Supplementary Information for

"Steel, Aluminum, and FRP-Composites: Race to Zero Carbon Emissions"

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S1. Cost Estimation Tables for Traditional Electrical Grid Cost Models

Note: All references marked with an asterisk (*) denote an assumption or calculation that is described in the primary manuscript.

Blast Furnace / Basic Oxygen Furnace Steelmaking Costs						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Scrap Steel	0.148	t	283	$41.8	[1]	[1]
Iron Ore	1.509	t	107	$ 161.5	[1]	[2]
Coking + PCI Coal	0.86	t	145	$ 124.7	[1]	[1]
Industrial Gases	162	m^3	0.12	$19.4	[1]	[1]
Ferroalloys	0.009	t	1600	$14.4	[1]	[1]
Fluxes	0.46	t	50	$23.0	[1]	[1]
Refractories	0.004	t	1300	$5.2	[1]	[1]
Other Costs	1	count	20	$20.0	[1]	[1]
Natural Gas	0	kWh_{th}	0.015	$-	*	[3]
Electricity -Reheat/Rolling	105	kWh	0	$-	[4]	*
Electricity - Steelmaking	295	kWh	0	$-	[4], *	*
Labor	1	count	25	$25.0		[5]
Capital Charges	1	count	148.5	$ 148.5		[4]
Carbon Emission Surcharge	2.17	t-CO_2	80	$ 173.9	*	*
Total (including carbon tax)				**$ 757.5**		

Electric Arc Furnace Steelmaking Costs						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Scrap Steel	1.1	t	283	$ 310.9	[1]	[1]
Ferroalloys	0.021	t	1600	$33.6	[1]	[1]
Electrodes	2	kg	4	$8.0	[1]	[1]
Other Costs	1	count	31	$31.0	[1]	[1]
Electricity - EAF	421	kWh	0.0545	$22.9	*	*
Electricity - Hot Rolling	105	kWh	0.0545	$5.7	[4]	*
Labor	1	count	15	$15.0		[5]
Capital Charges	1	count	105	$ 105		SI S4.1
Carbon Emission Surcharge	*0.4*	t-CO_2	*80*	$32.0	*	*
Total (including carbon tax)				**$ 564.5**		

Natural Gas DRI + EAF						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Iron Ore	1.4	t	107	$ 149.8	[6]	[2]
Natural Gas	262	Sm^3	0.136	$35.6	[6]	[3]
Other Costs	1	count	10.44	$10.4		[7]
Electricity - EAF	600	kWh	0.0545	$32.7	*	*
Electricity - Hot Rolling	105	kWh	0.0545	$5.7	*	*

Labor	1	count	27	$27.0		[5] , S4.1
Capital Charges	1	count	171.6	$ 171.6		S4.2
Carbon Emission Surcharge	*1.25*	$t\text{-}CO_2$	*80*	$ 100.2	*	*
Total (including carbon tax)				**$ 533.0**		

Hydrogen DRI+EAF						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Iron Ore	1.4	t	107	$ 149.8	[6]	[2]
Natural Gas	50	Sm^3	0.136	$6.8	[6]	[3]
Hydrogen	79.4	kg	4.5	$ 357.2	[6]	*
Other Costs	1	count	10.44	$10.4		[7]
Electricity - EAF	494	kWh	0.0545	$26.9	*	*
Electricity - Hot Rolling	105	kWh	0.0545	$5.7	*	*
Labor	1	count	27	$27.0		[5] , S4.1
Capital Charges	1	count	171.6	$ 171.6		S4.2
Carbon Emission Surcharge	*1.64*	$t\text{-}CO_2$	*80*	$ 130.9	*	*
Total (including carbon tax)				**$ 886.4**		

Blast Furnace / Basic Oxygen Furnace Steelmaking w/ Carbon Capture Costs						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Scrap Steel	0.148	t	283	$41.8	[1]	[1]
Iron Ore	1.509	t	107	$ 161.5	[1]	[2]
Coal	0.86	t	145	$ 124.7	[1]	[1]
Industrial Gases	162	m^3	$0.12	$19.4	[1]	[1]
Ferroalloys	0.009	t	1600	$14.4	[1]	[1]
Fluxes	0.46	t	50	$23.0	[1]	[1]
Refractories	0.004	t	1300	$5.2	[1]	[1]
Other Costs	1	count	20	$20.0	[1]	[1]
Thermal Cost	0	kWh_{th}	0.015	$-	*	[3]
Electricity	468	kWh	0.000	$-	[4]	*
Electricity - Hot Rolling	105	kWh	0.000	$-	[4], *	*
Labor	1	count	25.0	$25.0		[5]
Capital Charges	1	count	148.5	$ 148.5		[4]
CCS (all charges)	1.42	$t\text{-}CO_2$	100	$ 142.1	*	*
Carbon Emission Surcharge	0.7	$t\text{-}CO_2$	80	$56.1	*	*
Total (BF-BOF + Carbon Capture)				**$ 781.7**		

Natural Gas DRI + CCUS + EAF						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Iron Ore	1.4	t	107	$ 149.8	[6]	[2]
Natural Gas	262	m^3	0.136	$35.6	[6]	[3]
Other Costs	1	count	10.44	$10.4		[7]

Electricity	1000	kWh	0.0545	$54.5	*	*
Electricity - Hot Rolling	105	kWh	0.0545	$5.7	*	*
Capital Charges	1	count	171.6	$ 171.6		[5] , S4.1
CCS (all charges)	0.64	t-CO_2	100	$63.6	*	S4.2
Carbon Emission Surcharge	*0.68*	t-CO_2	*80*	$54.8	*	*
Total (including carbon tax)				**$ 546.0**		

Primary Aluminum Costs						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Bauxite	5.1	t	52	$ 265.2	[8]	[9]
Limestone	0.06	t	35	$2.1	[8]	[10]
Caustic Soda	0.09	t	495	$44.6	[8]	[11]
Thermal energy	5450	kWh	0.015	$84.1	*	[3]
Carbon Anode	0.45	t	110	$49.5	[8]	[12]
Electricity	13394	kWh	0.0545	$ 730.0	*	*
Labor	1	count	107.1	$ 107.1		[13]
Natural Gas - Sheet Prod.	524	kWh_{th}	0.015	$8.1	*	[3]
Electricity - Sheet Prod.	518	kWh	0.0545	$28.2	*	*
Capital Charges	1	count	93.78	$93.8		[14]
Carbon Emission Surcharge	8.22	t-CO_2	80	$ 657.3	*	*
Total (including carbon tax)				**$2,069.9**		

Secondary Aluminum Production Costs						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Scrap	1.2	t	860	$1,031.9	[15]	[16]
Natural Gas	1265	kWh_{th}	0.015	$19.5	*	[3]
Electricity	222	kWh	0.0545	$12.1	*	*
Labor	1	count	107.1	$ 107.1		[13]
Natural Gas - Sheet Prod.	524	kWh_{th}	0.015	$8.1	*	[3]
Electricity - Sheet Prod.	518	kWh	0.0545	$28.2	*	*
Capital Charges	1	count	93.78	$93.8		[14]
Carbon Emission Surcharge	0.4	t-CO_2	80	$35.8	*	*
Total (including carbon tax)				**$1336.5**		

Primary Aluminum With CCU Making Costs						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Bauxite	5.1	t	52	$ 265.2	[8]	[9]
Limestone	0.06	t	35	$2.1	[8]	[10]
Caustic Soda	0.09	t	495	$44.6	[8]	[11]
Thermal energy	5450	kWh	0.015	$84.1	*	[3]
Carbon Anode	0.45	t	110	$49.5	[8]	[12]
Electricity	13394	kWh	0.0545	$ 730.0	*	*

Labor	1	count	107.1	$ 107.1		[13]
Capital Charges	1	count	93.78	$93.8	*	[14]
Natural Gas - Sheet Prod.	524	kWh_{th}	0.015	$8.1	*	[3]
Electricity - Sheet Prod.	518	kWh	0.0545	$28.2		*
CCS (all charges)	1.5	t-CO_2	137	$ 205.5	*	*
Carbon Emission Surcharge	6.8	t-CO_2	80	$ 547.0	*	*
Total (Aluminum Production + CCS)				**$2,165.1**		

Primary Aluminum making Costs, Decarbonized path						
Item	Sizing Value	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Bauxite	5.1	t	52	$ 265.2	[8]	[9]
Limestone	0.06	t	35	$2.1	[8]	[10]
Caustic Soda	0.09	t	495	$44.6	[8]	[11]
Electricity - Thermal	5560	kWh	0.0545	$ 303.0	*	*
Inert anodes	0.01	t	7374.5	$73.7	[8]	Below
Electricity - Electrolysis	16000	kWh	0.0545	$ 872.0	*	*
Labor	1	count	107.1	$ 107.1		[13]
Natural Gas - Sheet Prod.	524	kWh_{th}	0.015	$8.1	*	[3]
Electricity - Sheet Prod.	518	kWh	0.0545	$28.2	*	*
Capital Charges	1	count	93.78	$93.8		[14]
Carbon Emission Surcharge	8.96	t-CO_2	80	$ 716.5	*	*
Total (including carbon tax)				**$2,514.3**		

Inert Anode Cost						
Item	Sizing Value	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Fe_2O_3	0.483	t	$700	$338.1	[17]	[18]
NiO	0.517	t	$13,610	$7,036.4	[17]	S5
Total				$7,374.5		

Glass Fiber Reinforced Composite (SMC)						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Epoxy Resin	0.5	t	4000	2000	*	
E-Glass (Structural Fabric)	0.5	t	2200	1100	*	[19]
Electricity (Thermoform)	972	kWh	0.0545	53	*	*
Non-Materials Costs	100%	of mat	$3,153	$ 3,153	*	Calc.
Carbon Emission Surcharge	*3.5*	t-CO_2	*80*	$ 278.7	*	*
Total (including carbon tax)				**$6,584.7**		

Carbon Fiber Reinforced Composite (CF-SMC)						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Carbon Fiber (Fabric)	0.35	t	25000	$8,750.0	*	[20]

Electricity (Thermoform)	972	kwh	0.0545	$53.0	*	*
Epoxy Resin	0.65	t	4000	$2,600.0	*	[20]
Non-Materials Costs	100%	of mat	$11,403	$ 11,403	*	Calc.
Carbon Emission Surcharge	*11.0*	t-CO_2	*80*	$ 876.6	*	*
Total (including carbon tax)				**$ 23,682.6**		

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19 **S2. Cost Estimation Tables for Renewables-Based Electrical Grid Cost Models**

20 *Note: All references marked with an asterisk (*) denote an assumption or calculation that is described in the primary*
21 *manuscript.*

Blast Furnace / Basic Oxygen Furnace Steelmaking Costs						
Item	**Quantity**	**Unit**	**$/Unit**	**Total Cost ($/t)**	**Quantity Reference**	**Cost Reference**
Scrap Steel	0.148	t	283	$41.8	[1]	[1]
Iron Ore	1.509	t	107	$ 161.5	[1]	[2]
Coking + PCI Coal	0.86	t	145	$ 124.7	[1]	[1]
Industrial Gases	162	m^3	0.12	$19.4	[1]	[1]
Ferroalloys	0.009	t	1600	$14.4	[1]	[1]
Fluxes	0.46	t	50	$23.0	[1]	[1]
Refractories	0.004	t	1300	$5.2	[1]	[1]
Other Costs	1	count	20	$20.0	[1]	[1]
Natural Gas	0	kWh_{th}	0.015	$-	*	[3]
Electricity -Reheat/Rolling	105	kWh	0	$-	[4]	*
Electricity - Steelmaking	295	kWh	0	$-	[4], *	*
Labor	1	count	25	$25.0		[5]
Capital Charges	1	count	148.5	$ 148.5		[4]
Carbon Emission Surcharge	2.03	t-CO_2	80	$ 162.6	*	*
Total (including carbon tax)				**$ 746.2**		

Electric Arc Furnace Steelmaking Costs						
Item	**Quantity**	**Unit**	**$/Unit**	**Total Cost ($/t)**	**Quantity Reference**	**Cost Reference**
Scrap Steel	1.1	t	283	$ 310.9	[1]	[1]
Ferroalloys	0.021	t	1600	$33.6	[1]	[1]
Electrodes	2	kg	4	$8.0	[1]	[1]
Other Costs	1	count	31	$31.0	[1]	[1]
Electricity - EAF	421	kWh	0.0545	$22.9	*	*
Electricity - Hot Rolling	105	kWh	0.0545	$5.7	[4]	*
Labor	1	count	15	$15.0		[5]
Capital Charges	1	count	105	$ 105.3		SI S4.1
Carbon Emission Surcharge	*0.2*	t-CO_2	*80*	$14.2	*	*
Total (including carbon tax)				**$ 546.7**		

Natural Gas DRI + EAF						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Iron Ore	1.4	t	107	$ 149.8	[6]	[2]
Natural Gas	262	Sm^3	0.136	$35.6	[6]	[3]
Other Costs	1	count	10.44	$10.4		[7]
Electricity - EAF	600	kWh	0.0545	$32.7	*	*
Electricity - Hot Rolling	105	kWh	0.0545	$5.7	*	*
Labor	1	count	27	$27.0		[5] , S4.1
Capital Charges	1	count	171.6	$ 171.6		S4.2
Carbon Emission Surcharge	*0.92*	$t\text{-}CO_2$	*80*	$74.0	*	*
Total (including carbon tax)				**$ 506.8**		

Hydrogen DRI+EAF						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Iron Ore	1.4	t	107	$ 149.8	[6]	[2]
Natural Gas	50	Sm^3	0.136	$6.8	[6]	[3]
Hydrogen	79.4	kg	4.5	$ 357.2	[6]	*
Other Costs	1	count	10.44	$10.4		[7]
Electricity - EAF	494	kWh	0.0545	$26.9	*	*
Electricity - Hot Rolling	105	kWh	0.0545	$5.7	*	*
Labor	1	count	27	$27.0		[5] , S4.1
Capital Charges	1	count	171.6	$ 171.6		S4.2
Carbon Emission Surcharge	*0.31*	$t\text{-}CO_2$	*80*	$24.7	*	*
Total (including carbon tax)				**$ 780.2**		

Blast Furnace / Basic Oxygen Furnace Steelmaking w/ Carbon Capture Costs						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Scrap Steel	0.148	t	283	$41.8	[1]	[1]
Iron Ore	1.509	t	107	$ 161.5	[1]	[2]
Coal	0.86	t	145	$ 124.7	[1]	[1]
Industrial Gases	162	m^3	$0.12	$19.4	[1]	[1]
Ferroalloys	0.009	t	1600	$14.4	[1]	[1]
Fluxes	0.46	t	50	$23.0	[1]	[1]
Refractories	0.004	t	1300	$5.2	[1]	[1]
Other Costs	1	count	20	$20.0	[1]	[1]
Thermal Cost	0	kWh_{th}	0.015	$-	*	[3]
Electricity	468	kWh	0.000	$-	[4]	*
Electricity - Hot Rolling	105	kWh	0.000	$-	[4], *	*
Labor	1	count	25.0	$25.0		[5]
Capital Charges	1	count	148.5	$ 148.5		[4]
CCS (all charges)	1.42	$t\text{-}CO_2$	100	$ 142.1	*	*
Carbon Emission Surcharge	0.4	$t\text{-}CO_2$	80	$34.8	*	*

Total (BF-BOF + Carbon Capture)		**$ 760.4**

Natural Gas DRI + CCUS + EAF						
Item	**Quantity**	**Unit**	**$/Unit**	**Total Cost ($/t)**	**Quantity Reference**	**Cost Reference**
Iron Ore	1.4	t	107	$ 149.8	[6]	[2]
Natural Gas	262	m^3	0.136	$35.6	[6]	[3]
Other Costs	1	count	10.44	$10.4		[7]
Electricity	1000	kWh	0.0545	$54.5	*	*
Electricity - Hot Rolling	105	kWh	0.0545	$5.7	*	*
Capital Charges	1	count	171.6	$ 171.6		[5] , S4.1
CCS (all charges)	0.64	t-CO_2	100	$63.6	*	S4.2
Carbon Emission Surcharge	*0.33*	t-CO_2	*80*	$26.3	*	*
Total (including carbon tax)				**$ 517.5**		

Primary Aluminum Costs						
Item	**Quantity**	**Unit**	**$/Unit**	**Total Cost ($/t)**	**Quantity Reference**	**Cost Reference**
Bauxite	5.1	t	52	$ 265.2	[8]	[9]
Limestone	0.06	t	35	$2.1	[8]	[10]
Caustic Soda	0.09	t	495	$44.6	[8]	[11]
Thermal energy	5450	kWh	0.015	$84.1	*	[3]
Carbon Anode	0.45	t	110	$49.5	[8]	[12]
Electricity	13394	kWh	0.0545	$ 730.0	*	*
Labor	1	count	107.1	$ 107.1		[13]
Natural Gas - Sheet Prod.	524	kWh_{th}	0.015	$8.1	*	[3]
Electricity - Sheet Prod.	518	kWh	0.0545	$28.2	*	*
Capital Charges	1	count	93.78	$93.8		[14]
Carbon Emission Surcharge	3.28	t-CO_2	80	$ 262.7	*	*
Total (including carbon tax)				**$1,675.3**		

Secondary Aluminum Production Costs						
Item	**Quantity**	**Unit**	**$/Unit**	**Total Cost ($/t)**	**Quantity Reference**	**Cost Reference**
Scrap	1.2	t	860	$1,031.9	[15]	[16]
Natural Gas	1265	kWh_{th}	0.015	19.5	*	[3]
Electricity	222	kWh	0.0545	$12.1	*	*
Labor	1	count	107.1	$ 107.1		[13]
Natural Gas - Sheet Prod.	524	kWh_{th}	0.015	$8.1	*	[3]
Electricity - Sheet Prod.	518	kWh	0.0545	$28.2	*	*
Capital Charges	1	count	93.78	$93.8		[14]
Carbon Emission Surcharge	0.4	t-CO_2	80	$29.5	*	*
Total (including carbon tax)				**$1,330.2**		

Primary Aluminum With CCU Making Costs

Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Bauxite	5.1	t	52	$ 265.2	[8]	[9]
Limestone	0.06	t	35	$2.1	[8]	[10]
Caustic Soda	0.09	t	495	$44.6	[8]	[11]
Thermal energy	5450	kWh	0.015	$84.1	*	[3]
Carbon Anode	0.45	t	110	$49.5	[8]	[12]
Electricity	13394	kWh	0.0545	$ 730.0	*	*
Labor	1	count	107.1	$ 107.1		[13]
Capital Charges	1	count	93.78	$93.8	*	[14]
Natural Gas - Sheet Prod.	524	kWh_{th}	0.015	$8.1	*	[3]
Electricity - Sheet Prod.	518	kWh	0.0545	$28.2		*
CCS (all charges)	1.5	count	137	$ 205.5	*	*
Carbon Emission Surcharge	1.7	t-CO_2	80	$ 132.1	*	*
Total (Aluminum Production + CCS)				**$1,750.2**		

Primary Aluminum making Costs, Decarbonized path						
Item	Sizing Value	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Bauxite	5.1	t	52	$ 265.2	[8]	[9]
Limestone	0.06	t	35	$2.1	[8]	[10]
Caustic Soda	0.09	t	495	$44.6	[8]	[11]
Electricity - Thermal	5560	kWh	0.0545	$ 303.0	*	*
Inert anodes	0.01	t	7374.5	$73.7	[8]	Below
Electricity - Electrolysis	16000	kWh	0.0545	$ 872.0	*	*
Labor	1	count	107.1	$ 107.1		[13]
Natural Gas - Sheet Prod.	524	kWh_{th}	0.015	$8.1	*	[3]
Electricity - Sheet Prod.	518	kWh	0.0545	$28.2	*	*
Capital Charges	1	count	93.78	$93.8		[14]
Carbon Emission Surcharge	1.16	t-CO_2	80	$93.0	*	*
Total (including carbon tax)				**$1,890.8**		

Inert Anode Cost						
Item	Sizing Value	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Fe_2O_3	0.483	t	$ 700	$ 338.1	[17]	[18]
NiO	0.517	t	$13,610	$7036.4	[17]	SI S5
Total				$ 7374.5		

Glass Fiber Reinforced Composite (SMC)						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Epoxy Resin	0.5	t	4000	2000	*	
E-Glass (Structural Fabric)	0.5	t	2200	1100	*	[19]
Electricity (Thermoform)	972	kWh	0.0545	53	*	*

Non-Materials Costs	100%	of mat	$3,153	$ 3,153	*	Calc.
Carbon Emission Surcharge	*2.9*	t-CO_2	*80*	$ 229.1	*	*
Total (including carbon tax)				**$6,535.1**		

Carbon Fiber Reinforced Composite (CF-SMC)						
Item	Quantity	Unit	$/Unit	Total Cost ($/t)	Quantity Reference	Cost Reference
Carbon Fiber (Fabric)	0.35	t	25000	$8,750.0	*	[20]
Electricity (Thermoform)	972	kwh	0.0545	$53.0	*	*
Epoxy Resin	0.65	t	4000	$2,600.0	*	[20]
Non-Materials Costs	100%	of mat	$11,403	$ 11,403	*	Calc.
Carbon Emission Surcharge	*6.7*	t-CO_2	*80*	$ 539.0	*	*
Total (including carbon tax)				**$ 23,345.0**		

S3. Calculations for Railroad Freight Cost and Global Warming Potential

Global Warming Potential for rail transport of bulk freight is approximately 0.048 lbs $CO_{2\ eq}$ per ton-mile or 0.0148 kg $CO_{2\ eq}$ per tonne-km.**[21]** We assume cost of transportation is $0.05 per ton-mile or $0.0328 per tonne-km.**[22]**

Each Distance in Miles is multiplied by the corresponding coefficient to determine the Global Warming Potential or Cost to transport 1 tonne of steel from Austin, TX to the corresponding capital of the 48 contiguous states. This represents a very rough synthetic logistics model if all US steel demand were to be made in Austin, Texas. Texas was chosen as a location with appropriate geology for subsurface carbon dioxide sequestration. We do not take actual steel demand by location into account as that is beyond the scope of this simple calculation, but it could be an area of interest for future efforts.

State	Capital	Distance from Austin, TX in miles [23]	Distance from Austin, TX in km	kg $CO_{2\ eq}$ / t steel (Metric Ton)	$/t steel (Metric Ton)
Alabama	Montgomery	1150	1851	27	61
Arizona	Phoenix	1100	1770	26	58
Arkansas	Little Rock	800	1287	19	42
California	Sacramento	1600	2575	38	84
Colorado	Denver	1200	1931	29	63
Connecticut	Hartford	2000	3219	48	106
Delaware	Dover	2000	3219	48	106
Florida	Tallahassee	1200	1931	29	63
Georgia	Atlanta	1200	1931	29	63
Idaho	Boise	1800	2897	43	95
Illinois	Springfield	1000	1609	24	53
Indiana	Indianapolis	1100	1770	26	58
Iowa	Des Moines	1300	2092	31	69
Kansas	Topeka	1200	1931	29	63
Kentucky	Frankfort	1300	2092	31	69
Louisiana	Baton Rouge	1000	1609	24	53
Maine	Augusta	2200	3541	52	116

Maryland	Annapolis	2000	3219	48	106
Massachusetts	Boston	2000	3219	48	106
Michigan	Lansing	1400	2253	33	74
Minnesota	Saint Paul	1500	2414	36	79
Mississippi	Jackson	1050	1690	25	55
Missouri	Jefferson City	1200	1931	29	63
Montana	Helena	2000	3219	48	106
Nebraska	Lincoln	1400	2253	33	74
Nevada	Carson City	1800	2897	43	95
New Hampshire	Concord	2000	3219	48	106
New Jersey	Trenton	2000	3219	48	106
New Mexico	Santa Fe	1600	2575	38	84
New York	Albany	2000	3219	48	106
North Carolina	Raleigh	1300	2092	31	69
North Dakota	Bismarck	1800	2897	43	95
Ohio	Columbus	1300	2092	31	69
Oklahoma	Oklahoma City	1100	1770	26	58
Oregon	Salem	2100	3380	50	111
Pennsylvania	Harrisburg	2000	3219	48	106
Rhode Island	Providence	2000	3219	48	106
South Carolina	Columbia	1300	2092	31	69
South Dakota	Pierre	1600	2575	38	84
Tennessee	Nashville	1200	1931	29	63
Utah	Salt Lake City	1600	2575	38	84
Vermont	Montpelier	2000	3219	48	106
Virginia	Richmond	1500	2414	36	79
Washington	Olympia	2200	3541	52	116
West Virginia	Charleston	1500	2414	36	79
Wisconsin	Madison	1400	2253	33	74
Wyoming	Cheyenne	1800	2897	43	95
Average		**1549**	**2493**	**37**	**82**

S4. Estimation of Capital Charges and Labor Charges

Capital charges are allocated per tonne of product based on corporate announcements for plant construction costs or directly from the literature as noted. These capital charges are dependent on an operating firm's debt financing choices, therefore we have selected a discount rate that is appropriate for an average firm. The average weighted average cost of capital (WACC) for the USA steel industry in 2023 is estimated to be 10 %.**[24]**

Capital Recovery Factor (CRF) is calculated as follows:

$$CRF = \frac{i(1+i)^n}{(1+i)^n-1} = 0.106$$

Where:

i = Discount Rate = 10 %/ year

n = Analysis Period = 30 years

The allocation termed "Capital Charge" includes Capital Expense and Maintenance, therefore to levelized the charge per tonne of product,

$$\textbf{\textit{Capital Charge}}\left(\$/_{t}\right) = \frac{\textbf{\textit{CAPEX}}[\$] * \textbf{\textit{CRF}}}{\textbf{\textit{Annual Capacity}}[t/y]}$$

S4.1 Electric Arc Furnace Capital Expenses

Capital Expense Estimate

"Hot on the heels of Tuesday's announcement of a new steel mill from U.S. Steel, Nucor Corp. revealed January 12 [2020] it would build its own new sheet metal plant in West Virginia. The $2.7 billion mill will employ 800 people and produce about 3 million tons of steel when it becomes operational in 2024, according to a company release." [25]

Converting 3 million short tons to metric tons yields 2.72 Mt/ y capacity. This investment includes automotive galvanizing equipment so it is appropriate for this study, but our calculation may slightly overestimate HRC costs.

S4.2 DRI / HBI Capital Expenses and Labor Expenses (Natural Gas and Hydrogen)

Capital Expense Estimate

"This $1 billion project has been transformative for our Company and the region." [26]

"Capacity 1.6 mt/ a" [27]

We use this as a data proxy for the DRI-based process costs.

Labor Expense Estimate

"This $1 billion project has been transformative for our Company and the region. It was one of the largest construction projects in the Great Lakes region, employing 1,100 people during peak construction. At the end of 2020, we employed 140 full-time employees at the plant with annual wages and benefits of approximately $17 million." [26]

"From 2017 to 2021, the company invested $1 billion in the HBI plant, and during 2021 it was able to ramp up operations to achieve full production rates. In 2021, Cleveland-Cliffs consumed 1.1 million tonnes of HBI in its operations. The HBI plant was designed with a capacity of 1.6 million tonnes a year." [28]

Allocating the $17 million wages and benefits to 1.1 million tonnes, we estimate $15/t of labor charges for DRI / HBI production. We assume this will hold for mature Hydrogen DRI plants as they will be somewhat similar in terms of plant design and automation.

S5 Price of Nickel Oxide, Iron Oxides, and Inert Anodes

United States Trade and Tariff Information can be searched online.[29] This search can provide declared value for difficult to find commodities. The average declared value for "Nickel Oxides and Hydroxides" in 2019 was determined to be $13.61 / kg.

Inert Anodes for the production of Aluminum are difficult to estimate costs for, as performance and cost data tends to be proprietary to the firms researching them. We assume long term costs will converge around the total cost of compositional materials. Consumption of inert anodes is assumed to be small**[17]**, so this is not a key contribution to the cost of the Decarbonized Primary Aluminum Scenario.

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