A Cost-Benefit Assessment of Gasification-Based Biorefining in the Kraft Pulp and Paper Industry

Volume 3: Fuel Chain and National Cost-Benefit Analysis

FINAL REPORT
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1 Introduction

This volume contains the detailed assumptions for the well-to-wheels (WTW) analysis and provides complete results of the national impacts analysis for all three market penetration scenarios. Figure 1 illustrates the components modeled in the WTW analysis. This volume is primarily a data volume. The reader is referred back to Volume 1 for a more complete discussion of the WTW approach and a description of the market penetration scenarios.

Note that the analysis, based on the assumptions presented here, is not intended to serve as a complete lifecycle analysis of biorefinery emissions. Rather the estimates provide indicative results of the potential impacts of biorefinery options relative to "business as usual" in the pulp and paper industry.

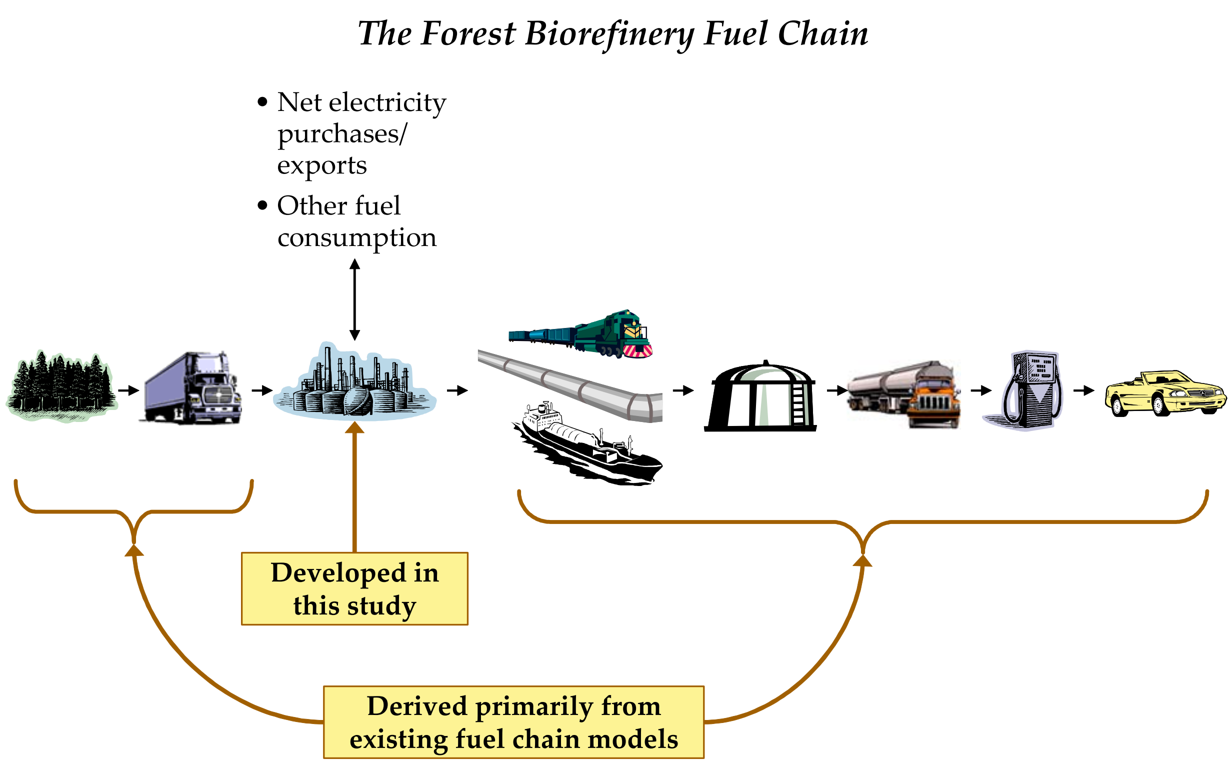


Figure 1: Well-to-wheels analysis framework for pulp and paper biorefineries

2 Emissions Factors for Stationary Sources

Table 1 through Table 9 show the emissions factors used for the point sources at the reference pulp and paper mill, expressed on a common basis for each of the configurations. All values are based on the higher heating value of the fuel. The primary energy represents the energy contained in the fuel consumed in the indicated step, e.g., black liquor in the case of the Tomlinson boilers and syngas in the case of the gas turbines. In the case of the gas turbine systems and the duct burners, the primary energy is a mixture of biomass syngas, unconverted syngas from biofuels synthesis, and natural gas (BLGCC configuration only), depending on the configuration. For this reason, CO_2 and SO_2 emissions rates differ among different cases. All other emissions are assumed to be the same. For the lime kiln, emissions are based on the use of #6 fuel oil. Because of the reactions taking place inside a lime kiln, emissions of criteria pollutants from burning #6 oil are not substantially different from emissions using natural gas. The CO_2 emissions shown in Table 1 through Table 9 include CO_2 from biomass. This CO_2 is netted out in the fuel chain analysis, as described in Volume 1.

Emissions factor estimates for mill related sources are based on the following references:

- Lime kiln and Tomlinson boiler: [1, 2, 3, 4, 5, 6, 7]
- Bark boiler: [8]
- Gas turbine: [9, 10, 11, 12, 13, 14, 15, 16]
- Duct burner: [17], assuming similar criteria pollutant emissions as for natural gas combustion.

Table 10 shows grid power emissions for 2010-2035 in five-year increments. Emissions in the intervening years are consistent with the trends indicated by the years shown.

Table 1. Unit emission factors assumed for the New Tomlinson case (lb/MMBtu fuel input - HHV)

	Lime kiln	Bark boiler	Tomlinson
VOC	0.0043	0.0130	0.0134
CO	0.0285	0.6000	0.0940
NOx	0.2857	0.2200	0.1544
PM10	0.0150	0.0540	0.0477
SOx	0.0286	0.0698	0.0215
CO2	172	213	205
TRS	0.0086	0.0000	0.0034

Table 2. Unit emission factors assumed for the Mill-Scale High-Temperature BLGCC case (lb/MMBtu fuel input - HHV)

	Lime kiln	Bark boiler	GT	Duct burner
VOC	0.0043	0.0130	0.0021	0.0054
CO	0.0285	0.6000	0.0330	0.0818
NOx	0.2857	0.2200	0.0897	0.0974
PM10	0.0150	0.0540	0.0066	0.0074
SOx	0.0286	0.0698	0.0000	0.0004
CO2	172	213	221	169
TRS	0.0086	0.0000	0.0000	0.0000

Table 3. Unit emission factors assumed for the DMEa case (lb/MMBtu fuel input - HHV)

	Lime kiln	Bark boiler
VOC	0.0043	0.0130
CO	0.0285	0.6000
NOx	0.2857	0.2200
PM10	0.0150	0.0540
SOx	0.0286	0.1141
CO2	172	265
TRS	0.0086	0.0000

Note: in DMEa, the bark boiler also burns unconverted syngas. Aside from impacts on CO_2 and SO_2, no other benefits are assumed from the co-firing of clean syngas.

Table 4. Unit emission factors assumed for the DMEb case (lb/MMBtu fuel input - HHV)

	Lime kiln	GT	Duct burner
VOC	0.0043	0.0021	0.0054
CO	0.0285	0.0330	0.0818
NOx	0.2857	0.0897	0.0974
PM10	0.0150	0.0066	0.0074
SOx	0.0286	0.1599	0.0000
CO2	172	245	474
TRS	0.0086	0.0000	0.0000

Table 5. Unit emission factors assumed for the DMEc case (lb/MMBtu fuel input - HHV)

	Lime kiln	GT	Duct burner
VOC	0.0043	0.0021	0.0054
CO	0.0285	0.0330	0.0818
NOx	0.2857	0.0897	0.0974
PM10	0.0150	0.0066	0.0074
SOx	0.0286	0.0895	0.0000
CO2	172	240	237
TRS	0.0086	0.0000	0.0000

Table 6. Unit emission factors assumed for the FTa case (lb/MMBtu fuel input - HHV)

	Lime kiln	GT	Duct burner
VOC	0.0043	0.0021	0.0054
CO	0.0285	0.0330	0.0818
NOx	0.2857	0.0897	0.0974
PM10	0.0150	0.0066	0.0074
SOx	0.0286	0.1069	0.0956
CO2	172	272	325
TRS	0.0086	0.0000	0.0000

Table 7. Unit emission factors assumed for the FTb case (lb/MMBtu fuel input - HHV)

	Lime kiln	GT
VOC	0.0043	0.0021
CO	0.0285	0.0330
NOx	0.2857	0.0897
PM10	0.0150	0.0066
SOx	0.0286	0.1319
CO2	172	259
TRS	0.0086	0.0000

Table 8. Unit emission factors assumed for the FTc case (lb/MMBtu fuel input - HHV)

	Lime kiln	GT
VOC	0.0043	0.0021
CO	0.0285	0.0330
NOx	0.2857	0.0897
PM10	0.0150	0.0066
SOx	0.0286	0.0000
CO2	172	322
TRS	0.0086	0.0000

Table 9. Unit emission factors assumed for the mixed alcohols (MA) case (lb/MMBtu fuel input - HHV).

	Lime kiln	GT	Duct Burner
VOC	0.0043	0.0021	0.0021
CO	0.0285	0.0330	0.0330
NOx	0.2857	0.0897	0.0897
PM10	0.0150	0.0066	0.0066
SOx	0.0286	0.0000	0.1667
CO2	172	303	259
TRS	0.0086	0	0

Table 10: Total average U.S. grid emissions (including non-fossil fuel sources) assumed in estimating grid offsets.[a]

lb/MWh	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**
VOC	0.024	0.021	0.018	0.015	0.013	0.011
CO	0.234	0.200	0.172	0.147	0.126	0.108
NOx	1.125	0.938	0.886	0.848	0.703	0.584
PM10	0.326	0.279	0.239	0.205	0.175	0.150
SOx	2.836	2.069	1.684	1.492	1.127	0.851
CO2	1,340	1,312	1,303	1,321	1,318	1,316

(a) power plants only. Our WTW analysis did not include emissions from fuel supply to the power plants, and can thus be viewed as conservative in terms of the emissions benefits from displaced grid power.
References: [18, 19, 20, 21]. Estimates for 2031-2035 were extrapolated from the EIA forecast [19], which only goes to 2030.

3 Emissions Factors for Biofuel Fuel Chain Elements

The following tables summarize the assumptions used for the elements of the biorefinery fuel chains other than the biorefinery itself. They are all based on version 1.7 of the GREET model [22]. For the vehicle end-use, adjustments to fossil energy consumption are based on the fraction of renewable fuel. For example in Table 19, fossil energy use by the vehicle is adjusted to reflect the blend of conventional fuels and FT biofuels. The values further reflect relative energy content of the different fuels, since blends are expressed on a volume basis. Similarly, CO_2 emissions are adjusted based on the relative carbon contents of the different fuels in the blends.

Table 11. Emissions and energy use[a] from biomass collection and transport (75-miles one-way)

		Collection	Transportation	Total
Total energy input	Btu/dry ton	296,885	535,817	832,703
Fossil Fuels	Btu/dry ton	291,701	534,341	826,042
VOC	g/dry ton	17	17	34
CO	g/dry ton	84	75	158
NOx	g/dry ton	163	221	384
PM10	g/dry ton	19	7	26
SOx	g/dry ton	14	14	28
CH4	g/dry ton	27	47	74
CO2	g/dry ton	23,293	41,882	65,175
Petroleum	Btu/dry ton	241,655	491,697	733,352

(a) As reported in the GREET model, energy use is reported here on an LHV basis.

Table 12. Emissions and energy use[a] from DME transportation and distribution

		Barge	Pipeline	Rail	Truck
Length of haul	miles (one-way)			250	50
Energy consumption and emissions by transport mode					
		Barge	Pipeline	Rail	Truck
Energy Consumption	Btu/MMBtu	-	-	4,398	6,108
Fossil Energy Consumption	Btu/MMBtu	-	-	4,386	6,091
VOC	g/MMBtu	-	-	0.30	0.20
CO	g/MMBtu	-	-	0.84	0.85
NOx	g/MMBtu	-	-	5.79	2.52
PM10	g/MMBtu	-	-	0.16	0.08
SOx	g/MMBtu	-	-	0.11	0.16
CH4	g/MMBtu	-	-	0.40	0.54
CO2	g/MMBtu	-	-	342.90	477.40
Petroleum	Btu/MMBtu	-	-	4,036	5,605
Shares by transport mode (shares need not sum to 100%)					
		Barge	Pipeline	Rail	Truck
Transportation	%	0%	0%	100%	0%
Distribution	%	0%	0%	0%	100%
Energy consumption and emissions in transportation and distribution					
		Transportation	Distribution	Total	
Energy Consumption	Btu/MMBtu	4,398	6,108	10,506	
Fossil Energy Consumption	Btu/MMBtu	4,386	6,091	10,477	
VOC	g/MMBtu	0.30	0.20	0.50	
CO	g/MMBtu	0.84	0.85	1.69	
NOx	g/MMBtu	5.79	2.52	8.31	
PM10	g/MMBtu	0.16	0.08	0.24	
SOx	g/MMBtu	0.11	0.16	0.27	
CH4	g/MMBtu	0.40	0.54	0.94	
CO2	g/MMBtu	342.90	477.40	820.31	
Petroleum	Btu/MMBtu	4,036	5,605	9,641	

(a) As reported in the GREET model, energy use is reported here on an LHV basis.

Table 13. Emissions and energy use[a] from FT Gasoline transportation and distribution

		Barge	Pipeline	Rail	Truck
Length of haul	miles (one-way)	520	400	800	30
Energy consumption and emissions by transport mode					
		Barge	Pipeline	Rail	Truck
Energy Consumption	Btu/MMBtu	10,844	3,244	9,356	1,949
Fossil Energy Consumption	Btu/MMBtu	10,822	3,185	9,330	1,943
VOC	g/MMBtu	0.46	0.11	0.65	0.06
CO	g/MMBtu	1.26	0.57	1.78	0.27
NOx	g/MMBtu	10.67	2.42	12.31	0.81
PM10	g/MMBtu	0.30	0.10	0.34	0.03
SOx	g/MMBtu	2.82	0.50	0.23	0.05
CH4	g/MMBtu	0.97	0.47	0.85	0.17
CO2	g/MMBtu	919.58	252.48	729.41	152.33
Petroleum	Btu/MMBtu	10,311.29	2,015.61	8,586	1,788
Shares by transport mode (shares need not sum to 100%)					
		Barge	Pipeline	Rail	Truck
Transportation	%	4%	73%	7%	0%
Distribution	%	0%	0%	0%	100%
Energy consumption and emissions in transportation and distribution					
		Transportation	Distribution	Total	
Energy Consumption	Btu/MMBtu	3,457	1,949	5,406	
Fossil Energy Consumption	Btu/MMBtu	3,411	1,943	5,355	
VOC	g/MMBtu	0.15	0.06	0.21	
CO	g/MMBtu	0.59	0.27	0.86	
NOx	g/MMBtu	3.06	0.81	3.86	
PM10	g/MMBtu	0.11	0.03	0.13	
SOx	g/MMBtu	0.49	0.05	0.54	
CH4	g/MMBtu	0.44	0.17	0.61	
CO2	g/MMBtu	272.15	152.33	424.48	
Petroleum	Btu/MMBtu	2,485	1,788	4,273	

(a) As reported in the GREET model, energy use is reported here on an LHV basis.

Table 14. Emissions and energy use[a] from FT Diesel transportation and distribution

		Barge	Pipeline	Rail	Truck
Length of haul	miles (one-way)	520	400	800	30
Energy consumption and emissions by transport mode					
		Barge	Pipeline	Rail	Truck
Energy Consumption	Btu/MMBtu	10,894	3,259	11,486	2,392
Fossil Energy Comsumption	Btu/MMBtu	10,873	3,200	11,470	2,389
VOC	g/MMBtu	0.47	0.11	0.67	0.07
CO	g/MMBtu	1.27	0.57	1.85	0.28
NOx	g/MMBtu	10.72	2.44	12.47	0.83
PM10	g/MMBtu	0.30	0.10	0.37	0.03
SOx	g/MMBtu	2.84	0.50	0.24	0.05
CH4	g/MMBtu	0.97	0.47	1.21	0.25
CO2	g/MMBtu	923.85	253.65	779.37	162.74
Petroleum	Btu/MMBtu	10,359.14	2,024.96	4,313	898
Shares by transport mode (shares need not sum to 100%)					
		Barge	Pipeline	Rail	Truck
Transportation	%	6%	75%	7%	0%
Distribution	%	0%	0%	0%	100%
Energy consumption and emissions in transportation and distribution					
		Transportation	Distribution	Total	
Energy Consumption	Btu/MMBtu	3,902	2,392	6,295	
Fossil Energy Consumption	Btu/MMBtu	3,855	2,389	6,244	
VOC	g/MMBtu	0.16	0.07	0.23	
CO	g/MMBtu	0.63	0.28	0.92	
NOx	g/MMBtu	3.34	0.83	4.17	
PM10	g/MMBtu	0.12	0.03	0.15	
SOx	g/MMBtu	0.56	0.05	0.61	
CH4	g/MMBtu	0.50	0.25	0.74	
CO2	g/MMBtu	300.23	162.74	462.96	
Petroleum	Btu/MMBtu	2,442	898	3,340	

(a) As reported in the GREET model, energy use is reported here on an LHV basis.

Table 15. Emissions and energy use[a] from mixed alcohol transportation and distribution

		Barge	Pipeline	Rail	Truck
Length of haul	miles (one-way)			250	50
Energy consumption and emissions by transport mode					
		Barge	Pipeline	Rail	Truck
Energy Consumption	Btu/MMBtu	-	-	4,713	5,236
Fossil Energy Consumption	Btu/MMBtu	-	-	4,700	5,222
VOC	g/MMBtu	-	-	0.33	0.17
CO	g/MMBtu	-	-	0.90	0.73
NOx	g/MMBtu	-	-	6.20	2.16
PM10	g/MMBtu	-	-	0.17	0.07
SOx	g/MMBtu	-	-	0.12	0.14
CH4	g/MMBtu	-	-	0.43	0.46
CO2	g/MMBtu	-	-	367.46	409.27
Petroleum	Btu/MMBtu	-	-	4,325	4,805
Shares by transport mode (shares need not sum to 100%)					
		Barge	Pipeline	Rail	Truck
Transportation	%	0%	0%	100%	0%
Distribution	%	0%	0%	0%	100%
Energy consumption and emissions in transportation and distribution					
		Transportation	Distribution	Total	
Energy Consumption	Btu/MMBtu	4,713	5,236	9,949	
Fossil Energy Consumption	Btu/MMBtu	4,700	5,222	9,922	
VOC	g/MMBtu	0.33	0.17	0.49	
CO	g/MMBtu	0.90	0.73	1.63	
NOx	g/MMBtu	6.20	2.16	8.36	
PM10	g/MMBtu	0.17	0.07	0.24	
SOx	g/MMBtu	0.12	0.14	0.26	
CH4	g/MMBtu	0.43	0.46	0.89	
CO2	g/MMBtu	367.46	409.27	776.73	
Petroleum	Btu/MMBtu	4,325	4,805	9,130	

(a) As reported in the GREET model, energy use is reported here on an LHV basis.

Table 16. Emissions and energy use[a] from FT Crude transportation and distribution

		Barge	Pipeline	Rail	Truck
Length of haul	miles (one-way)			100	0
Energy consumption and emissions by transport mode					
		Barge	Pipeline	Rail	Truck
Energy Consumption	Btu/MMBtu	-	-	1,190	-
Fossil Energy Consumption	Btu/MMBtu	-	-	1,187	-
VOC	g/MMBtu	-	-	0.08	-
CO	g/MMBtu	-	-	0.23	-
NOx	g/MMBtu	-	-	1.57	-
PM10	g/MMBtu	-	-	0.04	-
SOx	g/MMBtu	-	-	0.03	-
CH4	g/MMBtu	-	-	0.11	-
CO2	g/MMBtu	-	-	92.81	-
Petroleum	Btu/MMBtu	-	-	1,092	-
Shares by transport mode (shares need not sum to 100%)					
		Barge	Pipeline	Rail	Truck
Transportation	%	0%	0%	100%	0%
Distribution	%	0%	0%	0%	0%
Energy consumption and emissions in transportation and distribution					
		Transportation	Distribution	Total	
Energy Consumption	Btu/MMBtu	1,190	-	1,190	
Fossil Energy Consumption	Btu/MMBtu	1,187	-	1,187	
VOC	g/MMBtu	0.08	-	0.08	
CO	g/MMBtu	0.23	-	0.23	
NOx	g/MMBtu	1.57	-	1.57	
PM10	g/MMBtu	0.04	-	0.04	
SOx	g/MMBtu	0.03	-	0.03	
CH4	g/MMBtu	0.11	-	0.11	
CO2	g/MMBtu	92.81	-	92.81	
Petroleum	Btu/MMBtu	1,092	-	1,092	

(a) As reported in the GREET model, energy use is reported here on an LHV basis.

Table 17. Emissions and energy use[a] from FT Crude refining

FT Gasoline				
Energy Efficiency	86%	**Refining**	**Non-Combustion Emissions**	**Total**
Total energy	Btu/MMBtu	180,956		180,956
Fossil fuels	Btu/MMBtu	178,621		178,621
Petroleum	Btu/MMBtu	88,740		88,740
Total emissions: grams/mmBtu of fuel throughput				
VOC	g/MMBtu	0.92	2.31	3.226
CO	g/MMBtu	3.78	1.15	4.930
NOx	g/MMBtu	14.67	1.36	16.030
PM10	g/MMBtu	6.37	0.32	6.690
SOx	g/MMBtu	10.11	4.41	14.519
CH4	g/MMBtu	14.78	0.00	14.783
CO2	g/MMBtu	12,205.57	1,172.00	13,378

FT Diesel				
		Refining	**Non-Combustion Emissions**	**Total**
Energy Efficiency	89%			
Total energy	Btu/MMBtu	137,387		137,387
Fossil fuels	Btu/MMBtu	135,615		135,615
Petroleum	Btu/MMBtu	67,374		67,374
Total emissions: grams/mmBtu of fuel throughput				
VOC	g/MMBtu	0.70	2.23	2.927
CO	g/MMBtu	2.87	1.12	3.982
NOx	g/MMBtu	11.14	1.32	12.453
PM10	g/MMBtu	4.84	0.31	5.145
SOx	g/MMBtu	7.67	4.26	11.937
CH4	g/MMBtu	11.22	-	11.223
CO2	g/MMBtu	9,266.83	920.86	10,188

Assumed Yield of FT Diesel vs. Gasoline - Energy Basis	
FTD	62%
FTG	38%

(a) As reported in the GREET model, energy use is reported here on an LHV basis. We assume the same refining requirements as for conventional gasoline and conventional diesel. See Volume 1 for additional details.

Table 18. Energy consumption and emissions assumptions for DME in light-duty vehicles (CIDI Engines) [a]

DME in CIDI engines		
Energy Consumption Ratio to Conventional Fuel (c)		1.21
Energy Consumption	Btu/mile	3,405.1
Fossil Energy Cons.	Btu/mile	0.0
VOC	grams/mile	0.044
CO	grams/mile	0.269
NOx	grams/mile	0.106
PM10	grams/mile	0.021
SOx	grams/mile	0.000
CH4	grams/mile	0.005
CO2	grams/mile	238.1

Source data (DME from NG)			NCI Adjustments to Default GREET Values (b) %	New Estimate	Notes
Energy consumption	Btu/mile	3405.057	100%	3,405	
Fossil Energy Consumption	Btu/mile	3405.057	0%	-	100% biofuel
VOC: exhaust	grams/mile	0.088	50%	0.0440	
VOC: evaporation	grams/mile	0	100%	-	
CO	grams/mile	0.539	50%	0.2695	
NOx	grams/mile	0.141	75%	0.1058	
PM10: exhaust	grams/mile	0.009	10%	0.0009	
PM10: brake and tire wearin	grams/mile	0.0205	100%	0.0205	
SOx	grams/mile	0	100%	-	
CH4	grams/mile	0.0052	100%	0.0052	
N2O	grams/mile	0.012	100%	0.0120	
CO2	grams/mile	238.0607	100%	238	
From GREET "Vehicles" sheet, Table 3.					

(a) As reported in the GREET model, energy use is reported here on an LHV basis..
(b) Adjustments to VOC, CO, NOx and PM10 emissions are based on [23].
(c) This ratio is the total energy used in the conventional fuel chain (well to wheels) relative to the amount of biofuel used by the vehicle. It is used to calculate the emissions displaced in the conventional fuel chain per unit of biofuel produced.

Table 19. Energy consumption and emissions assumptions for FT fuels blended with conventional fuels in light-duty vehicles (FT gasoline in gasoline engines and FT diesel in CIDI engines) [a]

FT gasoline blend in gasoline engines						NCI Adjustments to Default GREET Values (b)		
Energy Consumption Ratio to Conventional Fuel (c)		1.24	Source data (100% CG+RFG)			%	New Estimate	Notes
Energy Consumption	Btu/mile	4,630.9	Energy consumption	Btu/mile	4630.877	100%	4,631	
Fossil Energy Cons.	Btu/mile	4,106.7	Fossil Energy Consumption	Btu/mile	4534.56	90.6%	4,107	
VOC	grams/mile	0.180	VOC: exhaust	grams/mile	0.122	100%	0.1220	
CO	grams/mile	3.745	VOC: evaporation	grams/mile	0.058	100%	0.0580	
NOx	grams/mile	0.141	CO	grams/mile	3.745	100%	3.7450	
PM10	grams/mile	0.029	NOx	grams/mile	0.141	100%	0.1410	
SOx	grams/mile	0.006	PM10: exhaust	grams/mile	0.0081	100%	0.0081	
CH4	grams/mile	0.015	PM10: brake and tire wearin	grams/mile	0.0205	100%	0.0205	
CO2	grams/mile	342.9	SOx	grams/mile	0.005808	100%	0.0058	
			CH4	grams/mile	0.0146	100%	0.0146	
			N2O	grams/mile	0.012	100%	0.0120	
			CO2	grams/mile	344.0764	99.6%	343	
			From GREET "Vehicles" sheet, Table 3.					

Note: the above figures are for Gasoline Vehicle: Baseline Gasoline (CG and RFG)

Assumed Mix (by volume)	
Gasoline	90%
FT Gasoline	10%

FT diesel blend in CIDI engines						NCI Adjustments to Default GREET Values (b)		
Energy Consumption Ratio to Conventional Fuel (c)		1.21	Source data (100% LSD)			%	New Estimate	Notes
Energy Consumption	Btu/mile	3,405.1	Energy consumption	Btu/mile	3,405.06	100%	3,405	
Fossil Energy Cons.	Btu/mile	3,078.4	Fossil Energy Consumption	Btu/mile	3,405.06	90.4%	3,078	
VOC	grams/mile	0.088	VOC: exhaust	grams/mile	0.088	100%	0.0880	
CO	grams/mile	0.539	VOC: evaporation	grams/mile	-	100%	-	
NOx	grams/mile	0.141	CO	grams/mile	0.54	100%	0.5390	
PM10	grams/mile	0.030	NOx	grams/mile	0.14	100%	0.1410	
SOx	grams/mile	0.002	PM10: exhaust	grams/mile	0.009	100%	0.0090	
CH4	grams/mile	0.003	PM10: brake and tire wearin	grams/mile	0.021	100%	0.0205	
CO2	grams/mile	268.3	SOx	grams/mile	0.002	100%	0.0019	
			CH4	grams/mile	0.003	100%	0.0026	
			N2O	grams/mile	0.012	100%	0.0120	
			CO2	grams/mile	269.238	99.6%	268	
			From GREET "Vehicles" sheet, Table 3.					

Assumed Mix (by volume)	
LS Diesel	90%
FT Diesel	10%

(a) As reported in the GREET model, energy use is reported here on an LHV basis.
(b) No adjustments made to emissions for low-level blends other than carbon and fossil fuel content.
(c) This ratio is the total energy used in the conventional fuel chain (well to wheels) relative to the amount of biofuel used by the vehicle. It is used to calculate the emissions displaced in the conventional fuel chain per unit of biofuel produced.

Table 20. Energy consumption and emissions assumptions for FT fuels in light-duty vehicles (FT gasoline in gasoline engines and FT diesel in CIDI engines).[a]

FT gasoline in gasoline engines						NCI Adjustments to Default GREET Values		
Energy Consumption Ratio to Conventional Fuel (c)		1.24	Source data (100% CG+RFG)			%	New Estimate	Notes
Energy Consumption	Btu/mile	4,630.9	Energy consumption	Btu/mile	4630.877	100%	4,631	
Fossil Energy Cons.	Btu/mile	0.0	Fossil Energy Consumption	Btu/mile	4534.56	0%	-	100% biofuel
VOC	grams/mile	0.180	VOC: exhaust	grams/mile	0.122	100%	0.1220	
CO	grams/mile	3.745	VOC: evaporation	grams/mile	0.058	100%	0.0580	
NOx	grams/mile	0.141	CO	grams/mile	3.745	100%	3.7450	
PM10	grams/mile	0.029	NOx	grams/mile	0.141	100%	0.1410	
SOx	grams/mile	0.000	PM10: exhaust	grams/mile	0.0081	100%	0.0081	
CH4	grams/mile	0.015	PM10: brake and tire wearin	grams/mile	0.0205	100%	0.0205	
CO2	grams/mile	332.0	SOx	grams/mile	0.005808	0%	-	
			CH4	grams/mile	0.0146	100%	0.0146	
			N2O	grams/mile	0.012	100%	0.0120	
			CO2	grams/mile	344.0764	96%	332	
			From GREET "Vehicles" sheet, Table 3.					

Note: the above figures are for conventional gasoline engine operation.
GREET does not provide figures for FT gasoline in internal combustion engine.

FT diesel in CIDI engines						NCI Adjustments to Default GREET Values		
Energy Consumption Ratio to Conventional Fuel (c)		1.21	Source data (FTD from NG)			%	New Estimate	Notes
Energy Consumption	Btu/mile	3,405.1	Energy consumption	Btu/mile	3405.057	100%	3,405	
Fossil Energy Cons.	Btu/mile	0.0	Fossil Energy Consumption	Btu/mile	3405.057	0%	-	100% biofuel
VOC	grams/mile	0.070	VOC: exhaust	grams/mile	0.088	80%	0.0704	
CO	grams/mile	0.350	VOC: evaporation	grams/mile	0	100%	-	
NOx	grams/mile	0.134	CO	grams/mile	0.539	65%	0.3503	
PM10	grams/mile	0.027	NOx	grams/mile	0.141	95%	0.1340	
SOx	grams/mile	0.000	PM10: exhaust	grams/mile	0.009	75%	0.0067	
CH4	grams/mile	0.003	PM10: brake and tire wearin	grams/mile	0.0205	100%	0.0205	
CO2	grams/mile	259.8	SOx	grams/mile	0	100%	-	
			CH4	grams/mile	0.0026	100%	0.0026	
			N2O	grams/mile	0.012	100%	0.0120	
			CO2	grams/mile	259.8028	100%	260	
			From GREET "Vehicles" sheet, Table 3.					

(a) As reported in the GREET model, energy use is reported here on an LHV basis..
(b) Adjustments to VOC, CO, NOx and PM10 emissions are based on [24].
(c) This ratio is the total energy used in the conventional fuel chain (well to wheels) relative to the amount of biofuel used by the vehicle. It is used to calculate the emissions displaced in the conventional fuel chain per unit of biofuel produced.

Table 21. Energy consumption and emissions assumptions for mixed alcohol use in light-duty vehicles (low-level blend with gasoline and Flexible-Fuel Vehicle ["E-85"])[a]

MA Case: Gasoline Vehicle - low-level blend with gasoline

Energy Consumption Ratio to Conventional Fuel (c)		1.24
Energy Consumption	Btu/mile	4,630.9
Fossil Energy Cons.	Btu/mile	4,232.7
VOC	grams/mile	0.180
CO	grams/mile	3.74
NOx	grams/mile	0.141
PM10	grams/mile	0.029
SOx	grams/mile	0.005
CH4	grams/mile	0.015
CO2	grams/mile	355.5

Source data (E10 in CG)		
Energy consumption	Btu/mile	4630.877
Fossil Energy Consumption	Btu/mile	4331.89
VOC: exhaust	grams/mile	0.122
VOC: evaporation	grams/mile	0.058
CO	grams/mile	3.745
NOx	grams/mile	0.141
PM10: exhaust	grams/mile	0.0081
PM10: brake and tire wearin	grams/mile	0.0205
SOx	grams/mile	0.0054
CH4	grams/mile	0.0146
N2O	grams/mile	0.012
CO2	grams/mile	355.2202

From GREET "Vehicles" sheet, Table 3.

NCI Adjustments to Default GREET Values (b)

%	New Estimate	Notes
100%	4,631	
98%	4,233	
100%	0.1220	
100%	0.0580	
100%	3.7450	
100%	0.1410	
100%	0.0081	
100%	0.0205	
100%	0.0054	
100%	0.0146	
100%	0.0120	
100%	355	

MA Case: Flexible-Fuel Vehicle ("E-85")

Energy Consumption Ratio to Conventional Fuel (c)		1.30
Energy Consumption	Btu/mile	4,410.4
Fossil Energy Cons.	Btu/mile	937.6
VOC	grams/mile	0.171
CO	grams/mile	3.745
NOx	grams/mile	0.141
PM10	grams/mile	0.029
SOx	grams/mile	0.002
CH4	grams/mile	0.015
CO2	grams/mile	334.5

Source data (E85 FFV)		
Energy consumption	Btu/mile	4410.36
Fossil Energy Consumption	Btu/mile	1164.299
VOC: exhaust	grams/mile	0.122
VOC: evaporation	grams/mile	0.0493
CO	grams/mile	3.745
NOx	grams/mile	0.141
PM10: exhaust	grams/mile	0.0081
PM10: brake and tire wearin	grams/mile	0.0205
SOx	grams/mile	0.001841
CH4	grams/mile	0.0146
N2O	grams/mile	0.012
CO2	grams/mile	332.6515

From GREET "Vehicles" sheet, Table 3.

NCI Adjustments to Default GREET Values (b)

%	New Estimate	Notes
100%	4,410	
81%	938	
100%	0.1220	
100%	0.0493	
100%	3.7450	
100%	0.1410	
100%	0.0081	
100%	0.0205	
100%	0.0018	
100%	0.0146	
100%	0.0120	
101%	334	

GREET assumptions on Ethanol fuel blends

Volumetric share of an alternative fuel in a fuel blend	
EtOH in low-level EtOH blend in gasoline	9.50%
Ethanol for FFV fuel	80.75%
Ethanol for dedicated vehicle fuel	80.75%

From GREET "Vehicles" sheet, Table 1

(a) As reported in the GREET model, energy use is reported here on an LHV basis.
(b) No adjustments made to emissions other than carbon and fossil fuel content.
(c) This ratio is the total energy used in the conventional fuel chain (well to wheels) relative to the amount of biofuel used by the vehicle. It is used to calculate the emissions displaced in the conventional fuel chain per unit of biofuel produced.

4 Emissions Factors for Conventional Fuel Chains

These factors are all taken from the GREET model.

Table 22. Energy consumption[a] and emissions for the gasoline fuel chain

Gasoline Vehicle: Baseline Gasoline (CG and RFG) (Btu/mile or grams/mile)	Feedstock	Fuel	Vehicle Oper.	Total
Total Energy	177.34	942.32	4,630.88	5,750.53
Fossil Fuels	170.71	929.85	4,534.56	5,635.12
Petroleum	56.25	444.69	4,534.56	5,035.50
CO2	17.71	70.14	344.08	431.93
CH4	0.42	0.08	0.01	0.52
N2O	0.00	0.01	0.01	0.02
GHGs	27.52	73.87	347.96	449.36
VOC: Total	0.02	0.11	0.18	0.31
CO: Total	0.03	0.03	3.74	3.81
NOx: Total	0.09	0.11	0.14	0.35
PM10: Total	0.01	0.04	0.03	0.07
SOx: Total	0.04	0.08	0.01	0.12

(a) As reported in the GREET model, energy use is reported here on an LHV basis.

Table 23. Energy consumption[a] and emissions for the low-sulfur diesel fuel chain

CIDI Vehicle: LS Diesel (Btu/mile or grams/mile)	Feedstock	Fuel	Vehicle Oper.	Total
Total Energy	130.30	586.94	3,405.06	4,122.29
Fossil Fuels	125.43	579.45	3,405.06	4,109.94
Petroleum	41.33	294.58	3,405.06	3,740.96
CO2	13.01	43.61	269.238	325.86
CH4	0.31	0.05	0.003	0.36
N2O	0.00	0.00	0.012	0.01
GHGs	20.22	44.93	272.850	338.00
VOC: Total	0.01	0.02	0.088	0.11
CO: Total	0.02	0.02	0.539	0.58
NOx: Total	0.07	0.07	0.141	0.28
PM10: Total	0.01	0.02	0.030	0.06
SOx: Total	0.03	0.05	0.002	0.08
VOC: Urban	0.00	0.01	0.055	0.07
CO: Urban	0.00	0.01	0.335	0.35
NOx: Urban	0.00	0.03	0.088	0.12
PM10: Urban	0.00	0.00	0.018	0.02
SOx: Urban	0.00	0.02	0.001	0.03

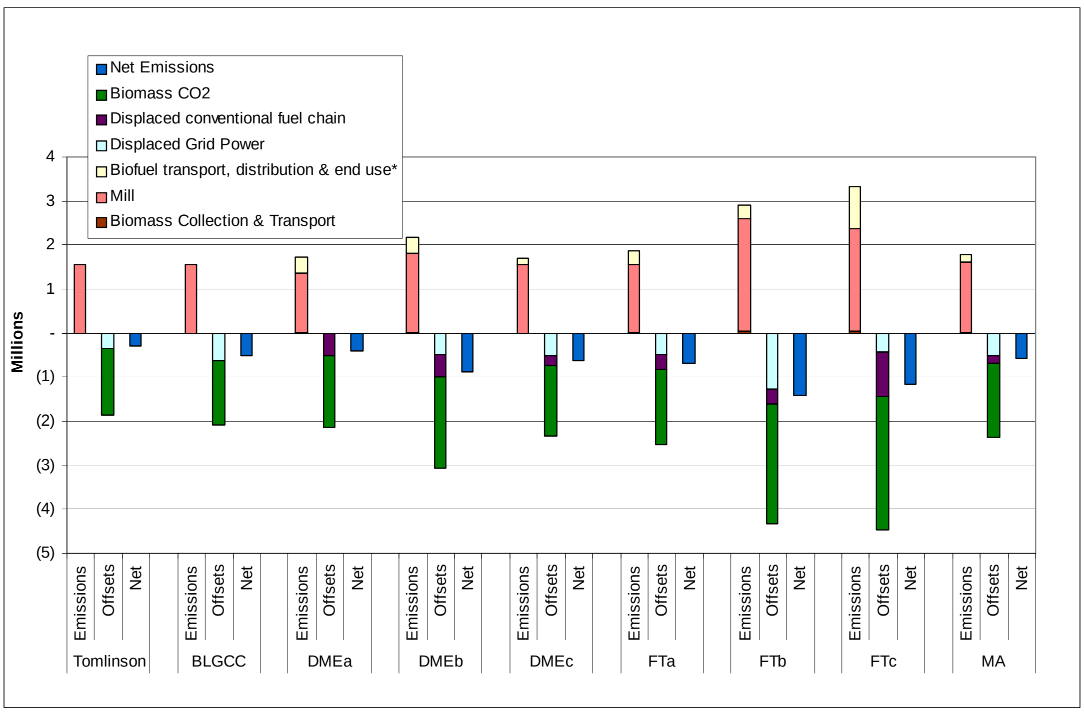
(a) As reported in the GREET model, energy use is reported here on an LHV basis.

5 Annual Emissions Estimate per Mill in 2010

Figure 2 through Figure 8 provide the results of the WTW analysis for the year 2010. They provide details of the emissions from the different biorefinery cases, the associated offsets and the net emissions. The difference between the net emissions of the Tomlinson case and the net emissions of the biorefinery cases is the improvement resulting from deployment of biorefinery technology. These were presented in Volume 1. Here we provide the details behind the results shown in Volume 1.

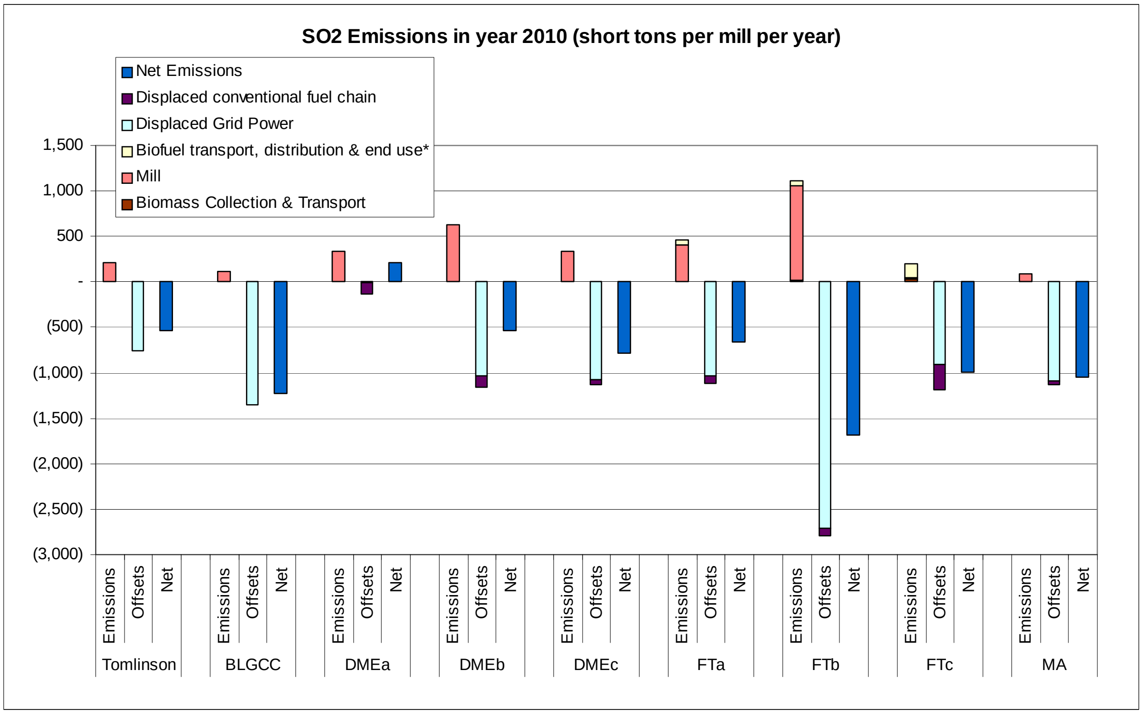
Figure 2 includes within the "mill" category the CO_2 emissions from biomass . It is then taken as a credit in the "offset" column as "Biomass CO_2". In Figure 8, only combustion sources of TRS are shown. Other existing sources of TRS emissions are not included in the analysis, as they are assumed to be the same in all cases, and were therefore not quantified here.

Figure 2: CO_2 emissions in year 2010, short tons per mill per year



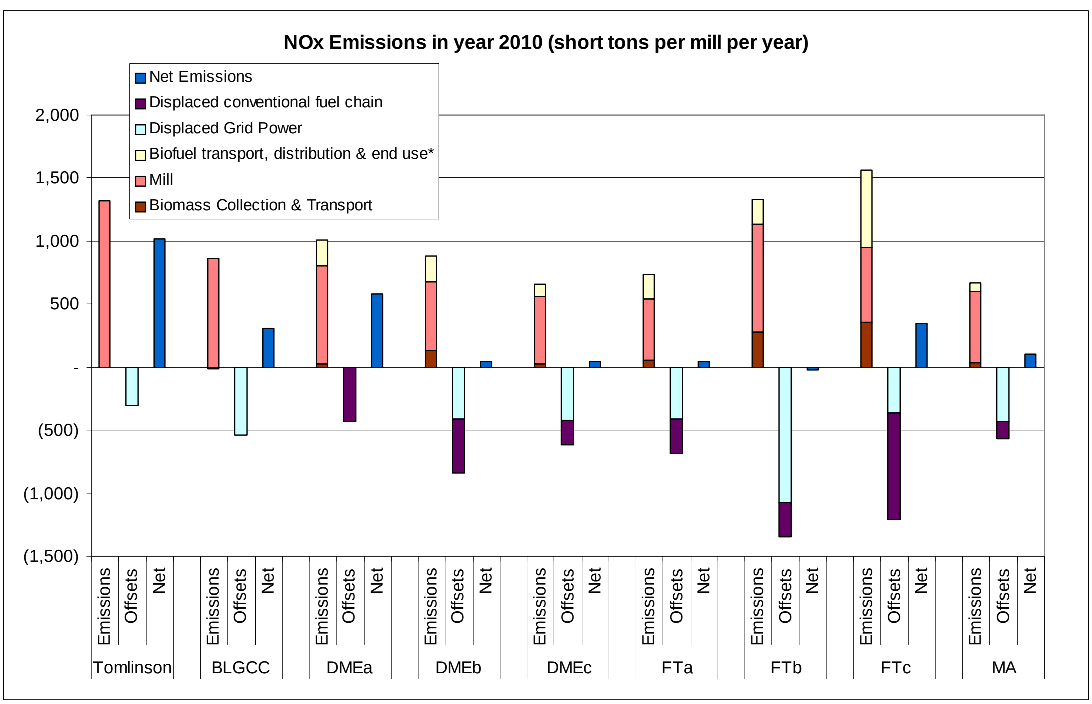
* Transportation of the crude FT product to the oil refinery included in FT cases.
Note: excludes any emissions from land use changes and biomass growth that are not related to harvesting and transportation.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 3: SO_2 emissions in year 2010, short tons per mill per year



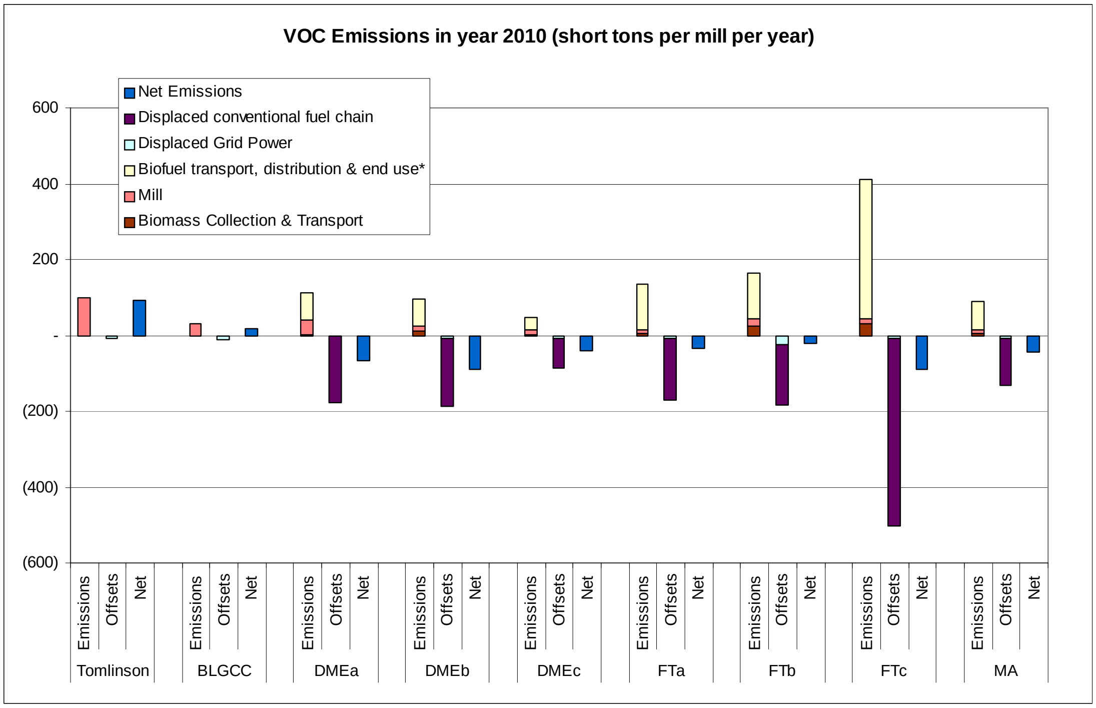
* Transportation of the crude FT product to the oil refinery included in FT cases.
Note: excludes any emissions from land use changes and biomass growth that are not related to harvesting and transportation.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 4: NOx emissions in year 2010, short tons per mill per year



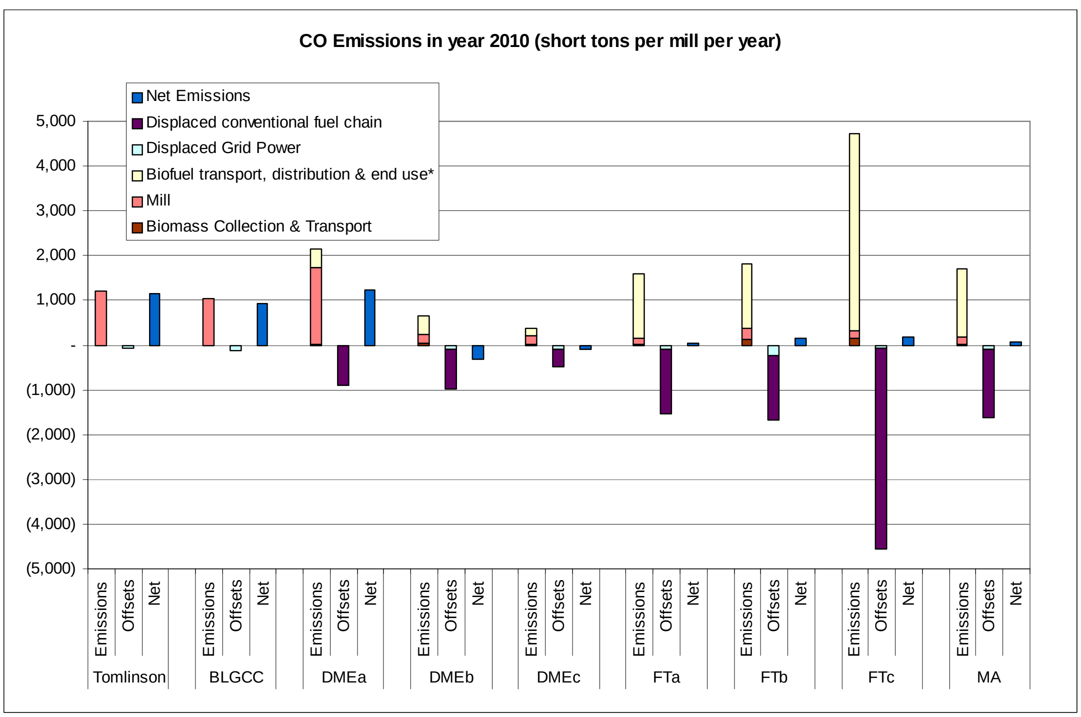
* Transportation of the crude FT product to the oil refinery included in FT cases.
Note: excludes any emissions from land use changes and biomass growth that are not related to harvesting and transportation.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 5: VOC emissions in year 2010, short tons per mill per year



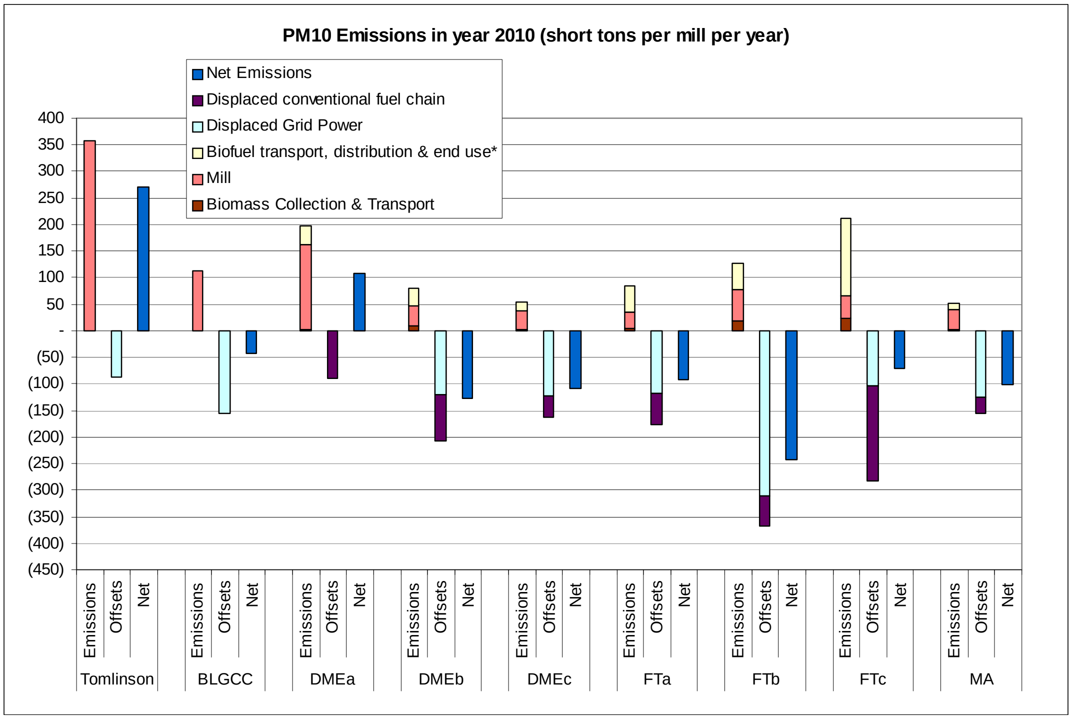
* Transportation of the crude FT product to the oil refinery included in FT cases.
Note: excludes any emissions from land use changes and biomass growth that are not related to harvesting and transportation.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 6: CO Emissions in year 2010, short tons per mill per year



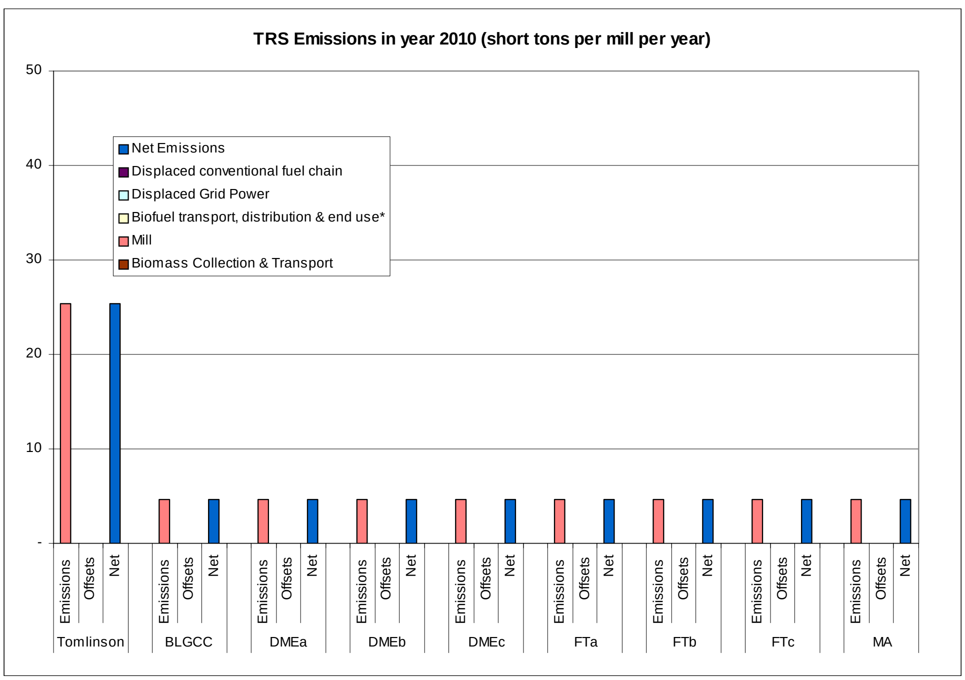
* Transportation of the crude FT product to the oil refinery included in FT cases.
Note: excludes any emissions from land use changes and biomass growth that are not related to harvesting and transportation.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 7: PM10 Emissions in year 2010, short tons per mill per year



* Transportation of the crude FT product to the oil refinery included in FT cases.
Note: excludes any emissions from land use changes and biomass growth that are not related to harvesting and transportation.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 8: TRS Emissions in year 2010, short tons per mill per year



* Transportation of the crude FT product to the oil refinery included in FT cases.
Note: excludes any emissions from land use changes and biomass growth that are not related to harvesting and transportation.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.
TRS emissions are for combustion sources only.

6 Results from the Market Penetration Analysis

National energy and emissions impacts were estimated under three separate market penetration scenarios. Table 24 summarizes the basic inputs to the three scenarios and Figure 9 shows the results, expressed in terms of total black liquor capacity and the number of reference mills this would represent. The reader is referred to Volume 1 for additional details on these scenarios, which were developed based on [25, 26, 27]. Figure 10 through Figure 30 summarize the results of the energy and emissions impacts for all the biorefinery cases and market penetration scenarios. These impact estimates assume that mixed alcohols and FT biofuels are used in low-level blends with their conventional counterparts, specifically, a 10% blend of mixed alcohols with gasoline and a 10% blend of FT diesel with low-sulfur diesel. Impacts with high-level blends are described in Section 6.1.

Table 24: Summary of Biorefinery market penetration scenarios developed in this study.

	***Low* Scenario**	***Base* Scenario**	***Aggressive* Scenario**
Technical Market Potential[a]	• 180 operable recovery boilers • Combined capacity of ~472 million lbs/day dry solids (~86 million t/yr)		
Ultimate Adoption Rate	• 90% of the technical market potential		
Industry Growth	• 1.27% per year, based on total black liquor capacity, estimated from data provided in [28]		
Basis	• Traditional market penetration "S" curve for capital intensive, facility-level investments		• Aggressive penetration curve assuming that normal rules of market penetration may not apply due to the age of the Tomlinson boiler fleet and other market drivers (see main text for discussion)
Saturation Time (years)[b]	30	20	10
Age of "New" boilers when replacement with BLGCC is considered	35	30	30
Age of "Rebuilt" boilers when replacement with BLGCC is considered	15	10	10

(a) The Black Liquor Recovery Boiler Committee (BLRBC) of the American Forest and Paper Association maintains a database of individual recovery boilers with information on capacity, location, age, rebuild year (if any), and in some cases, the nature of the rebuild. This database can be used to calculate the average boiler size, average boiler age when a rebuild occurred (~20 years), and to identify which boilers will be ready for replacement in any given future year. Because additional industry consolidation and mill closures are expected, and few if any new mills are likely to be built, the analysis is based on total capacity rather than number of mills.

(b) Defined as the time required to go from 10% penetration to 90% penetration.

Figure 9: Market penetration estimates used to assess energy and environmental impacts of biorefinery implementation in the United States.

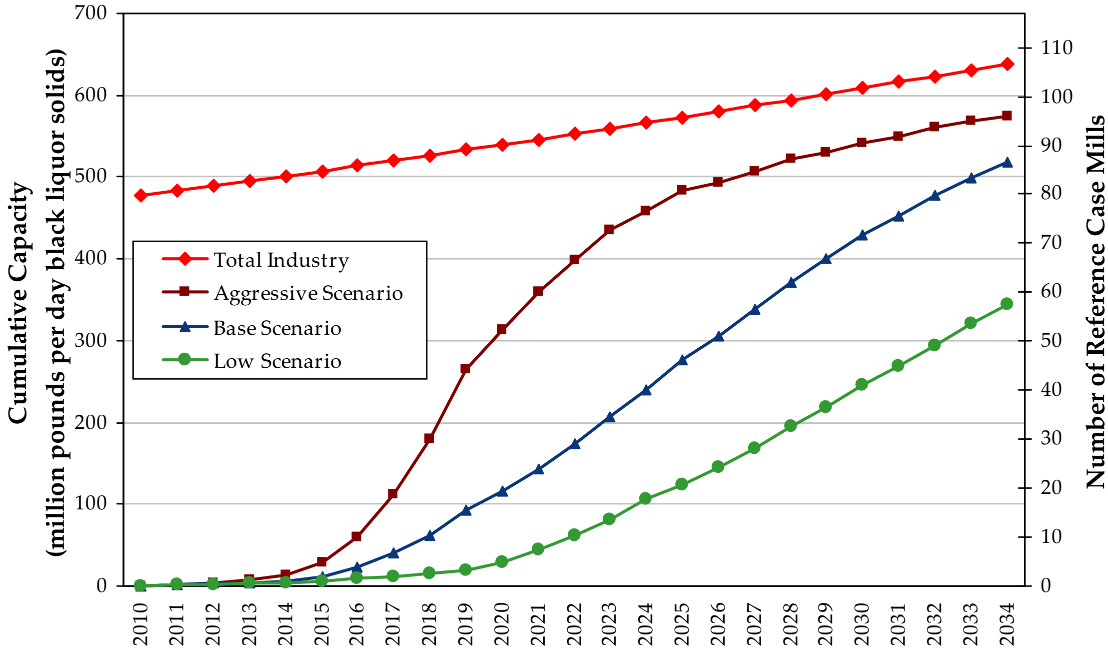
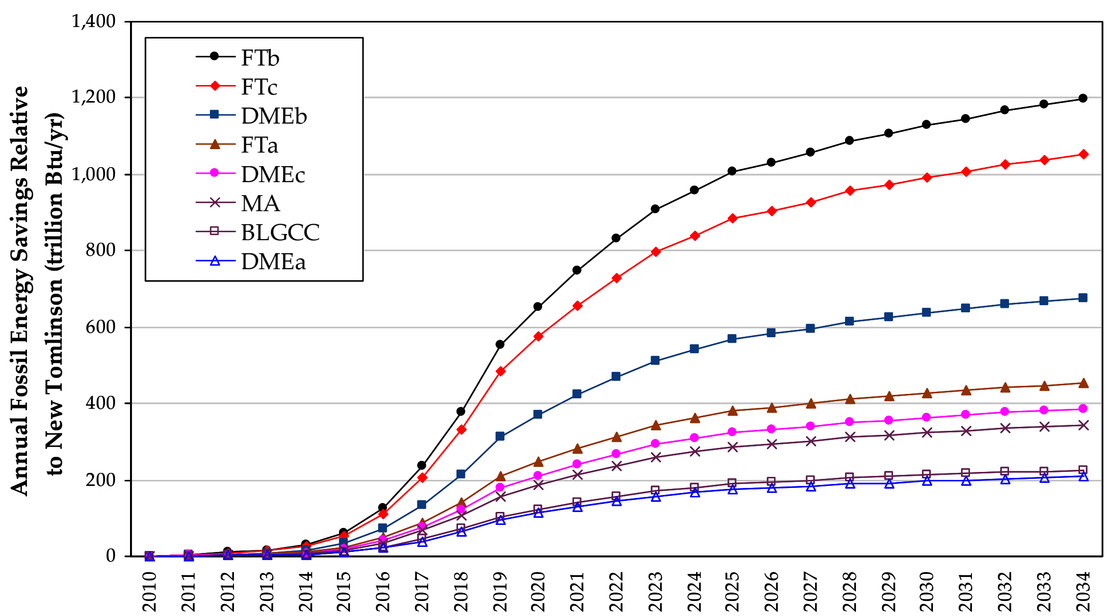
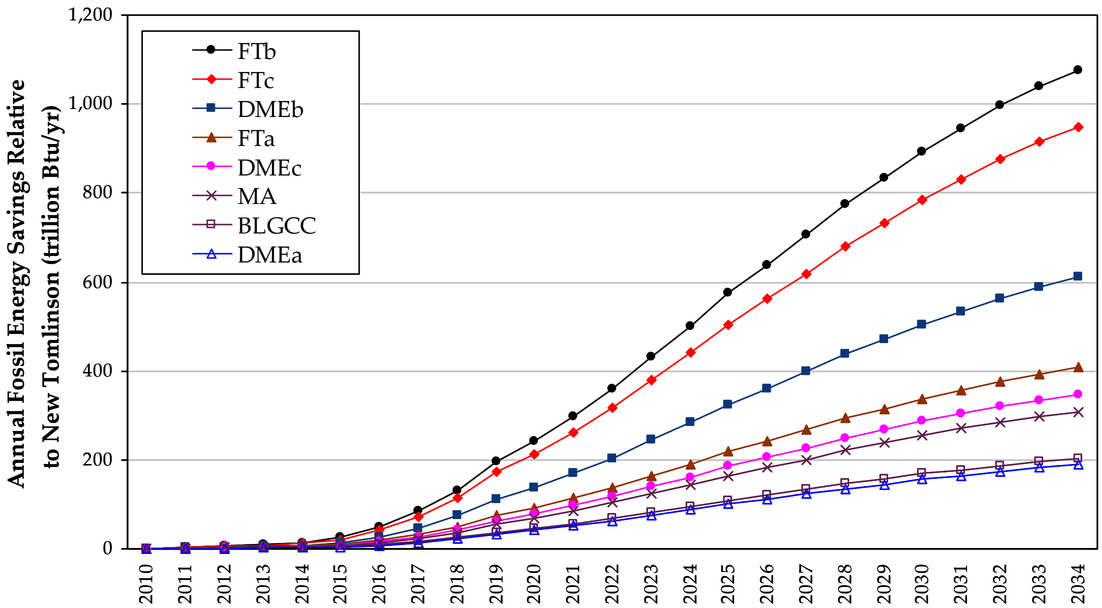


Figure 10: Net fossil fuel energy savings – HHV (*Aggressive* market penetration scenario)



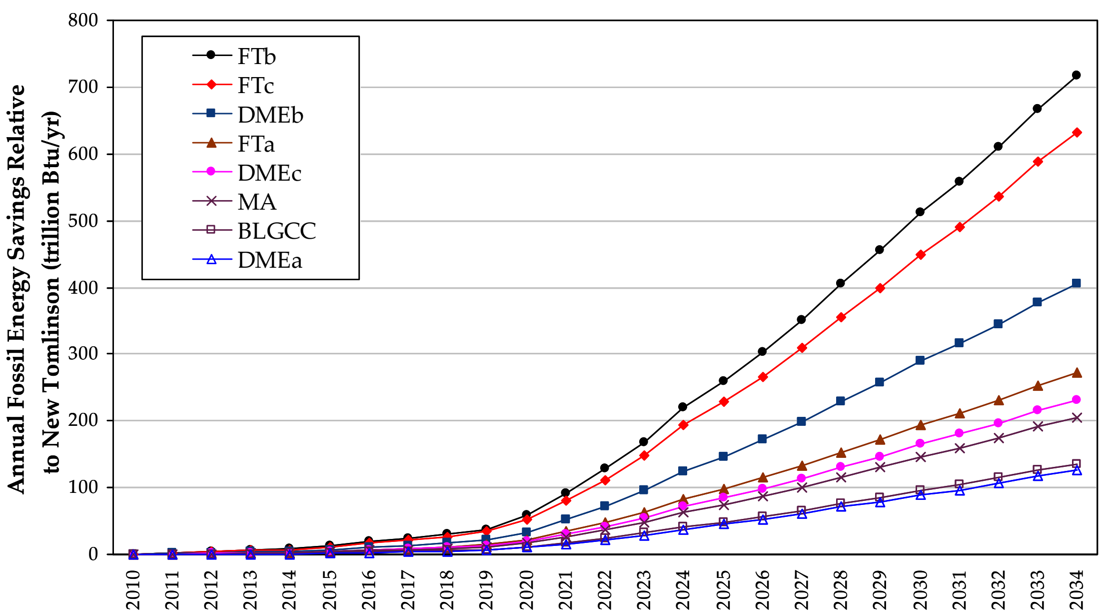
Note: Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 11: Net fossil fuel energy savings – HHV (*Base* market penetration scenario)



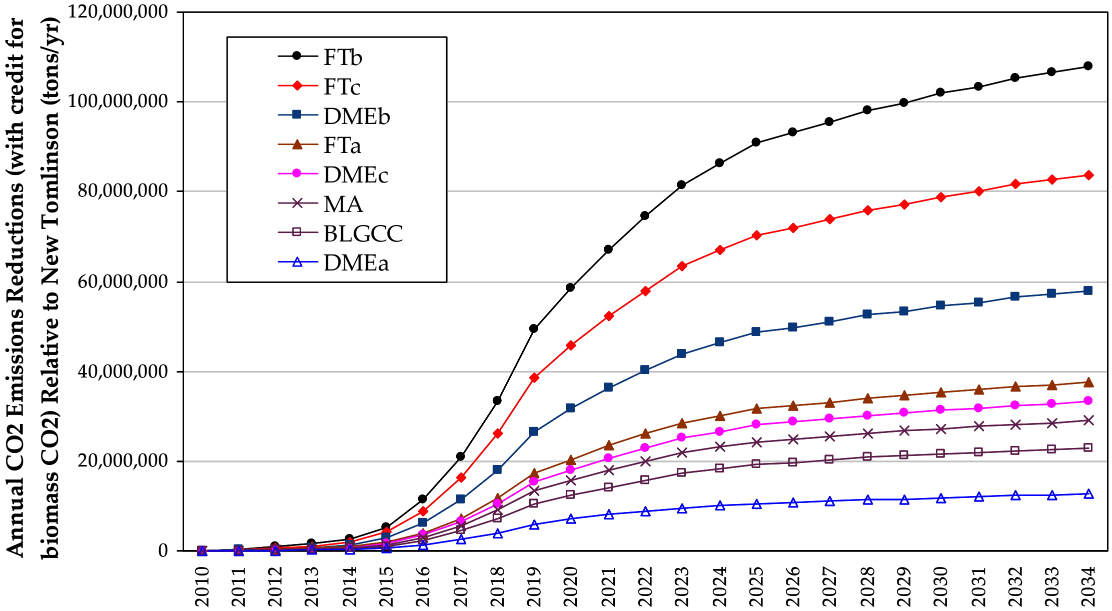
Note: Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 12: Net fossil fuel energy savings – HHV (*Low* market penetration scenario)



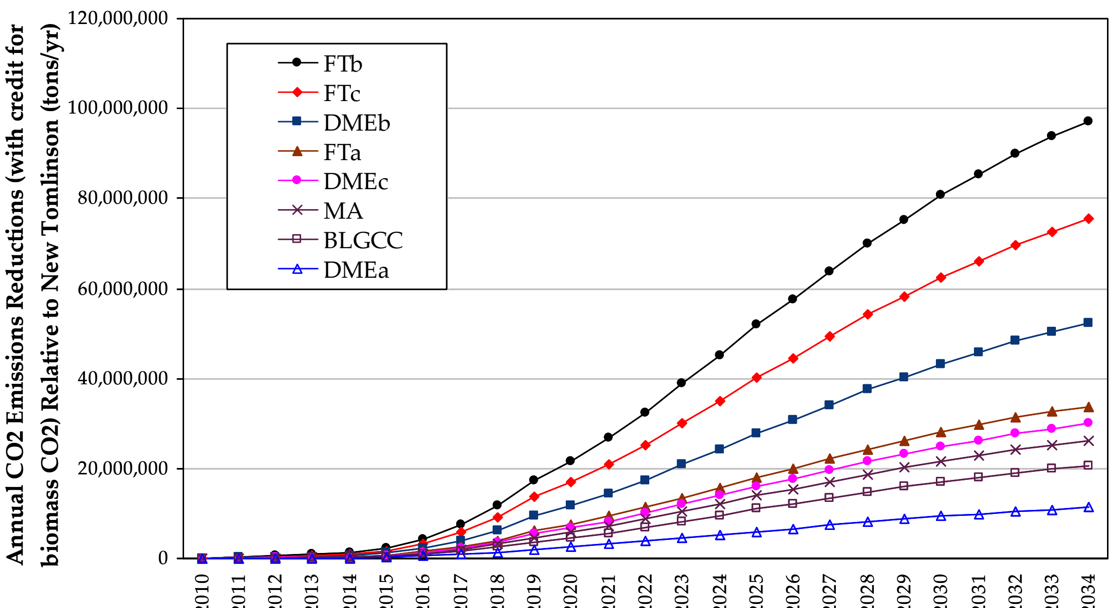
Note: Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 13: Net CO_2 emissions reductions (with credit for biomass CO_2) (*Aggressive* market penetration scenario)



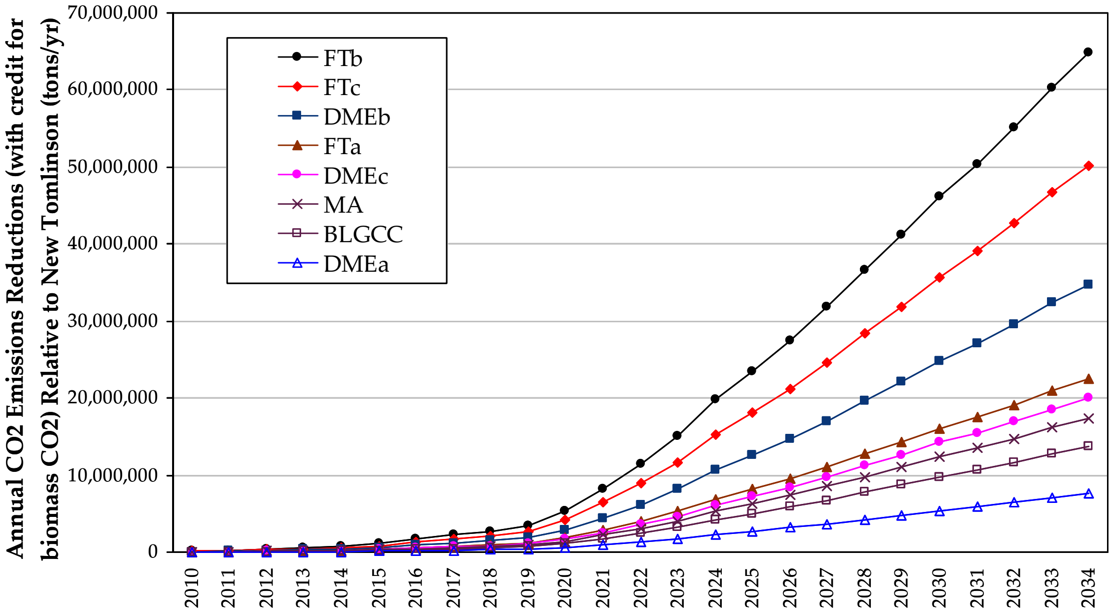
Transportation of the crude FT product to the oil refinery included in FT cases.
Note: excludes any emissions from land use changes and biomass growth that are not related to harvesting and transportation.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 14: Net CO_2 emissions reductions (with credit for biomass CO_2) (*Base* market penetration scenario)



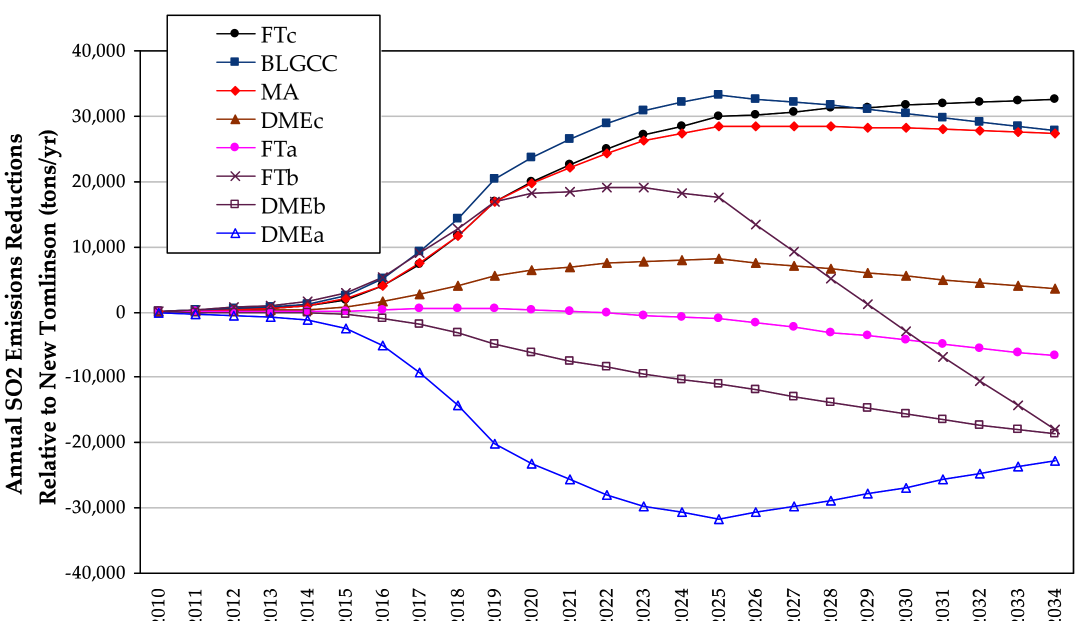
Transportation of the crude FT product to the oil refinery included in FT cases.
Note: excludes any emissions from land use changes and biomass growth that are not related to harvesting and transportation.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 15: Net CO_2 emissions reductions (with credit for biomass CO_2) (*Low* market penetration scenario)



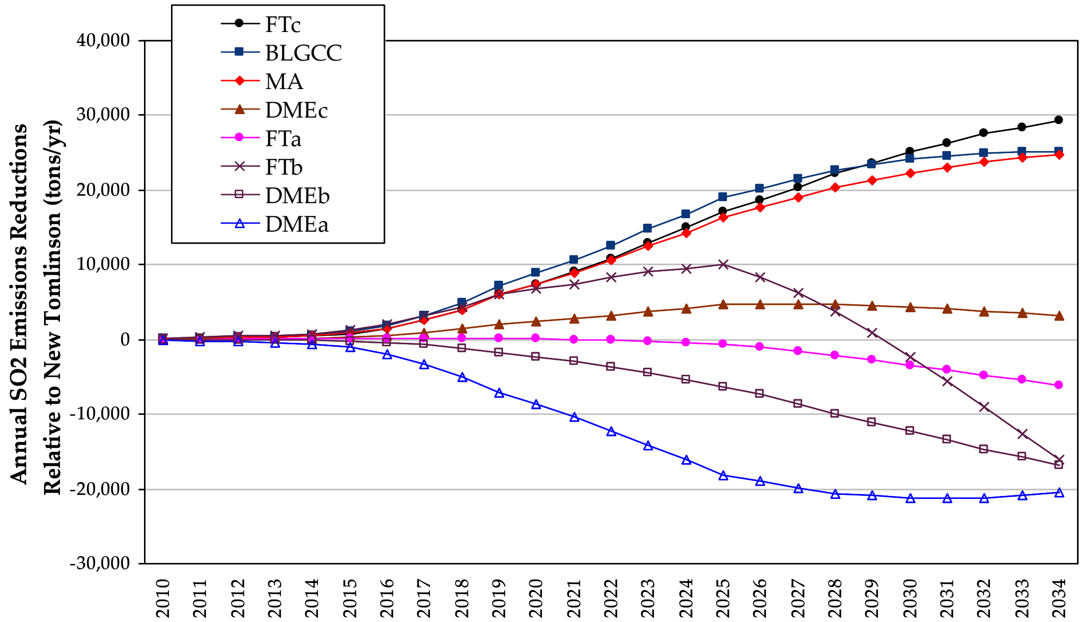
Transportation of the crude FT product to the oil refinery included in FT cases.
Note: excludes any emissions from land use changes and biomass growth that are not related to harvesting and transportation.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 16: Net SO_2 emissions reductions (*Aggressive* market penetration scenario)



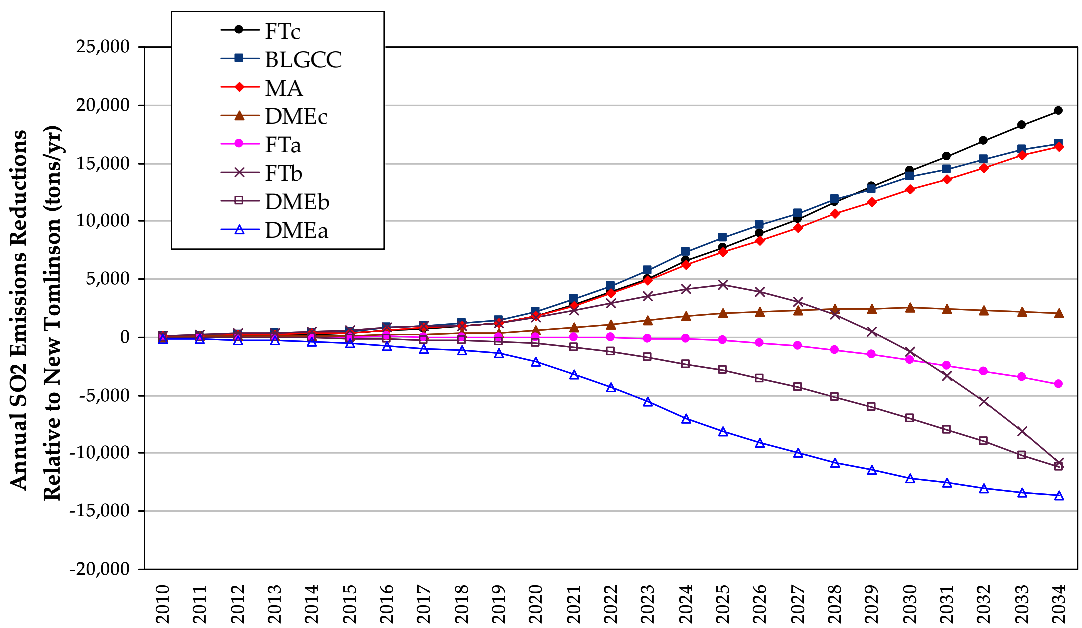
Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 17: Net SO_2 emissions reductions (*Base* market penetration scenario)



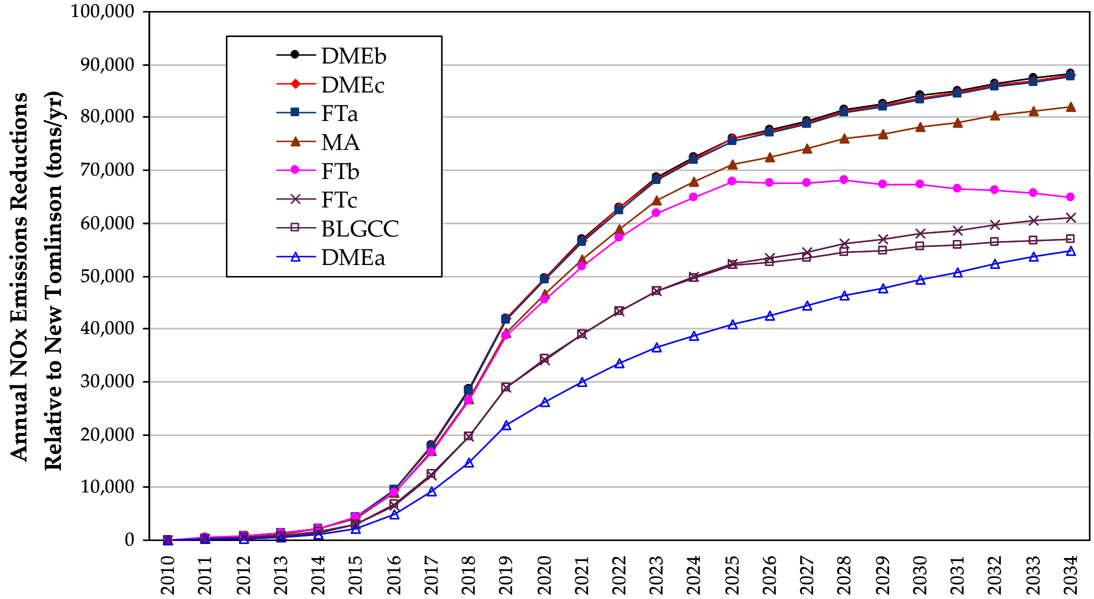
Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 18: Net SO_2 emissions reductions (*Low* market penetration scenario)



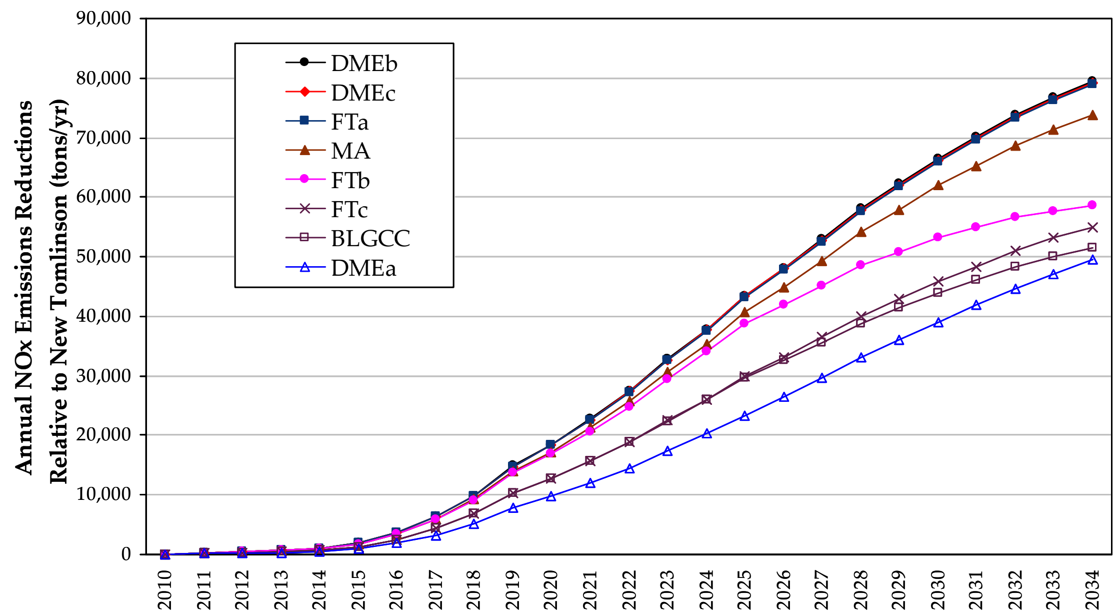
Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 19: Net NOx emissions reductions (*Aggressive* market penetration scenario)



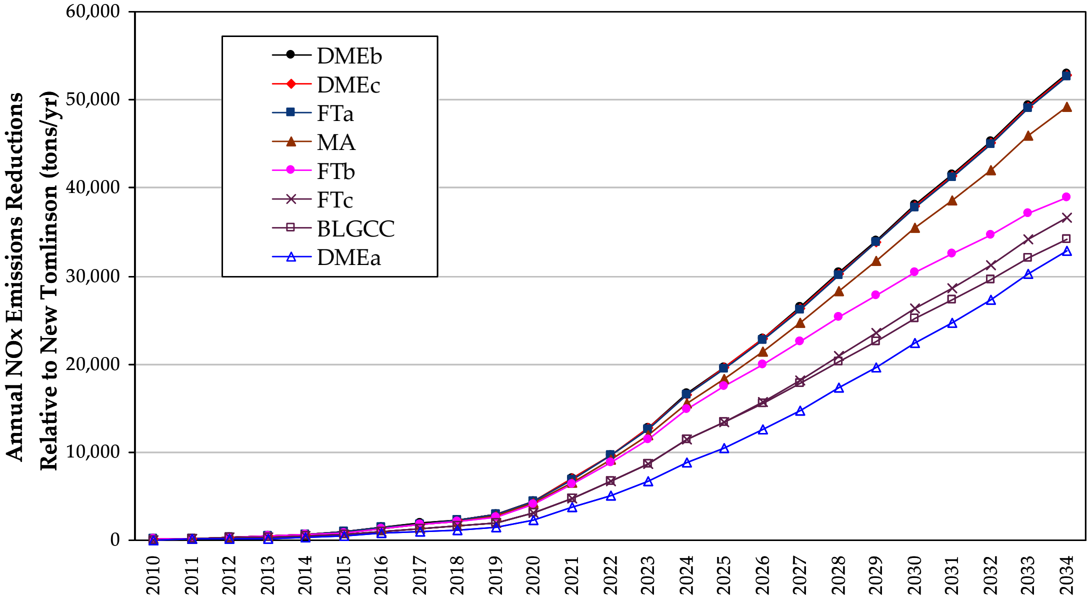
Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 20: Net NOx emissions reductions (*Base* market penetration scenario)



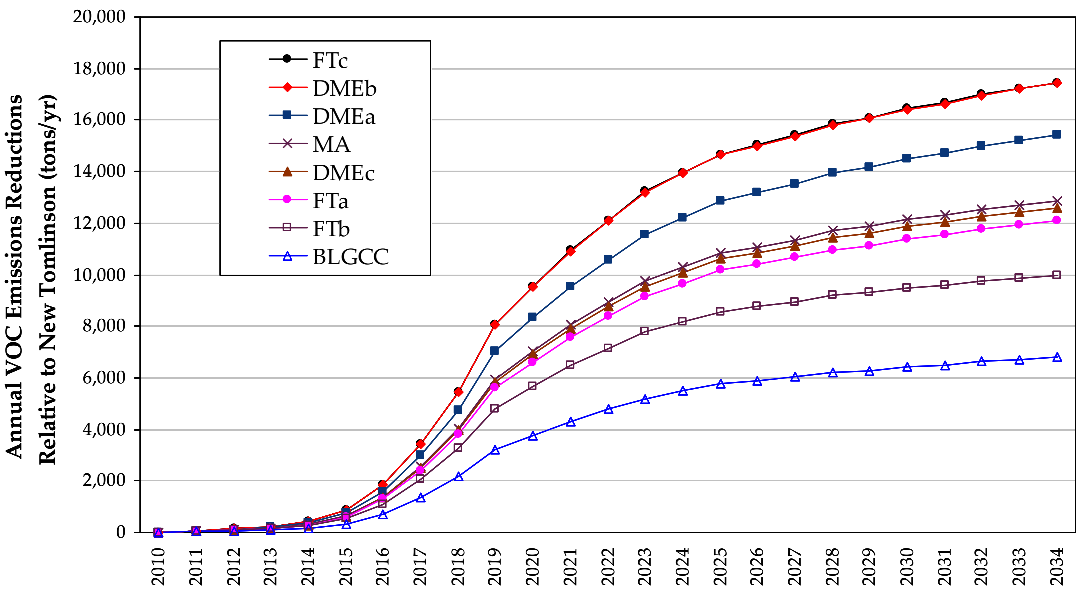
Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 21: Net NOx emissions reductions (*Low* market penetration scenario)



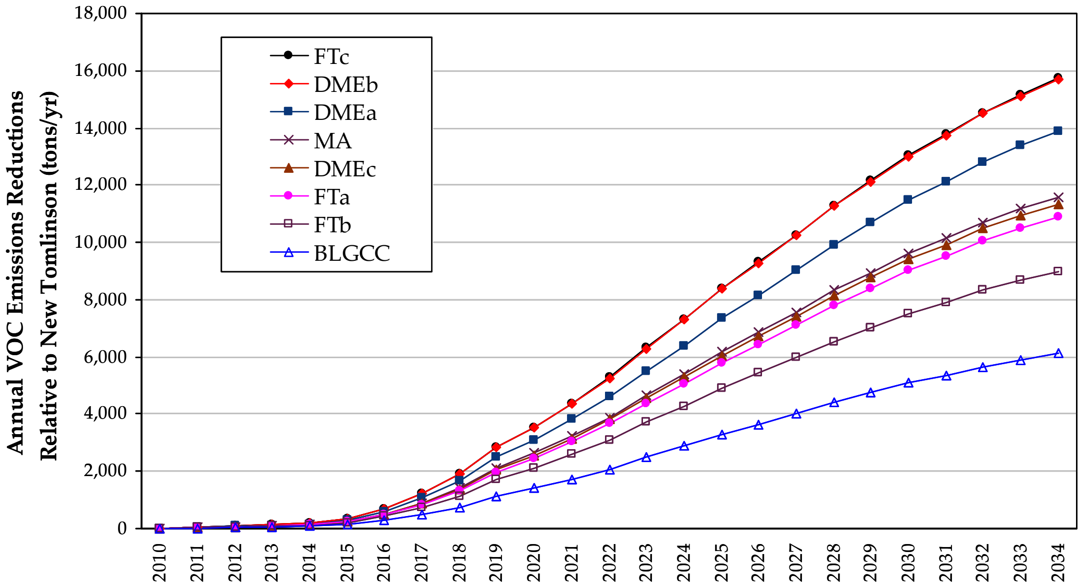
Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 22: Net VOC emissions reductions (*Aggressive* market penetration scenario)



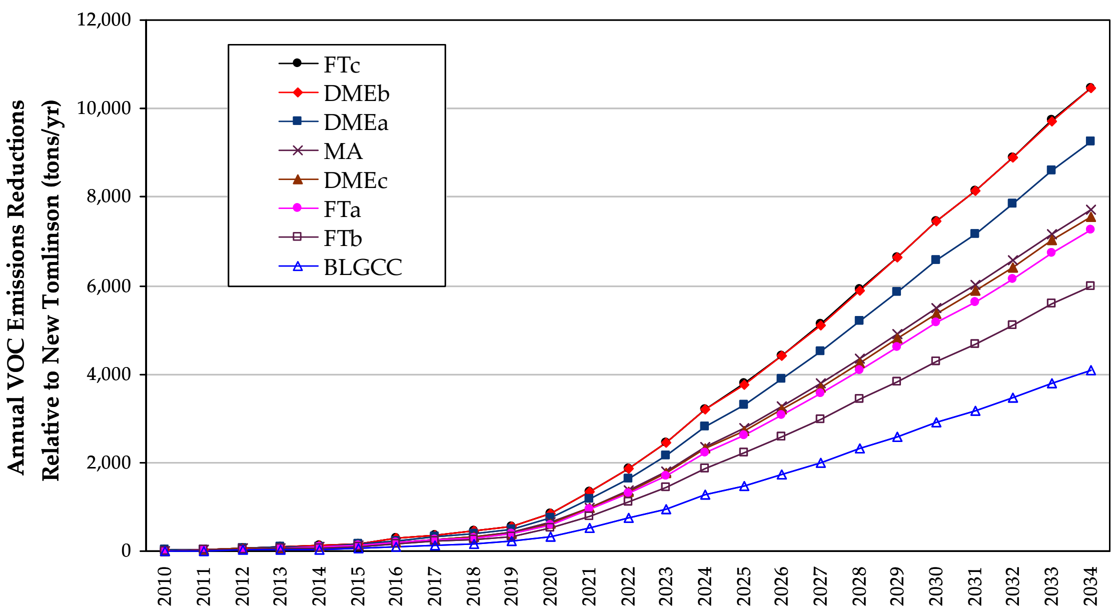
Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 23: Net VOC emissions reductions (*Base* market penetration scenario)



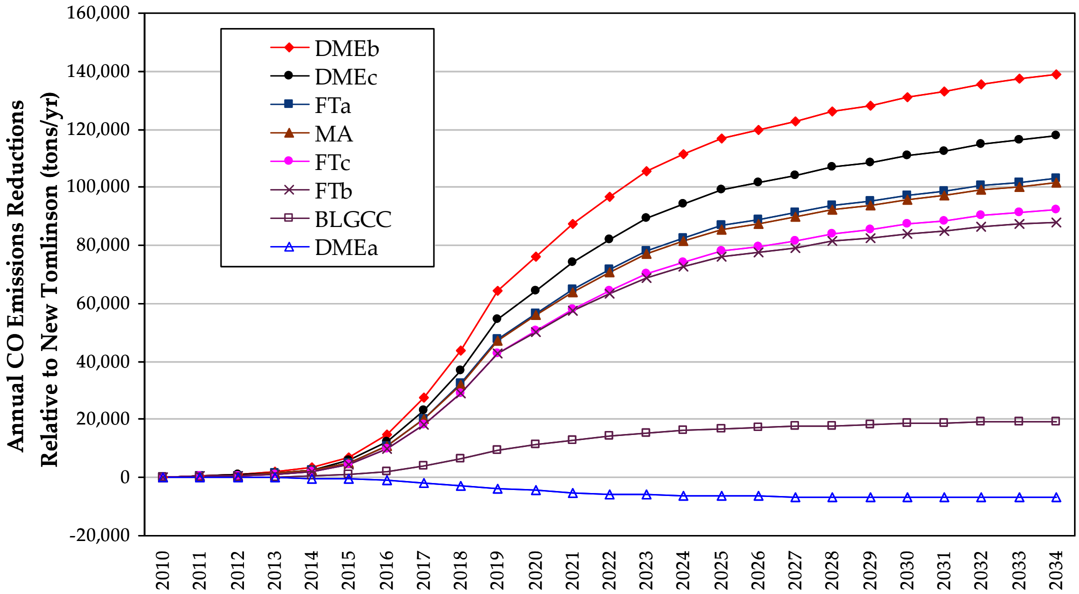
Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 24: Net VOC emissions reductions (*Low* market penetration scenario)



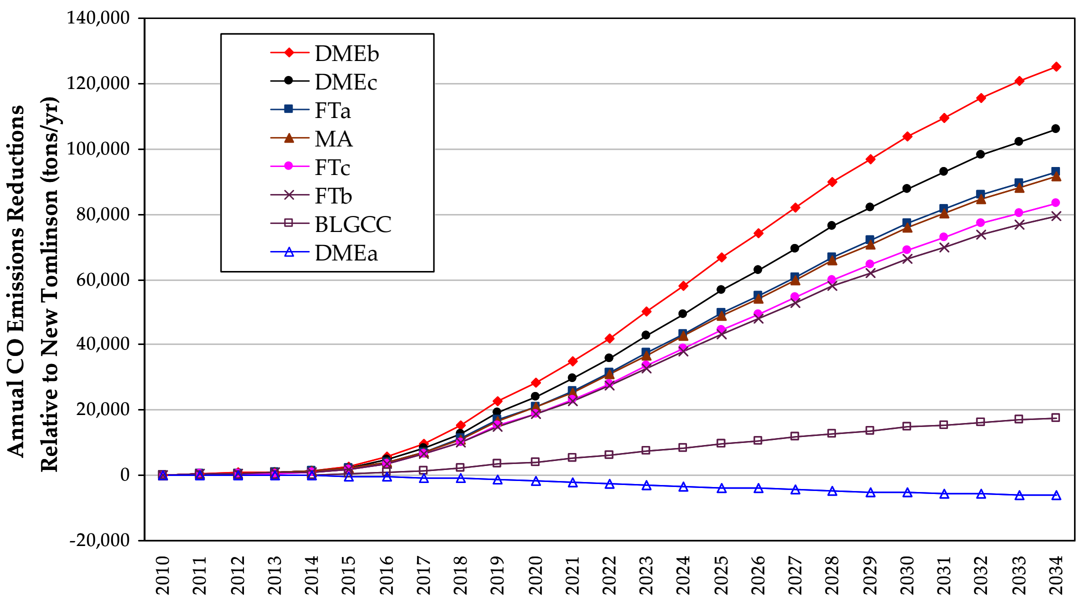
Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 25: Net CO emissions reductions (*Aggressive* market penetration scenario)



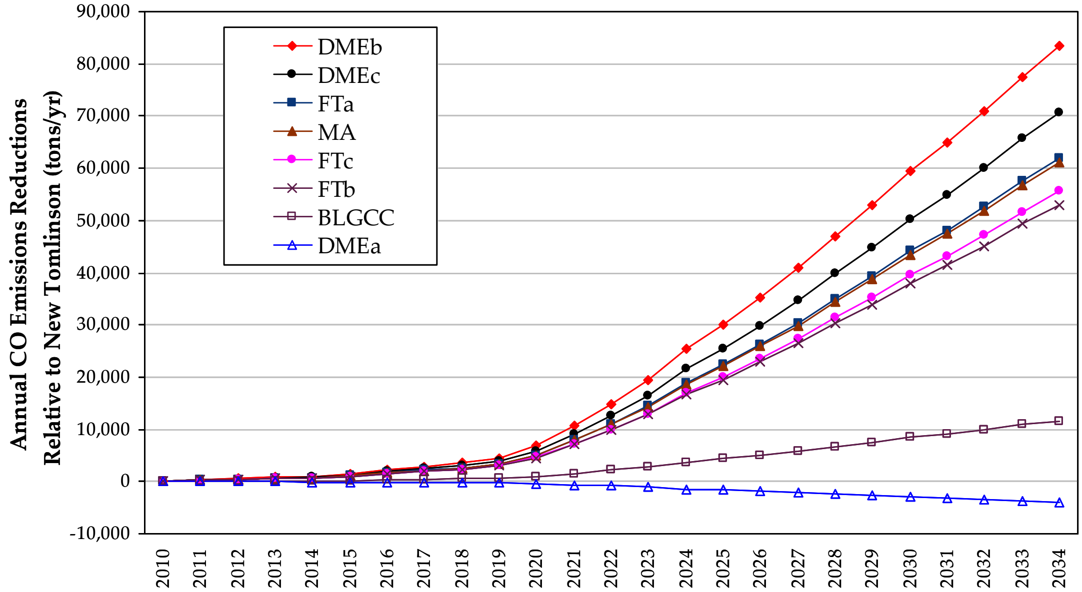
Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 26: Net CO emissions reductions (*Base* market penetration scenario)



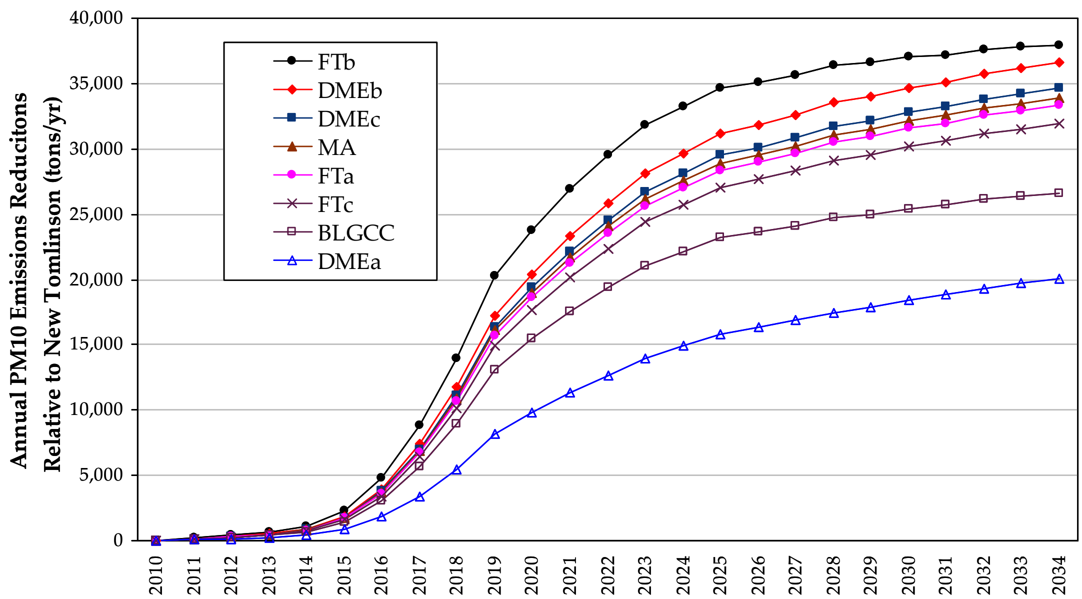
Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 27: Net CO emissions reductions (*Low* market penetration scenario)



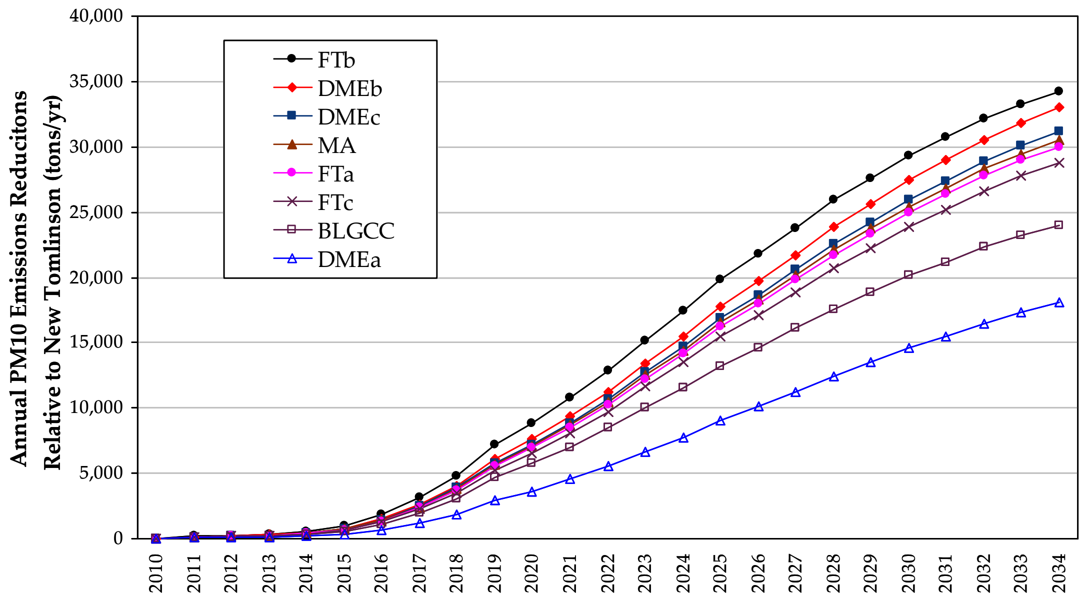
Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 28: Net PM10 emissions reductions (*Aggressive* market penetration scenario)



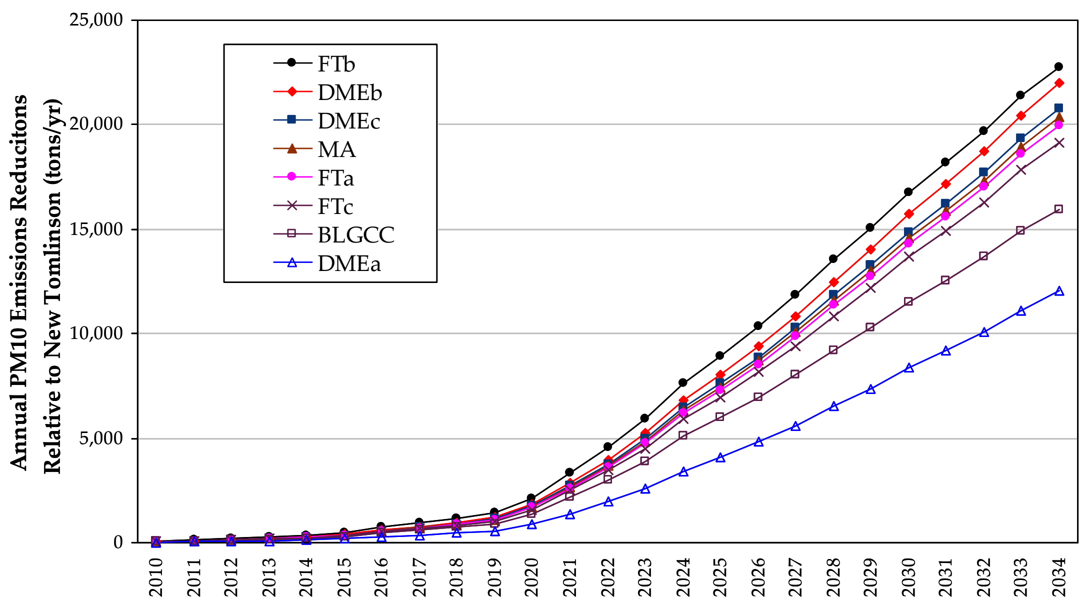
Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 29: PM10 emissions reductions (*Base* market penetration scenario)



Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

Figure 30: PM10 emissions reductions (*Low* market penetration scenario)



Transportation of the crude FT product to the oil refinery included in FT cases.
Note on vehicle end use: FT cases assume FT gasoline blend in gasoline engines and FT diesel blend in CIDI engines. MA case assumes low-level blend with gasoline.

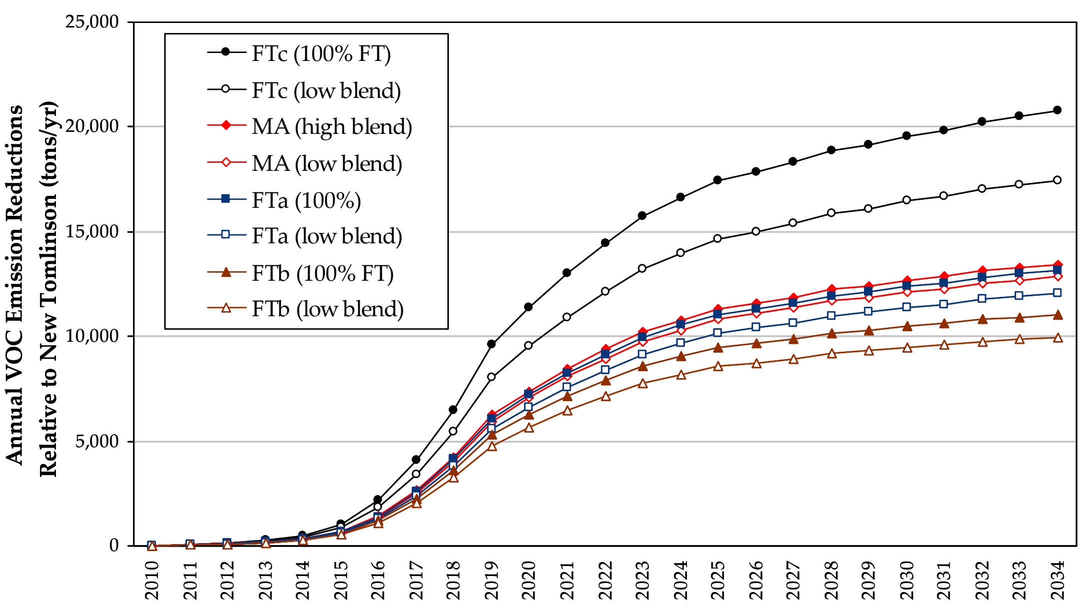
6.1 High Level/Low Level Blend Comparison

The preceding national impacts estimates assumed that mixed alcohols and FT biofuels were used in low-level blends with their conventional counterparts, specifically, a 10% blend of mixed alcohols with gasoline and a 10% blend of FT diesel with low-sulfur diesel. However, with some relatively minor engine and vehicle modifications (more so for alcohol fuels than FT fuels) these fuels can also be used in either high-level blends or as neat (100%) biofuels. If used in this manner, certain tailpipe emissions are expected to decrease. However, data are either limited or non-existent regarding light-duty vehicle performance. As discussed in Volume 1, based on a review of the literature, we made estimates of the reductions in certain tailpipe emissions when vehicles are optimized for biofuels usage. Our assumptions in this regard are summarized in Table 20 and Table 21. The major impacts are expected to be:

- VOC emissions: tailpipe VOCs may be further reduced when neat FT diesel is used instead of low-sulfur diesel. Also, evaporative VOC emissions should be lower when mixed alcohols are used in a flex fuel vehicle compared to gasoline vehicles.
- CO emissions: CO may be reduced when neat FT diesel is used instead of low-sulfur diesel.
- There would be modest reductions in SO_2 and possibly NO_x, but these are expected to be minimal.

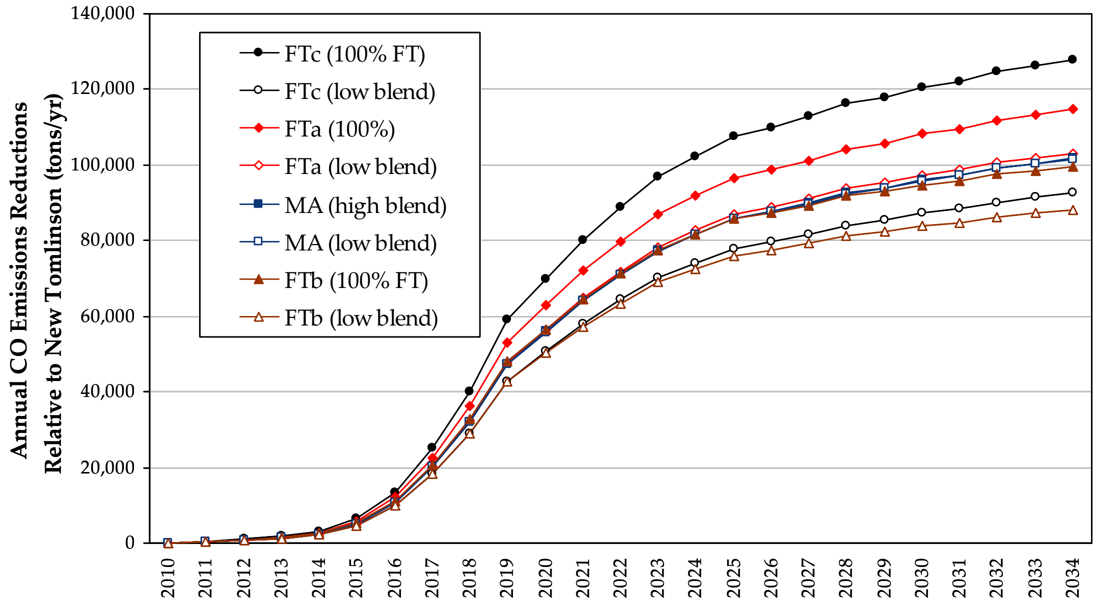
For the VOC and CO cases, the differences between the low-blend and high blend cases are given in Figure 31 and Figure 32. Only the *Aggressive* market penetration scenario is shown.

Figure 31: Net VOC emissions reductions comparing low-level and high-level blends of mixed alcohols and FT biofuels (*Aggressive* market penetration scenario)



Transportation of the crude FT product to the oil refinery included in FT cases.
Note: excludes any emissions from land use changes and biomass growth that are not related to harvesting and transportation.
Note on vehicle end use: FT cases assume FT gasoline used in SI engines and FT diesel in CIDI engines. "Low Blend" cases assumes 10% blend with conventional fuels, "high blend" assumes 85% blend of mixed alcohols with conventional gasoline.

Figure 32: Net CO emissions reductions comparing low-level and high-level blends of mixed alcohols and FT biofuels (*Aggressive* market penetration scenario)



Transportation of the crude FT product to the oil refinery included in FT cases.
Note: excludes any emissions from land use changes and biomass growth that are not related to harvesting and transportation.
Note on vehicle end use: FT cases assume FT gasoline used in SI engines and FT diesel in CIDI engines. "Low Blend" cases assumes 10% blend with conventional fuels, "high blend" assumes 85% blend of mixed alcohols with conventional gasoline.

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