434	0	0
3	114	9279	0	9279	0	0	0	0	0
4	25	138	0	0	0	0	0	138	0
5	278	23418	0	1035	3971	1973	16434	0	5
6	454	9279	0	9279	0	0	0	0	0
7	230	1104	0	1104	0	0	0	0	0
8	230	8175	0	8175	0	0	0	0	0
9	25	6370	0	6370	0	0	0	0	0
10	100	7474	0	7474	0	0	0	0	0
11	25	1040	0	1035	0	0	0	0	5
12	60	22378	0	0	3971	1973	16434	0	0
13	30	18694	0	0	398	1973	16323	0	0
14	40	7474	0	1104	0	0	0	0	0
15	30	3683	0	0	3573	0	110	0	0
16	40	3683	0	0	3573	0	110	0	0

Overall Mass Balance			
	Mass in	Mass out	% diff
Boiler	34140	32835	3.82%
Turbine	9279	9279	0.00%
Heat Exchange	7474	7474	0.00%
Gas Clean-Up	23418	23418	0.00%
Amine System	29851	29851	0.00%
Total	104162	102856	1.25%

Table S12. Itemized capital costs and scaling factors for the BB + SS-CC system

Equipment Name	Original installed price	Reference	Year of quote	Scaling stream	Scaling Value	Units	Scaling exponent	New value	Size ratio	Scaled installed cost	Index base year	Index project year (2016)	Installed cost in project year
Preprocessing	$ 24,155,013	*(16)*	2009	Biomass Feed	2000	dry tonne/day	0.8	2300	1.15	$ 27,012,548	521.9	541.7	$ 28,037,358
Boiler	$ 48,652,589	*(16)*	2010	High Quality Steam Production	235	tonne/h	0.8	387	1.65	$ 72,508,866	550.8	541.7	$ 71,310,917
Turbine/generator	$ 16,145,591	*(16)*	2010	Power Production	41	MW	0.8	110	2.67	$ 35,453,254	550.8	541.7	$ 34,867,515
Boiler accessories + gas cleaning	$ 1,161,393	*(16)*	2010	Biomass Feed	622.2	dry tonne/day	0.8	2300	3.70	$ 3,305,273	550.8	541.7	$ 3,250,665
Cooling tower system/HX	$ 2,186,673	*(16)*	2010	High Quality Steam Production	235	tonne/h	0.8	387	1.65	$ 3,258,885	550.8	541.7	$ 3,205,043
Blower	$ 21,000,000	*(5)*	2016	Gas flow rate	10.2	Mt-gas/day	0.8	0.02	0.00	$ 162,336	541.7	541.7	$ 162,336
Vacuum Pump	$ 26,000,000	*(5)*	2016	CO2 Capacity	1	Mt-CO2/y	0.8	1.17	1.17	$ 29,553,222	541.7	541.7	$ 29,553,222
Contactor	$ 13,000,000	*(5)*	2016	CO2 Capacity	1	Mt-CO2/y	0.8	1.17	1.17	$ 14,776,611	541.7	541.7	$ 14,776,611
Compressor	$ 15,500,000	*(10)*	2016	CO2 Capacity	1.45	Mt-CO2/y	0.8	1.17	0.81	$ 13,053,172	541.7	541.7	$ 13,053,172
Indirect costs		*(10)*											$ 70,242,267
Contingency													$ 80,537,732
												Total Direct Costs:	$ 198,216,839
												Total Indirect Costs:	$ 150,779,998
												Total Capital Costs:	$ 348,996,837
												Capital Intensity ($/t-CO2-year)	$ 297

Table S13. A summary of results from the Biomass Boiler plus Solid Sorbent Carbon Capture (BB + SS-CC) techno-economic analysis showing levelized costs of CO_2 removal with a biomass cost of $70/dry short ton and CRF values of 7.5% and 12.5%.

Biomass Boiler + Solid Sorbent with Carbon Capture BB + SS-CC Economic Summary		
Direct air CO2 capacity (Mt-CO2/y)		0.00
Biogenic CO2 capacity (Mt-CO2/y)		1.17
Total capacity (Mt-CO2/y)		1.17
Specific biogenic CO2 capacity (t-CO2/t-biomass)		1.55
Biomass cost ($/short t-biomass)	$	70
Electricity cost ($/kWh)	$	0.05
Equipment Costs (2016$)		**Installed Capital Cost**
Preprocessing	$	28,037,358
Boiler	$	71,310,917
Turbine/generator	$	34,867,515
Boiler accessories + gas cleaning	$	3,250,665
Cooling tower system	$	3,205,043
Blower	$	162,336
Vacuum Pump	$	29,553,222
Contactor	$	14,776,611
Compressor	$	13,053,172
Indirect costs	$	70,242,267
Contingency	$	80,537,732
Total Installed Capital	$	348,996,837
Capital Intensity ($/t-CO2-year)	$	297
Levelized Capital Cost (CRF 7.5%) ($/t-CO2)	**$**	**25**
Levelized Capital Cost (CRF 12.5%) ($/t-CO2)	**$**	**41**
Operating Costs (2016$)		**Annual cost ($/y)**
Biomass feedstock	$	58,299,522
Sorbent material (6-month life span)	$	90,221,241
Non-energy O&M	$	28,519,718
Electricity to grid	$	(27,610,545)
Process steam byproduct	$	(23,832,413)
Net Operating Costs	$	125,597,522
Net Operating Costs ($/t-CO2)	**$**	**107**
Total Costs (w/ CRF 7.5%) ($/t-CO2)	**$**	**132**
Total Costs (w/ CRF 12.5%) ($/t-CO2)	**$**	**148**

Table S14. A) Levelized costs of CO_2 removal by the NG + LS-DAC system with variation in natural gas price and capital recovery factor (CRF). Baseline scenario assumes no natural gas leakage. Penalty scenario assumes a quantity of carbon equivalent to 3% of the natural gas-carbon captured on-site is emitted to the atmosphere during extraction and transportation. Natural gas is taken to have a global warming potential of 25. Relative to Baseline, the Penalty scenario increases levelized cost by 15%. **B)** Levelized costs of CO_2 removal by the BB + SS-CC system with variation in biomass price and CRF. Baseline scenario assumes biomass is carbon neutral. Penalty scenario assumes a quantity of carbon equivalent to 15% of the biogenic carbon captured on-site is emitted to the atmosphere during cultivation, harvest, and transportation of biomass. Relative to Baseline, the Penalty scenario increases costs by 18%.

A

Levelized Cost of CO_2 Removal ($/t-$CO_2$)
NG +LS-DAC

	Natural Gas Price ($/GJ)									
	$1.50		$3.50		$5.50		$7.50		$9.50	
CRF	Baseline	Penalty	Baseline	Penalty	Baseline	Penalty	Baseline	Penalty	Baseline	Penalty
2.5%	$65	$75	$83	$95	$100	$116	$118	$136	$136	$156
7.5%	$109	$126	$127	$146	$145	$166	$162	$187	$180	$207
12.5%	$153	$177	$171	$197	$189	$217	$206	$237	$224	$258
17.5%	$197	$227	$215	$248	$233	$268	$250	$288	$268	$308

B

Levelized Cost of CO_2 Removal ($/t-$CO_2$)
BB + SS-CC

	Biomass Prices ($/short ton)									
	$20		$40		$60		$80		$100	
CRF	Baseline	Penalty	Baseline	Penalty	Baseline	Penalty	Baseline	Penalty	Baseline	Penalty
2.5%	$80	$94	$94	$111	$108	$127	$122	$144	$137	$161
7.5%	$96	$113	$111	$130	$125	$147	$139	$163	$153	$180
12.5%	$113	$133	$127	$149	$141	$166	$155	$183	$170	$200
17.5%	$129	$152	$144	$169	$158	$186	$172	$202	$186	$219

Table S15. Levelized costs of CO_2 removal by the BB + SS-CC system with variation in biomass price and capital recovery factor (CRF). No revenue from excess steam.

Levelized Cost of CO2 Removal ($/t-CO2)
BB + SS-CC (no steam byproduct)

	Biomass Price ($/ short ton)				
CRF	$20	$40	$60	$80	$100
2.5%	$100	$114	$128	$143	$157
7.5%	$117	$131	$145	$159	$173
12.5%	$133	$147	$162	$176	$190
17.5%	$150	$164	$178	$192	$206