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Well-to-Wheels Energy and Greenhouse Gas Emission Analysis of Bio-Blended High-Octane Fuels for High-Efficiency Engines

Appendix 5 – Capital Expansion Cases Study

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A5.1 Capital Expansion Methodology

Previous research has shown that for some cases of producing high octane bio-blended fuels, some refinery configuration models were not able to reach feasible solutions with the targeted specifications and market shares [1]. Other modeling cases reached feasible solutions but with compromise in refinery margins or economics. In these cases, some capital expansion might be needed to debottleneck the production constraints. Thus, this study examined capital investment options for increasing the economic feasibility of certain solutions. Note that these cases were not meant to optimize or reduce refinery CO2 emissions.

Although largely determined by existing individual configurations, the refinery locations (impacting crude slate options) and target product portfolios, capital expansion options might also differ between regions and at different times. Capital expansion options are also impacted by both global and domestic factors such as market conditions, economic cycles/business cycles, regulations, and so on. The capital analysis attempted to capture key drivers typically associated with capital spending, such as supply/demand of feedstock and products, high/low margin environment, cost of capital, process unit limitations, and so on. The analytical goal was to identify the practical choices for the potential future scenarios.

In addition to the refinery models constructed for PADD 2, PADD 3 and CA and for configurations (CRK, LtCOK, HvyCOK and COKHCK), we also investigated LP modeling of certain refinery configurations with capital expansion options for some fuels.

Capital expansion might benefit refinery cases in several ways:

- In the LP model, some E set or BR set fuels cannot be produced in 2022 in quantities to reach 50 vol% HOF market share. Capital expansion options to debottleneck refinery operation constraints could be investigated in order to yield feasible solutions for LP modeling for 2022.
- For some fuels, LP modeling yielded feasible solutions for 2022 with 50 vol% HOF, but infeasible solutions for 2040 with 100 vol% HOF share. Capital expansion options to debottleneck refinery operation constraints could be investigated in order to increase the HOF production for 2040.
- For some fuels, LP modeling yielded feasible solutions for both 2022 and 2040. However, given the importance of these fuels with their higher chance of adoption/prevalence, capital expansion options to seek broader production alternatives with potential economic improvement were investigated.

The third option above was selected for the current study, and high octane F14 and F18 were selected to be modeled with capital expansions. The LP modeling component blending values of the four major blend components — alkylate, light (Lt) reformate, heavy (Hvy) reformate, and FCC naphtha — are shown below. The combination of alkylate, reformate, and FCC naphtha constitutes about 80% of the total gasoline pool. More details are summarized in the Jacobs Consultancy report that documents their LP modeling efforts [2].

The LP modeling results indicate that the alkylate stream is the preferred component when incremental refinery-sourced octane is required. In the 2040 base case, before HOF production, alkylate has a value approximately 1.02 times that of unleaded regular gasoline (ULR) [2]. In the Fuel 14 and Fuel 18 cases, the value of alkylate grows to 1.05 and 1.1 times ULR, respectively, clearly showing the strongest growth. Light (Lt) reformate increases slightly, and heavy (hvy) reformate increases in the Fuel 14 case, but decreases in the Fuel 18 case. The high blending value of alkylate is consistent in all HOF cases. The use of high-octane reformate can be limited due to its high boiling range, which poses challenges to meeting distillation specifications. Consequently, alkylate is the focus for the investment analysis.

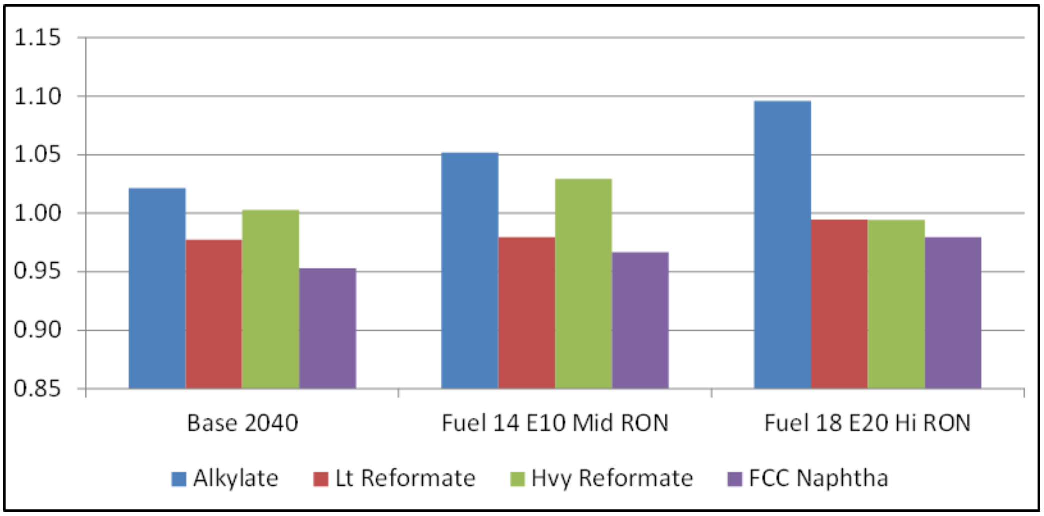

Figure A5-1. Approximate Relative Component Values Compared with Unleaded Regular Gasoline

Alkylate is produced via reacting isobutanes with light olefins (mainly C4 olefins, sometimes C3 olefins as well). In the refinery, these olefins are primarily produced from the fluidized catalytic cracking (FCC) unit, which typically generates 90% of alkylation feedstock. Generally speaking, the volume of alkylate produced is directly related to the FCC throughput. C3 alkylate is about 90 RON and C4 alkylate 96 RON, making C4 alkylate the choice to increase the octane balance.

If olefin feedstock is limiting alkylate production, a refiner could use a different catalyst additive to increase overall production of FCC liquefied petroleum gas (LPG), which includes C3/C4 olefins. Increasing FCC conversion can also increase LPG production, at the expense of gasoline yield. These two options will likely fall short to achieve for any significant increase in alkylation production. Thus, in the present study in order to increase alkylate production, a new butane dehydrogenation unit was added to convert butanes to C4 olefins to provide sufficient alkylate olefin feedstock. C4 dehydrogenation is our focus for the capital expansion study.

In the current LP modeling, both isobutene (IC4) and normal butane (NC4) were purchased to provide feedstocks for alkylation. This is consistent with current refinery practice. On balance, the U.S. refining industry is a net buyer of both IC4 and NC4. Both IC4 and NC4 production has grown in tandem with higher production of tight light oil (TLO) in recent years and should continue to track TLO production. Most refiners with pipeline access should have IC4 and NC4 availability. One capital expansion option for IC4 would be a Butamer™ unit, which converts NC4 into IC4, but this option is not considered for the current study.

The EIA projected reduction in G/D from 2015 to 2022 and from 2022 to 2040 has an interesting impact on FCC throughput. A reduction in gasoline production creates pressure to reduce FCC throughput; however, there is an incentive to run the unit (with higher conversion) for higher LPG production to feed the alkylation unit. This balance will be different for specific refiners.

Fuel 14 and Fuel 18 were selected for capital expansion studies. To model the capital expansion, we used PADD 3 cases in 2040. Capital investment was allowed for C4 dehydrogenation and alkylation, incremental IC4 and NC4 purchases were allowed, and optimizing the FCC unit on throughput and severity is allowed.

A5.2 LP Modeling of Selected Capital Expansion Cases

Two capital expansion cases, for producing Fuel 14 and Fuel 18 in PADD 3 in 2040, were developed. The modeling of F14 and F18 cases yield feasible solutions for most cases. Capital expansion cases were explored to improve the refinery operation for these cases. As summarized in the Jacobs report (Jenkins and DiVita, 2017), the alkylate stream was identified as the key and ideal component to boost the octane numbers of the gasoline pool. The capital expansion cases studied options and scenarios for dehydrogenating isobutane (purchased) to produce light olefins to feed alkylation units to increase alkylate yield. The cases studied for investment were done with the goal of improving the refinery operation on fuel cases previously deemed to be feasible without investment, not for seeking feasibility for the infeasible cases.

A5.2.1 Refinery Products

The refinery margins and products of F14 and F18 cases, before and after capital expansions, are shown in the table below. It is worth mentioning that although the capital expansion study was for F14 and F18 produced in PADD 3 refinery, the capital estimate cannot be carried out on the 8 million bpd aggregate PADD 3 refinery directly as the estimation methods and cost curves are developed for individual refineries. Thus, the capital expansion of F14 and F18 was carried out on “typical sized” refinery (150 MBPD) and then was normalized (re-scaled) to the PADD 3 refinery to estimate capital.

Table A5-1. Refinery Products of Capital Expansion Cases with F14 and F18 Production in PADD 3 in 2040

Products	F14	F14-Cap	F18	F18-Cap	F14 Relative Change	F18 Relative Change
LPG Produced	455,572	400,099	470,145	406,375	-12.2%	-13.6%
Finished Mogas	4,020,103	4,268,989	4,322,665	4,622,208	6.2%	6.9%
USA Mogas	3,024,404	3,024,404	3,024,404	3,024,404	0.0%	0.0%
USA Gasoline HOF	3,024,404	3,024,404	3,024,404	3,024,404	0.0%	0.0%
USA HOF CG	2,416,171	2,416,171	2,416,171	2,416,171	0.0%	0.0%
USA HOF RFG	608,233	608,233	608,233	608,233	0.0%	0.0%
Export Gasoline	995,700	1,244,586	1,298,261	1,597,805	25.0%	23.1%
Ethanol	302,440	302,440	604,881	604,881	0.0%	0.0%
Total Diesel	4,008,787	4,008,754	4,008,404	4,012,530	0.0%	0.1%
US Diesel	2,199,012	2,199,012	2,199,012	2,199,012	0.0%	0.0%
Export Diesel	1,809,774	1,809,741	1,809,392	1,813,518	0.0%	0.2%
Total Jet	1,012,926	1,012,926	1,012,926	1,012,926	0.0%	0.0%
Total Distillate	5,021,713	5,021,680	5,021,330	5,025,456	0.0%	0.1%
Heavies	496,585	496,585	496,585	506,738	0.0%	2.0%
Other Lights	536,067	521,326	536,067	521,326	-2.7%	-2.7%
Export Gasoline/Total	19.9%	22.6%	23.1%	25.7%	13.7%	11.2%

After capital expansionmost refinery product yields do not change, the few exceptions are shown in Table A5-2.

Table A5-2. Major Refinery Product Changes After Capital Expansions

Refinery Product	F14	F18
LPG	-12.2%	-13.6%
Finished Mogas	6.2%	6.9%
Export gasoline	25.0%	23.1%
Other lights	-2.7%	-2.7%

With the additional alkylate production (from dehydrogenating butanes to provide alkylation unit feedstocks), the gasoline yield increases, at the expense of LPG and other lights. Meanwhile, the export gasoline amount increases by 25% and 23% for F14 and F18, respectively.

A5.2.2 F14 and F18 Gasoline Component Changes After Capital Expansions

F14 and F18 alkylate content before and after capital expansions are compared in Table A5-3.

Table A5-3. F14 and F18 Alkylate Volume Before and After Capital Expansion (PADD 3, 2040)

Alkylate (bbl/day)	F14	F14-Cap	F18	F18-Cap	F14 Change	F18 Change
Domestic	499,049	642,787	459,971	506,501	28.8%	10.1%
Export	129,870	201,479	168,754	355,513	55.1%	110.7%
Total	628,919	844,266	628,725	862,014	34.2%	37.1%

For both F14 and F18 cases, the capital expansion is effective in boosting alkylate production (an increase of 34% for F14 and 37% for F18) with the addition of a dehydrogenation unit.

With the alkylate volume increase, the gasoline pool component distribution varies as well. The F14 and F18 gasoline component distribution, before and after the capital expansion to boost alkylate production, are shown in Figure A5-2 for both domestic gasoline and export gasoline.

For F14 and F18 gasoline, the capital expansion leads to an increased alkylate share in both domestic and export gasoline. For the domestic gasoline, the alkylate share increase is coupled with a decrease of reformate, and for the export gasoline with a decrease of naphtha. The results indicate that the additional capital for dehydrogenation can lead to a significant increase in the amount of valuable alkylate and decrease in the amount of less valuable naphtha.

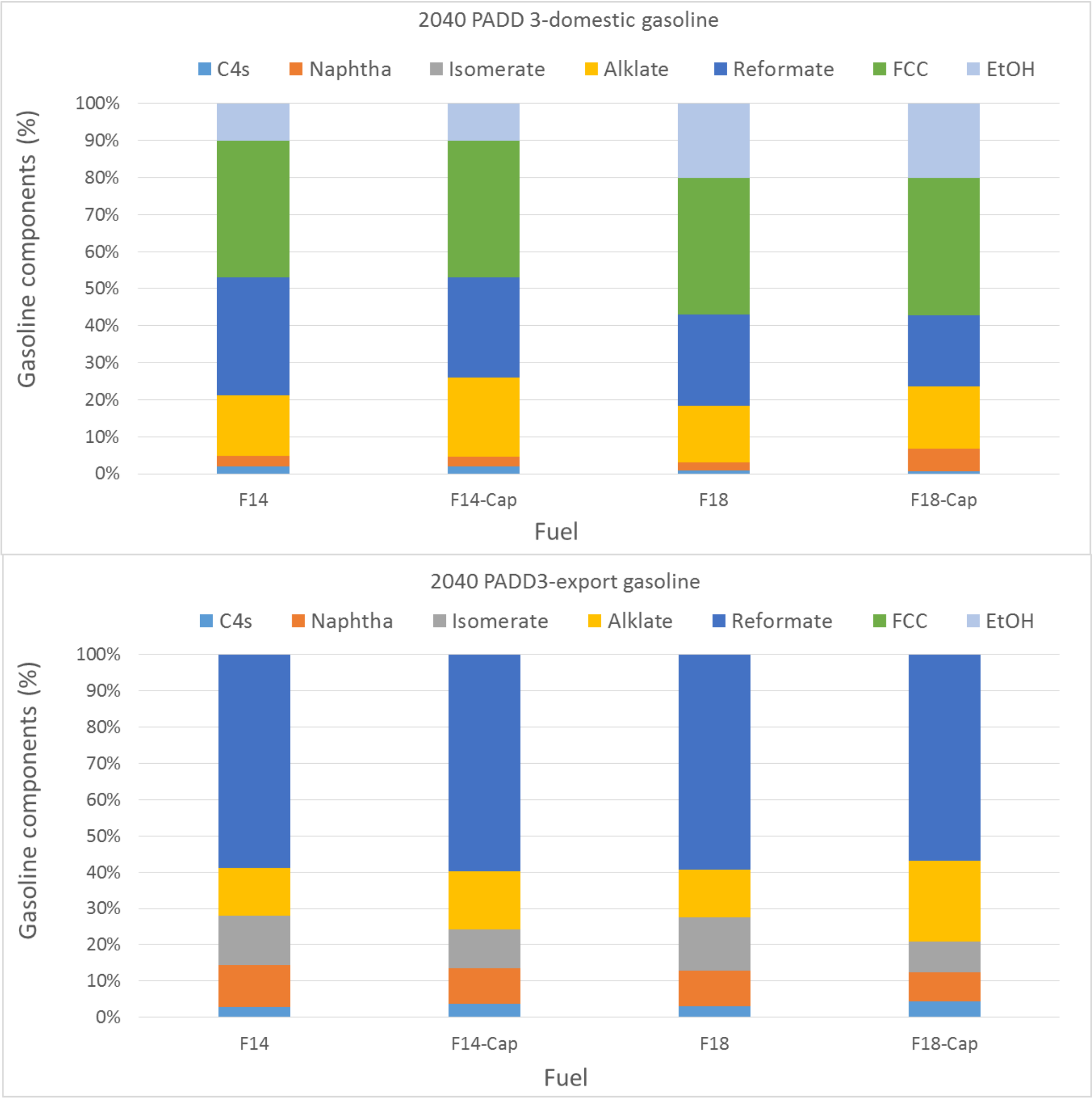

Figure A5-2. E Set Gasoline F14 and F 18 Components Before and After Capital Expansion

A5.2.3 Reformer Operations of F14 and F18 Gasoline with Capital Expansions

The reformate contribution of F14 and F18 fuels before and after the capital expansions are compared in Table A5-4.

Table A5-4. Reformer Operations of F14 and F18 Gasoline with Capital Expansion

Unit Operations	F14	F14-Cap	F18	F18-Cap	F14 Change	F18 Change
Total Reforming	1,898,020	1,897,628	1,843,048	1,792,462	-0.02%	-2.7%
Reforming Severity	94.6	93.3	93.4	92.4	-1.4%	-1.1%
1000Sev × BPD	179,557	177,074	172,119	165,558	-1.4%	-3.8%

As expected, for both F14 and F18 the capital expansions to increase alkylate production lead to the decrease of reformate contribution, in both volume and severity.

A5.2.4 Hydrogen Supply Change After Capital Expansion

The reduction of the reformate contribution after capital expansion leads to a reduction in hydrogen co-production from the reformer. Meanwhile, the hydrogen supply from the SMR, based on demand, also decreases slightly after the capital expansion. Overall, the hydrogen production and use in PADD 3 refineries with F14 and F18 production decreases 2.6% and 3.1%, respectively. See Table A5-5.

Table A5-5. The Hydrogen Supply for F14 and F18 Fuels Production in PADD 3 in 2040 Before and After Capital Expansion

Unit Operations	F14	F14-Cap	F18	F18-Cap	F14 Change	F18 Change
HYD SCF/BblCrude	626	610	623	604	-2.6%	-3.1%
Reformer HYD SCF/BblCrude	225	216	211	197	-3.9%	-6.6%
SMR HYD SCF/BblCrude	402	394	412	406	-2.0%	-1.3%

A5.3 Energy Intensity and Efficiency and Refinery and Gasoline Production

Capital expansion studies explored potential opportunities to improve economics and/or reduce the GHG emissions from E14 and E18 fuel production in 2040. The impact of such expansions on overall refinery energy intensity and efficiency, gasoline production intensity and efficiency, and gasoline production GHG emissions, are summarized below.

A5.3.1 Comparison of Overall Energy Efficiency of F14 and F18 Production Before and After Capital Expansion

As expected, for both Fuel 14 and Fuel 18, capital expansion leads to increases in butane input and electricity input and decreases in crude input, purchased H_2 input, and natural gasoline input. Adding up all the changes in energy inputs results in a net increase in total energy input per MJ of refinery products, or refinery intensity, as shown in Figure A5-3.

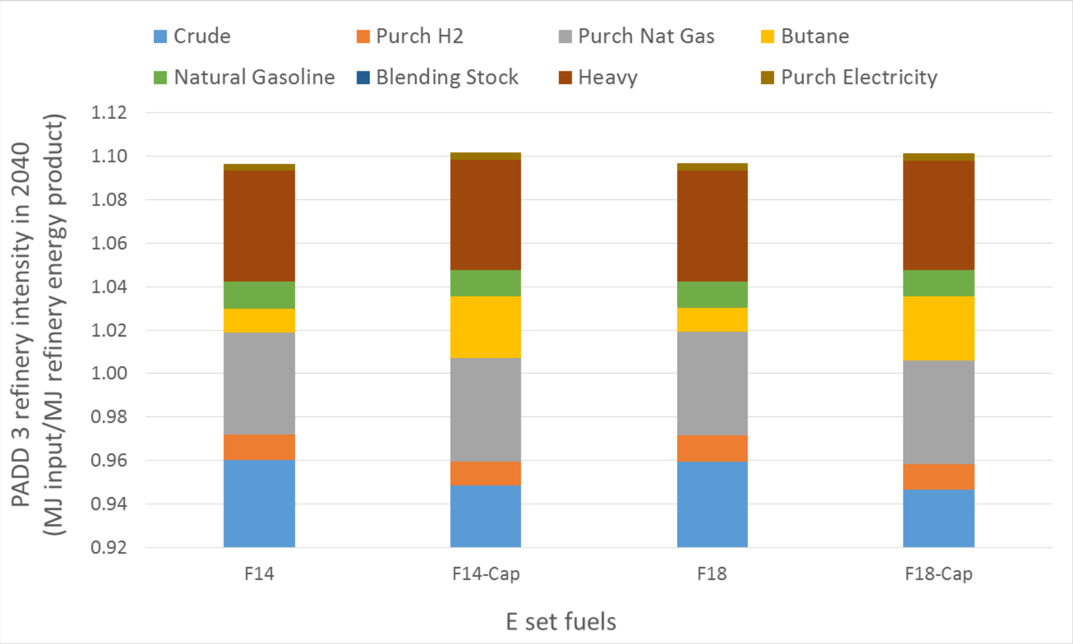

Figure A5-3. PADD 3 Refinery Intensity for F14 and F18 Production Before and After Capital Expansions in 2040

As noted, the reciprocal of energy intensity is refinery efficiency. Refinery efficiency for the production of Fuel 14 and Fuel 18 before and after capital expansion is shown in Figure A5-4.

For both E14 and E18 fuels, the capital expansion for higher alkylate production leads to lower refinery efficiency with new process addition.

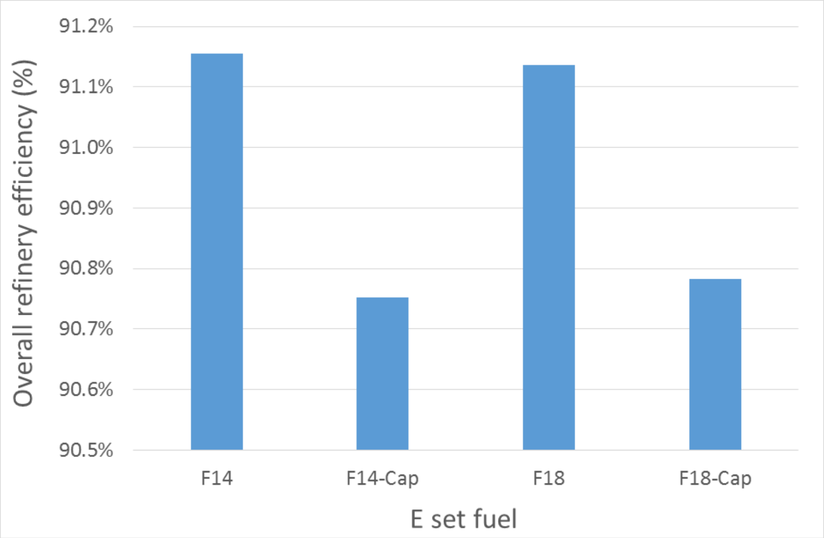

Figure A5-4. PADD 3 Refinery Energy Efficiency with the Production of E14 and F18 in 2040 Before and After Capital Expansions

A5.3.2 Comparison of E14 and E18 Gasoline Production Energy Efficiency Before and After Capital Expansion

The energy intensity of F14 and F18 gasoline production, before and after capital expansion, is shown in Figure A5-5.

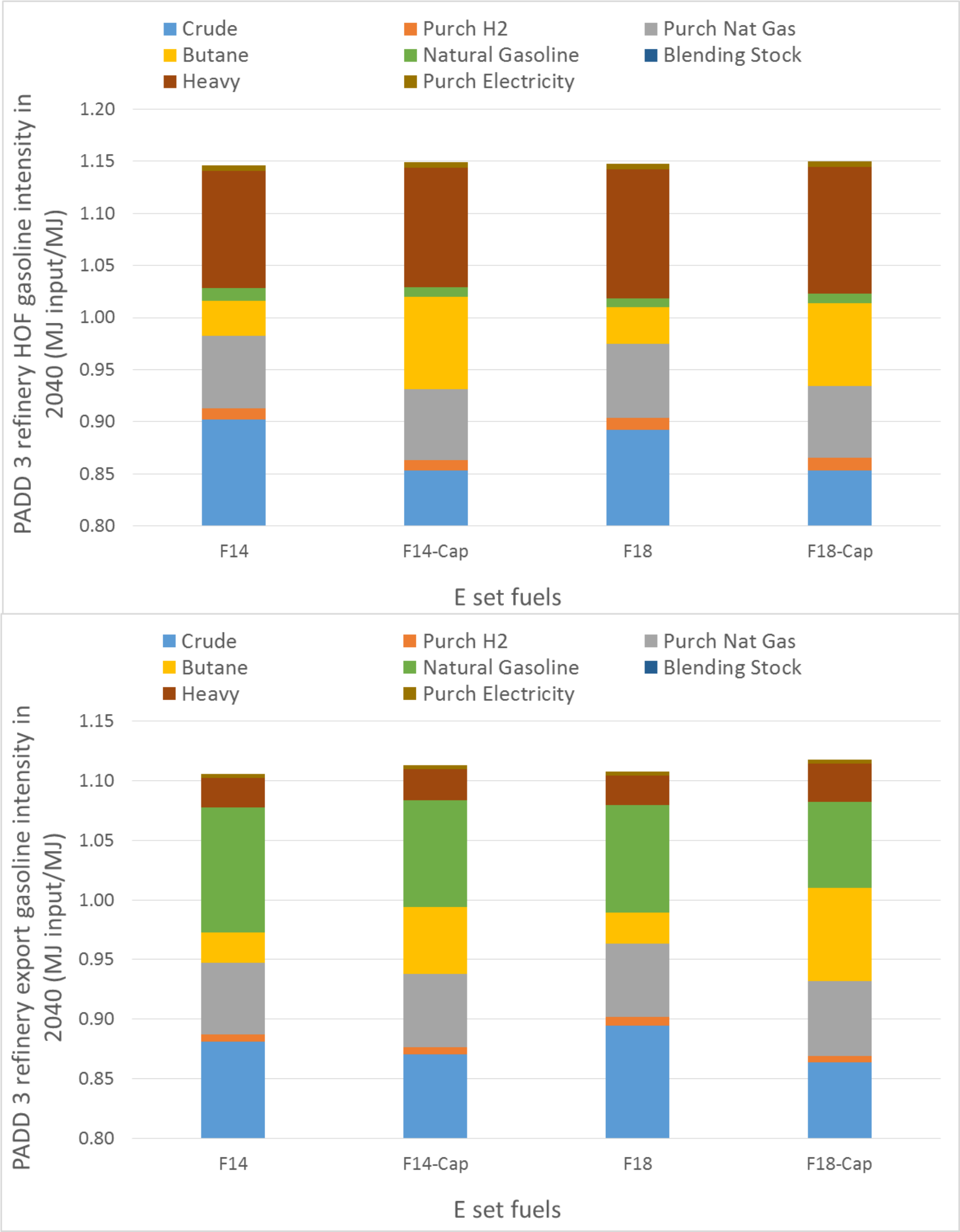

Figure A5-5. PADD 3 Refinery F14 and F18 Gasoline (BOB) Intensity Before and After Capital Expansions in 2040

As expected, the butane contribution to all gasoline pools increased after capital expansion. It is interesting to note that both F14 and F18 domestic gasoline, both before and after capital expansion, have major energy inputs from crude, heavy (unfinished oil purchased from other refineries) and natural gas, while export gasoline has major energy inputs from crude, natural gasoline and natural gas, shown in Figure above. It is also worth noting that for both F14 and F18 fuels, the export gasoline burden (GHG emissions) added to domestic fuels is zero, as the export gasolines have lower intensity than baselines have.

The gasoline production efficiencies for Fuel F14 and F18, both domestic gasoline and export gasoline, are shown in Figure A5-6.

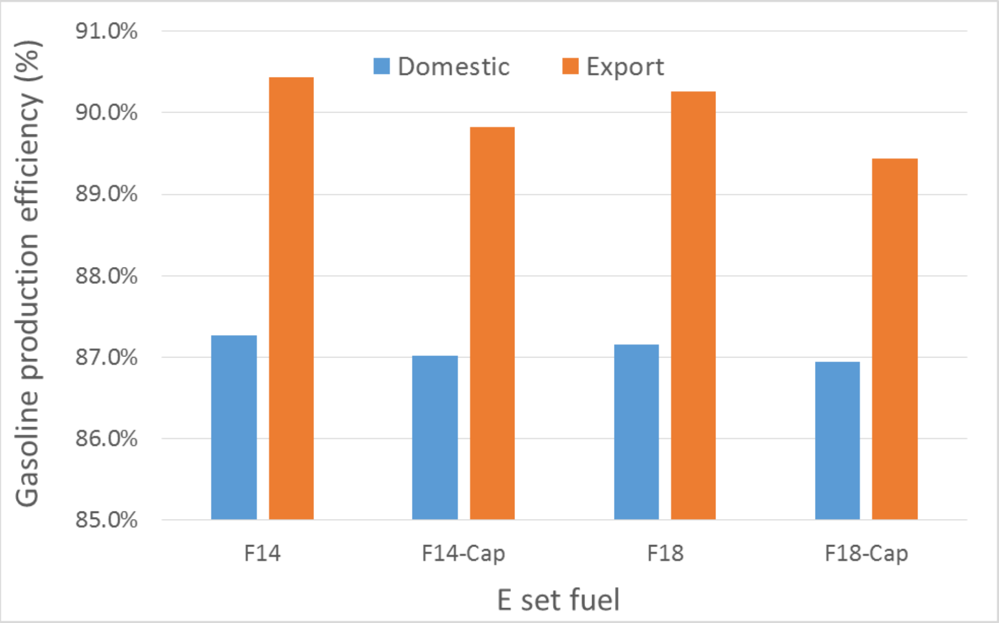

Figure A5-6. Domestic and Export Gasoline BOB Production Efficiency for Fuel F14 and F18 Produced in PADD 3 in 2040

A5.4 WTP Analysis of F14 and F18 Gasoline BOB Production with Capital Expansion

The WTP energy use and GHG emissions of E14 and E18 productions with capital expansion (for increasing alkylate yields) are shown in Figure A5-7 below.

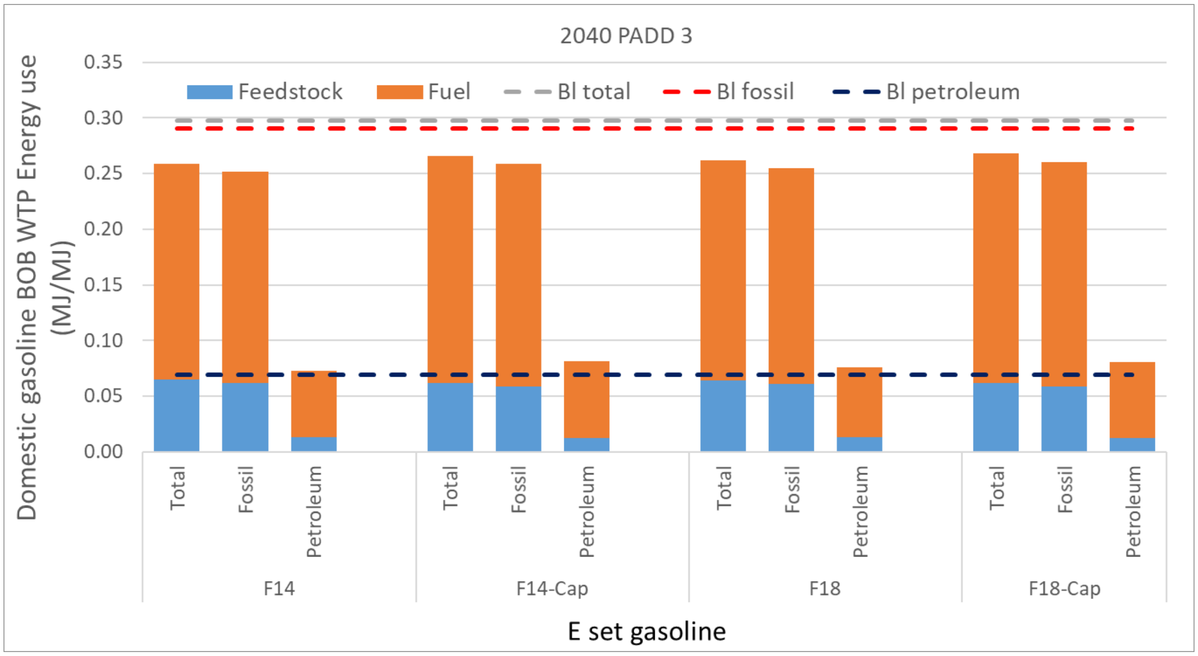

Figure A5-7. WTP Energy Use for F14 and F18 Domestic Gasoline BOB Production in PADD 3 in 2040 Before and After Capital Expansion

With capital expansion, both F14 and F18 show a slight increase in energy use, mostly from petroleum energy use. The petroleum energy use increase is mainly caused by the increase of butane input to feed the alkylation unit, based on the changes in the gasoline production energy intensity.

The WTP GHG emissions of F14 and F18 BOBs are shown in Figure A5-8 below.

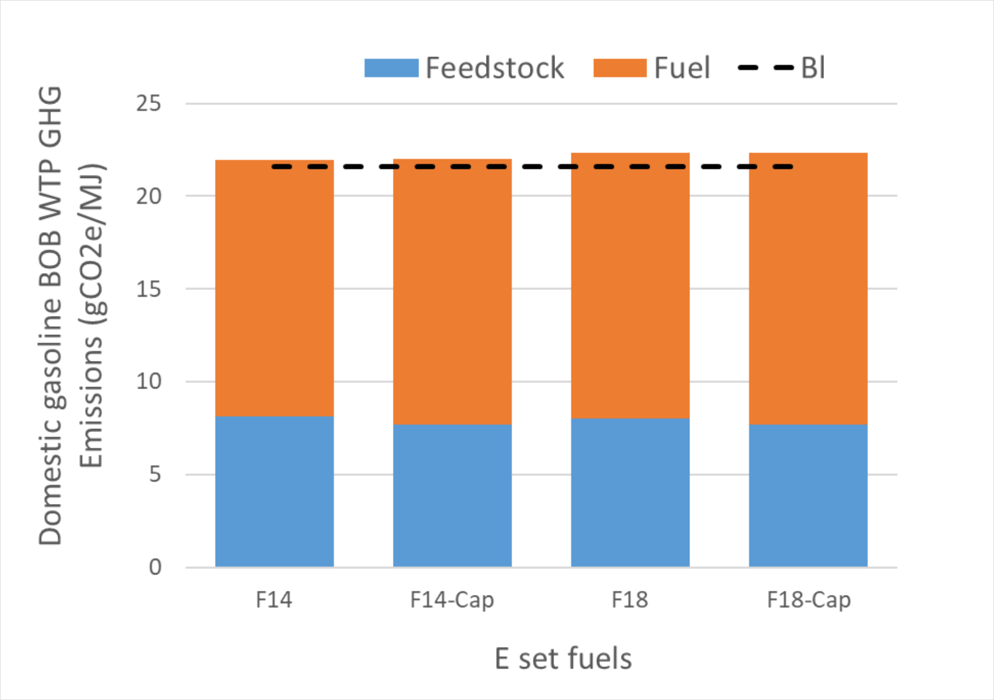

Figure A5-8. WTP GHG Emissions for F14 and F18 Domestic Gasoline BOB Production in PADD 3 in 2040 Before and After Capital Expansion

For F14 and F18 gasoline BOB production, the capital expansion resulted in slightly increased or almost negligible changes in GHG emissions.

To interpret how the capital expansion changes gasoline BOB GHG emissions, the WTP GHG emissions of BOB production are itemized in Table A5-6 with the individual impact of each GHG contributor.

Table A5-6. Breakdown of GHG Emissions for the PADD 3 Production of Fuel 14 and F18 Domestic Gasoline BOBs Before and After Capital Expansion

GHG Emission Contributions (g/MJ domestic gasoline BOB)	F14	F14-Cap	F14 Change	F18	F18-Cap	F18 Change
Crude recovery	8.11	7.67	-5.4%	8.02	7.67	-4.4%
Refinery fuel						
Residual oil	1.06	1.07	1.4%	1.17	1.14	-2.3%
Natural gas	0.52	0.49	-4.6%	0.50	0.49	-2.1%
Electricity	0.49	0.54	11.0%	0.50	0.56	11.4%
Hydrogen	0.90	0.84	-6.8%	0.97	1.02	5.1%
Butane	0.27	0.70	158.0%	0.29	0.64	121.3%
Intermediate combustion [1]	8.18	8.06	-1.5%	8.40	8.11	-3.5%
Non-combustion emission	0.34	0.33	-3.3%	0.35	0.38	6.3%
Gasoline T&D	0.43	0.43	0.0%	0.43	0.43	0.0%
WTP VOC/CO	0.09	0.09	1.4%	0.09	0.09	1.1%
WTP CH_4/N_2O	1.58	1.79	12.8%	1.63	1.80	10.4%
WTP GHG	21.96	22.02	0.2%	22.36	22.33	-0.1%
Total refinery fuel [2]	3.23	3.65	12.8%	3.43	3.85	12.3%

[1] Intermediate combustions refers to the combustion of FCC catalyst coke and refinery still gas for internal energy supply.

[2] Total refinery fuels refers to all the energy inputs for refinery processing as process fuels, including the items from residual oil to butane in the table.

The table shows that although there are negligible changes to total WTP GHG emissions to produce F14 and F18 domestic gasoline BOBs, the distribution of GHG emission contributions varies. As expected, the emissions from butane increased significantly (158% for F14 and 121% for Fuel 18) as more butane was purchased to produce olefins, via dehydrogenation, to feed the alkylation unit. Along with the increased GHG contribution from butane, the contribution from crude and natural gas decreases. It is worth noting that overall the contribution from butane is small, even after capital expansion.

Currently, in GREET 2016, butane is sourced from crude, and is estimated to account for as much as one third of gasoline GHG emissions during refinery operation. There is an alternative future scenario in which butane could come from natural gas liquid associated with natural gas production. The alternative scenario for butane source is not discussed here.

A5.5 WTP Analysis of Finished Gasolines for Capital Expansion Cases

The WTP energy uses and GHG emissions of F14 and F18 production after capital expansions are shown in the table below, and are compared to that before capital expansions.

Table A5-7. The WTP Energy Uses and GHG emissions of F14 and F18 Finished Gasoline, Before and After Capital Expansions

	Corn Starch				Corn Stover			
Fuel	Total Energy (MJ/MJ)	Fossil (MJ/MJ)	Petroleum (MJ/MJ)	GHG (g/MJ)	Total Energy (MJ/MJ)	Fossil (MJ/MJ)	Petroleum (MJ/MJ)	GHG (g/MJ)
F14	0.279	0.271	0.071	21.8	0.367	0.247	0.075	24.1
F14-Cap	0.285	0.277	0.079	21.8	0.374	0.254	0.083	24.2
F18	0.302	0.294	0.072	21.9	0.479	0.246	0.080	26.7
F18-Cap	0.307	0.299	0.076	21.9	0.485	0.251	0.084	26.7

For both F14 and F18, the capital expansion leads to slight increase in WTP energy use, for total energy, fossil energy and petroleum energy, with both corn starch ethanol and corn stover ethanol. As shown earlier, the capital expansion has very minor impact on the gasoline BOB WTP GHG emissions. As a result, the E14 and E18 domestic gasolines have about the same WTP GHG emissions before and after capital expansions, with ethanol from either corn stover or from corn starch.

A5.6 WTW Analysis of Capital Expansion Cases of F14 and F18 Produced in PADD 3 in 2040

A5.6.1 Comparison of WTW Energy Use and GHG Emissions of E14 and E18 Production Before and After Capital Expansion on MJ Basis

WTW energy use for F14 and F18 before and after capital expansion is compared in Table A5-8 below.

Table A5-8. F14 and F18 WTW Energy Use Before and After Capital Expansion

	Corn Starch (MJ/MJ)			Corn Stover (MJ/MJ)		
Fuel	Total Energy	Fossil	Petroleum	Total Energy	Fossil	Petroleum
F14	1.28	1.22	1.02	1.36	1.19	1.02
F14-Cap	1.28	1.22	1.03	1.37	1.20	1.03
F18	1.30	1.15	0.93	1.48	1.10	0.94
F18-Cap	1.31	1.16	0.93	1.48	1.11	0.94

For both Fuel 14 and Fuel 18, capital expansion leads to only minor changes in the use of total energy, fossil energy and petroleum energy. As noted earlier, although capital expansion leads to widespread changes in the use of inputs and fuels (e.g., butanes increase, electricity increase, crude decreases, etc.), the net results show minor changes. One possible reason is that in the GREET 2016 model, butane is sourced from crude based on current practice, so the redistribution between crude and butane leads to minor changes. In the future, if butane is sourced from natural gas liquid, the capital expansion might have a different impact on energy use and GHG emissions.

Fuel 14 and Fuel 18 GHG emissions are compared on an energy basis (per MJ), in Table A5-9.

Table A5-9. The WTW GHG Emissions of F14 and F18 in PADD 3 in 2040 Before and After Capital Expansion per MJ Basis

	Corn Starch		Corn Stover	
Fuel	g/MJ	Change Relative To Baseline Per MJ	g/MJ	Change Relative To Baseline Per MJ
F14	91.65	0.6%	89.38	0.6%
F14-Cap	91.70	0.6%	89.43	0.7%
F18	89.56	-1.7%	84.75	-4.6%
F18-Cap	89.53	-1.7%	84.73	-4.6%

The capital expansion has a minor impact on WTW GHG emissions. This is expected as capital expansion has shown a minor impact on the net WTP GHG emissions, although they result in noticeable changes in operations and fuel consumption across the refinery.

A5.6.2 Comparison of WTW GHG Emissions of F14 and F18 Gasoline Production and Energy Use Before and After Capital Expansion per Mile Basis

A comparison of F14 and F18 GHG emissions with three sets of assumed fuel economies, on a distance (per mile) basis is shown in Table A5-10, with three sets of assumed ON/CR fuel economies.

Table A5-10. The WTW Energy Use for F14 and F18 Domestic Gasolines in PADD 3 in 2040 Before and After Capital Expansion

	Ethanol	Corn Starch (MJ/Mile)						Corn Stover (MJ/Mile)					
E Fuel	Energy	3 ON/CR		3.7 ON/CR		5.6 ON/CR		3 ON/CR		3.7 ON/CR		5.6 ON/CR	
		WTP	PTW	WTP	PTW	WTP	PTW	WTP	PTW	WTP	PTW	WTP	PTW
F14	Total	0.95	3.41	0.96	3.43	0.96	3.46	1.25	3.41	1.26	3.43	1.27	3.46
	Fossil	0.92	3.17	0.93	3.19	0.94	3.22	0.84	3.17	0.85	3.19	0.86	3.22
	Petroleum	0.24	3.17	0.24	3.19	0.25	3.22	0.25	3.17	0.26	3.19	0.26	3.22
F14-Cap	Total	0.97	3.41	0.98	3.43	0.99	3.46	1.27	3.41	1.28	3.43	1.29	3.46
	Fossil	0.95	3.17	0.95	3.19	0.96	3.22	0.87	3.17	0.87	3.19	0.88	3.22
	Petroleum	0.27	3.17	0.27	3.19	0.27	3.22	0.28	3.17	0.29	3.19	0.29	3.22
F18	Total	1.01	3.33	1.01	3.35	1.02	3.40	1.60	3.33	1.61	3.35	1.63	3.40
	Fossil	0.98	2.86	0.98	2.88	1.00	2.92	0.82	2.86	0.82	2.88	0.83	2.92
	Petroleum	0.24	2.86	0.24	2.88	0.24	2.92	0.27	2.86	0.27	2.88	0.27	2.92
F18-Cap	Total	1.02	3.33	1.03	3.35	1.04	3.40	1.61	3.33	1.63	3.35	1.65	3.40
	Fossil	0.99	2.86	1.00	2.88	1.01	2.92	0.84	2.86	0.84	2.88	0.85	2.92
	Petroleum	0.25	2.86	0.25	2.88	0.26	2.92	0.28	2.86	0.28	2.88	0.28	2.92

Energy use after capital expansion is very similar to the cases without capital expansion (see main report). Capital expansion also has minimal impact on GHG emissions, as shown in Table A5-11 and Figure A5-9.

Table A5-11. The WTW GHG Emissions of F14 and F18 in PADD 3 in 2040 Before and After Capital Expansion per Mile Basis

E Set Fuel	Corn Starch (g/mile)			Corn Stover (g/mile)		
ON/CR	3 ON/CR	3.7 ON/CR	5.6 ON/CR	3 ON/CR	3.7 ON/CR	5.6 ON/CR
F14	313.0	315.0	317.6	304.9	306.8	309.3
F14-Cap	313.2	315.2	317.7	305.1	307.0	309.5
F18	298.3	300.4	304.1	282.4	284.3	287.8
F18-Cap	298.3	300.4	304.0	282.3	284.3	287.7

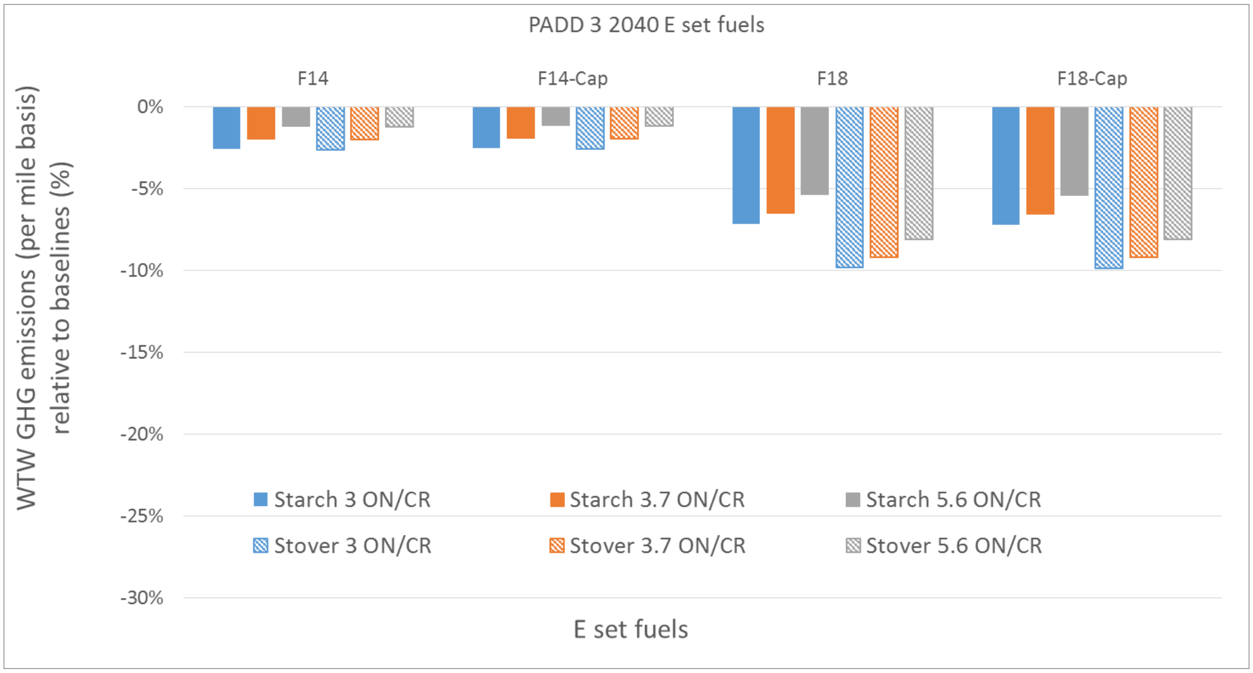

Figure A5-9. F14 and F18 GHG Emissions Relative to Baseline Before and After Capital Expansion per Mile Basis

The different ON/CR assumption has a minor or negligible impact on F14 and F18 WTW GHG emissions of about 2-4 g/mile, or about 1%.

Conclusion

A couple of capital expansion cases were carried out for F14 and F18 gasolines in PADD 3 in 2040 to seek production alternatives. Capitals were expended to add a dehydrogenation unit to produce olefins for feeding alkylation unit. As a result, the refinery alkylate production increased significantly. However, this change has negligible impact on F14 and F18 domestic gasoline WTW energy uses and GHG emissions.

References

[1] Han, J., M.Q. Wang, A. Elgowainy, and V.B. DiVita. *Well-to-Wheels Greenhouse Gas Emission Analysis of High-Octane Fuels with Ethanol Blending: Phase II Analysis with Refinery Investment Options*, Report ANL/ESD-16/09. Argonne National Laboratory, Argonne, IL (2016).

[2] Jenkins, J. (Jacobs Consultancy), and V. DiVita (Jacobs Consultancy). Refinery Modeling for Argonne National Laboratory. (November 2017). https://greet.es.anl.gov/publication-refinery_anl.