Electronic Supplementary Material (ESI) for Energy & Environmental Science.

Supplementary Information for *Energy, Economic, and Environmental Benefits Assessment of Co-Optimized Engines and Bio-Blendstocks*

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Additional Information on the Biomass Scenario Model

The Biomass Scenario Model (BSM) uses a modular architecture, such that major components (feedstock supply and logistics, multiple feedstock conversion options, and downstream elements) can be simulated in isolation or in combination with other components. The modules that comprise the feedstock supply and logistics sector capture the production of bioenergy and commodity crops through farmer decision-making, land allocation dynamics, and new agricultural practices, markets, and prices; they also track costs associated with harvesting, collection, storage, preprocessing, and transportation of feedstocks. The feedstock conversion modules capture investment and operation of various conversion pathways, including algae, oil crops, renewable hydrocarbons, corn-grain ethanol, and cellulosic ethanol. The model represents multiple conversion platforms at three production scales; however, each platform can be included or excluded in model simulations. For this analysis, the E17, furan mixture, and isopropanol were each run as separate simulations, with non-related pathways also available to be developed. Biofuel produced during conversion was then distributed and consumed as finished fuel, blended with E10 (gradually replaced by E15 over time).

Additional Information on the Automotive Deployment Options Projection Tool (ADOPT)

ADOPT uses techniques from the multinomial logit method and the mixed logit method to estimate vehicle sales. Specifically, it estimates sales based on the weighted value of key attributes including vehicle price, fuel cost, acceleration, range and usable volume. The average importance of several attributes changes nonlinearly across its range and changes with income. For several attributes, a distribution of importance around the average value can be used to represent consumer heterogeneity. The majority of existing vehicle makes, models, and trims are included to fully represent the market. It captures the influence of federal regulations and incentives. ADOPT has been extensively validated with historical sales data. It matches in key dimensions including the distribution of sales by fuel economy, acceleration, price, vehicle size class, and powertrain across multiple years.

ADOPT has been posted online (https://www.nrel.gov/transportation/adopt.html) with two standard scenarios. It has a Low Technology scenario, which assumes a lower level of advanced vehicle technology research. And it includes a High Technology scenario, which estimates the impact from achieving the DOE’s VTO technical targets. These targets capture price, mass, and efficiency improvements for vehicle components including the battery, electric motor, engine, fuel cell, and hydrogen storage. ADOPT currently estimates a significant increase in vehicle electrification from achieving the High Technology technical targets, as shown in Figure 1. The extensive list of input assumptions can be found in the user interface by downloading ADOPT 2019.

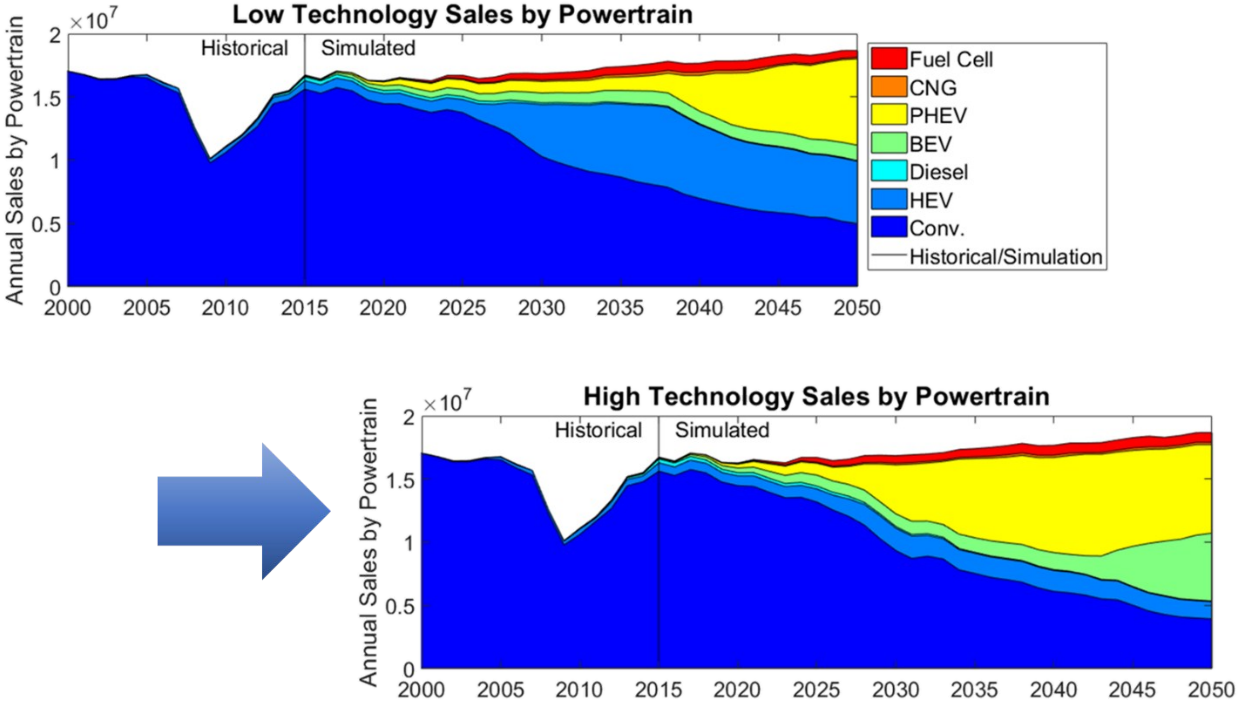

Figure 1. Online default ADOPT 2019 results.

Business-as-Usual Scenario Description

Analysis was conducted using the BSM in conjunction with ADOPT. In these simulations, ADOPT was used to generate vehicle sales estimates over time. These vehicle sales estimates were then incorporated into the BSM framework and used to drive demands for fuel, and biofuel industry development. To facilitate evaluation of blended biofuel and petroleum cases, we defined a set of baseline model conditions and background assumptions. These were used both in a business-as-usual (BAU) scenario and in the blended fuel cases, with the blended fuel cases differing from the BAU only in the availability of co-optimized fuel and vehicles.

The oil price trajectory from the 2017 Annual Energy Outlook (AEO) reference case[1] is used as a baseline in both the BSM and ADOPT. Additionally, ADOPT uses the AEO 2017 projection for overall vehicle sales. Other ADOPT-specific baseline conditions include the following:

- Corporate Average Fuel Economy (CAFE) standards are in place, and
- Federal electric vehicle incentives are consistent with current law, phasing out after 200,000 sales per manufacturer.

It is important to provide some information about how ADOPT evolves the vehicle fleet. In the BAU case results, for example, the best-selling PHEV's nominal price in 2026 is $35,500, compared to the best-selling conventional vehicle's $28,500. The conventional vehicle's price advantage was reduced by applying incentives and penalties to meet the CAFE and greenhouse gas (GHG) standards. These incentives and penalties were applied proportionally to how much a vehicle exceeds or falls short of these standards. Thus, the PHEV price was reduced by $3,200 while the price of the conventional vehicle was increased by $500. The PHEV then remains at just over a $3,000 price disadvantage. The PHEV, which runs on low-cost electricity most of the time, has half the fuel cost at 6 cents per mile compared to the conventional vehicle's (internal combustion engine, light duty) 13 cents per mile. This operating cost advantage is viewed by most vehicle consumers in ADOPT to be worth the extra initial cost, tipping the best-selling powertrain to a PHEV. The best-selling PHEV also provides slightly better acceleration, providing additional market benefit. With the PHEV powertrain becoming the best-seller, ADOPT starts creating additional PHEV options and, as a result, PHEV market shares increase more rapidly.

Within the BSM, development of corn and cellulosic ethanol as well as biofuels from cellulosic and oil-based feedstocks can occur under favorable market conditions. In all the simulations, we assume that policies such as the U.S. Department of Agriculture's Biofuels Infrastructure Partnership[2] will support increased usage of E15; therefore, we assume a linear increase in E15 adoption, from 1% of fuel use in 2010 to 60% of fuel use in 2050. Co-optimized vehicles are assumed to be compatible with E10–15 fuels (although with lower efficiency), and we assume that owners of these vehicles will substitute E10–15 fuels for the fuels that enable increased fuel economy at large price differentials.*

Other currently active policies incorporated in the BSM include the Renewable Fuel Standard,[3] the Low Carbon Fuel Standard[4] (in the Pacific Coast states), and the Biomass Crop Assistance Program.[5]

Additional Information on Sensitivity Analyses

The BSM provides a representation of the supply chain associated with biofuel industry development in the U.S. The overall model structure and model inputs are described in other publications,[6–8] and "downstream" stages of the supply chain associated with fuel distribution and dispensing are addressed by Johnson et al.[9] and Vimmerstedt et al.[10] A large-scale sensitivity analysis of the BSM is described in Inman et al.[11] In this section, we focus on the sensitivity of selected input parameters in the BSM as they relate to isopropanol. These include parameters associated with investment risk, with fuel price sensitivity, and with carbon taxes.

In the isopropanol base case, we assume that conversion facilities are constructed and that dispensing-station tankage and equipment are acquired to meet projected fuel demand. It is also possible in the BSM to use a net present value (NPV) metric to drive investment in conversion facilities based on financial considerations. One important input to the NPV metric is the required or target rate of return (RoR) for investors, which reflects the risk associated with the potential investment in a conversion facility.

In sensitivity cases, we compared the base case to four NPV-driven cases (Figure S-1):

- a dynamic relationship, in which the required RoR declines as a function of industry development;
- an assumed constant required RoR of 10%;
- an assumed constant required RoR of 30%; and
- an assumed constant required RoR of 50%.

With a constant 50% required RoR, the biofuel industry that produces the biomass-derived portion of the fuel economy-enhancing blended fuel never takes off. With a 30% required RoR, there is instability in the growth trajectory during the period from 2038 to 2043. Simulations with a 10% required RoR and with a dynamic required RoR based on industry maturity also show instability relative to the base case, but this instability is limited to the period from 2042 to 2046.

These results suggest that efforts to reduce investment risk are important to facilitate early industry growth, but to the extent that the required RoR is dependent on industry development, risk-reduction initiatives may be less important in the longer term.

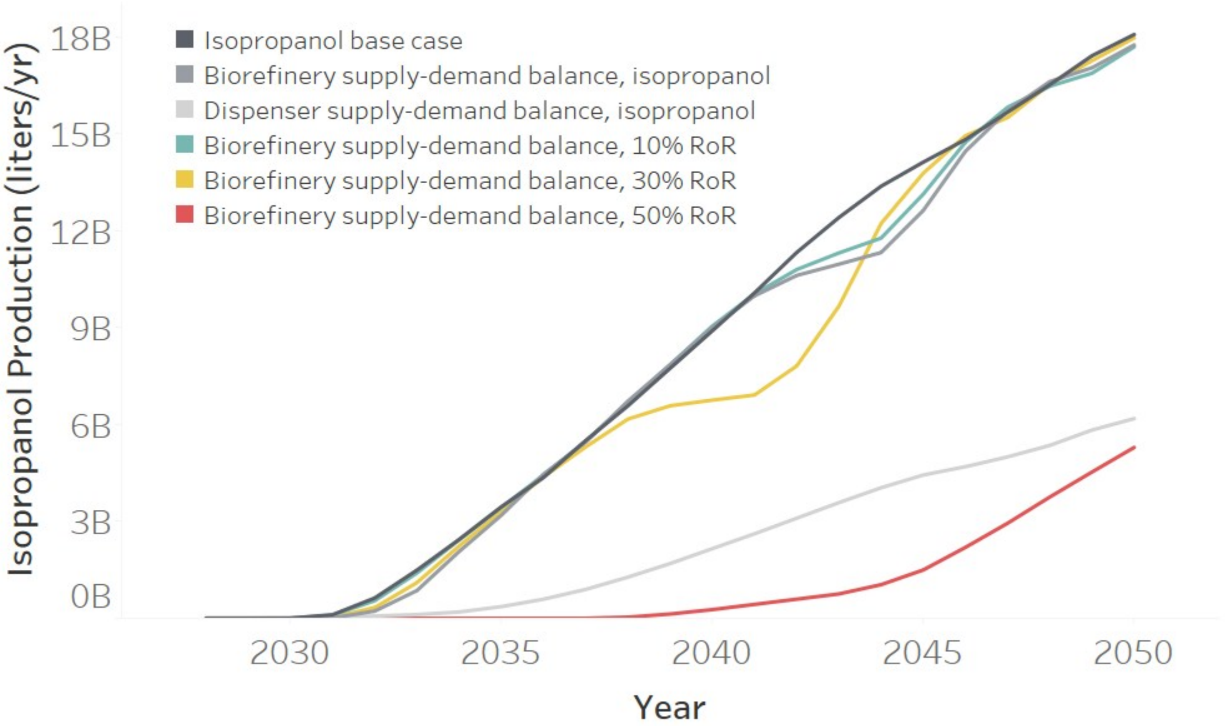

Figure S-1. Isopropanol production (2025–2050) with different assumptions about biorefinery investor rate of return (colored lines) in comparison with the base case, biorefinery supply-demand balance, and dispenser supply-demand balance (gray lines).

In the co-optimized fuel and vehicle simulations, we assume that vehicles are capable of using either the co-optimized fuel or E10–15 fuel, and that co-optimized vehicle owners will substitute E10–15 for the co-optimized fuel at large price differentials (see footnote above). To test system responsiveness to this assumption, we increased price sensitivity by 50% such that substitution would occur at lower price differentials between the two fuels (Figure S-2). Isopropanol production is decreased relative to the isopropanol base case, but only by roughly 14% in the final year of the simulation.

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[*] E.g., if the price of the blended fuel is triple the price of E10–15, only around 1% of co-optimized vehicle owners will pay for the blended, fuel economy-enhancing fuel. If the price is double, around 20% will fuel up with the blended fuel.

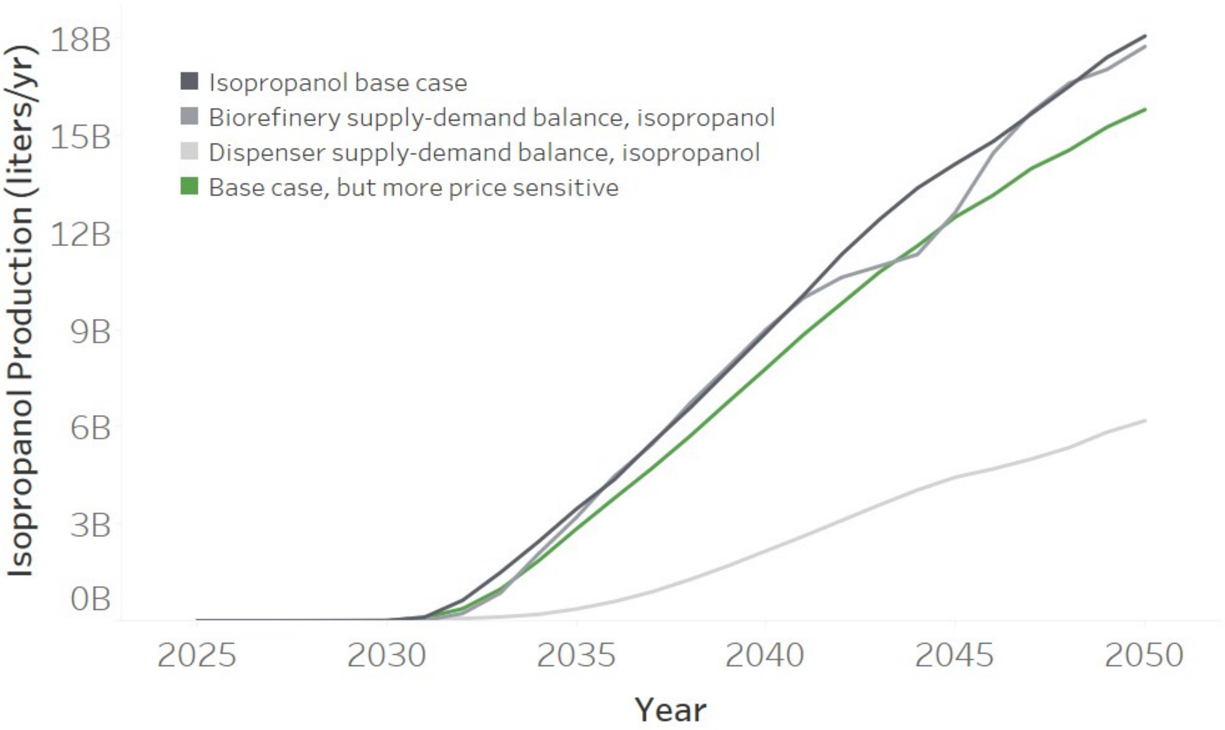

Figure S-2. Isopropanol production (2025–2050) with different assumptions about the price sensitivity of consumers (green line) in comparison with the base case, biorefinery supply-demand balance, and dispenser supply-demand balance (gray lines).

Carbon taxes and the LCFS have the potential to impact biofuel production by affecting the cost/price of biofuels relative to other fuel options. This in turn affects the price of the blended fuels that we included in our analysis. Here, we compared a broad set of options:

- isopropanol base case
- NPV-driven investment in isopropanol conversion in which the required RoR declines as the industry matures,
  - …without any incentives;
  - …with a constant \$50/tonne carbon tax;
  - …with a constant \$100/tonne carbon tax; and
  - …with a constant \$150/tonne LCFS credit (compares with baseline of \$90/tonne).
- NPV-driven investment in dispensing equipment,
  - …without any incentives; and
  - …with a constant \$100/tonne carbon tax.

Figure S-3 shows the results of these tests. Initiatives focused on conversion do not appear to result in substantial changes in isopropanol production until the last five years of the simulation. On the other hand, because the carbon tax acts to lower the relative biofuel price, it increases the attractiveness of investment to station owners and thus facilitates investment relative to a no-incentive case.

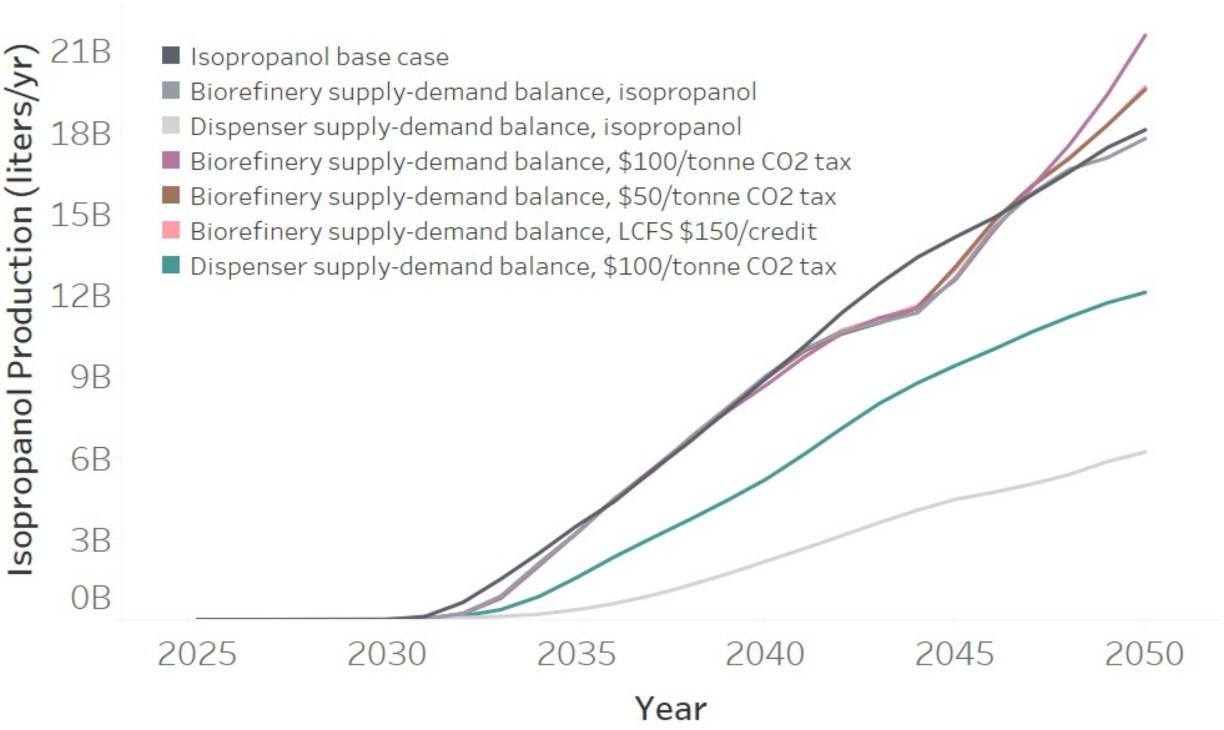

Figure S-3. Isopropanol production (2025–2050) with different assumptions about carbon policies in the biorefinery supply-demand balance and dispenser supply-demand balance cases (colored lines) in comparison with the base case, biorefinery supply-demand balance, and dispenser supply-demand balance (gray lines).

Additional Information on Life-cycle GHG Emission Intensities, Water Consumption Intensities, and $PM_{2.5}$ Emission Intensities of a Variety of Fuels Modeled with Bioeconomy AGE

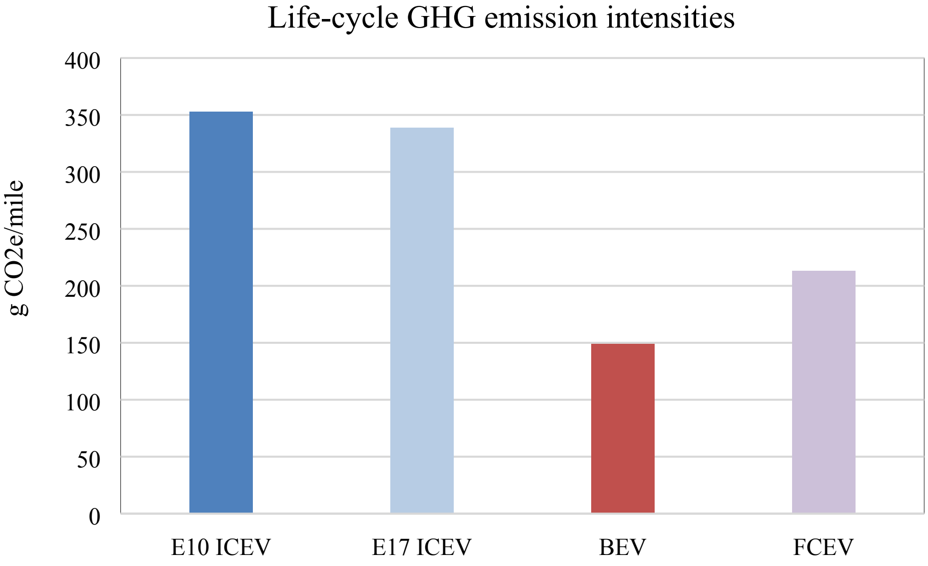

Figure S-4. Life-cycle GHG emission intensities, in g CO_2e/mile, of BEV and FCEV, compared to E10 ICEV

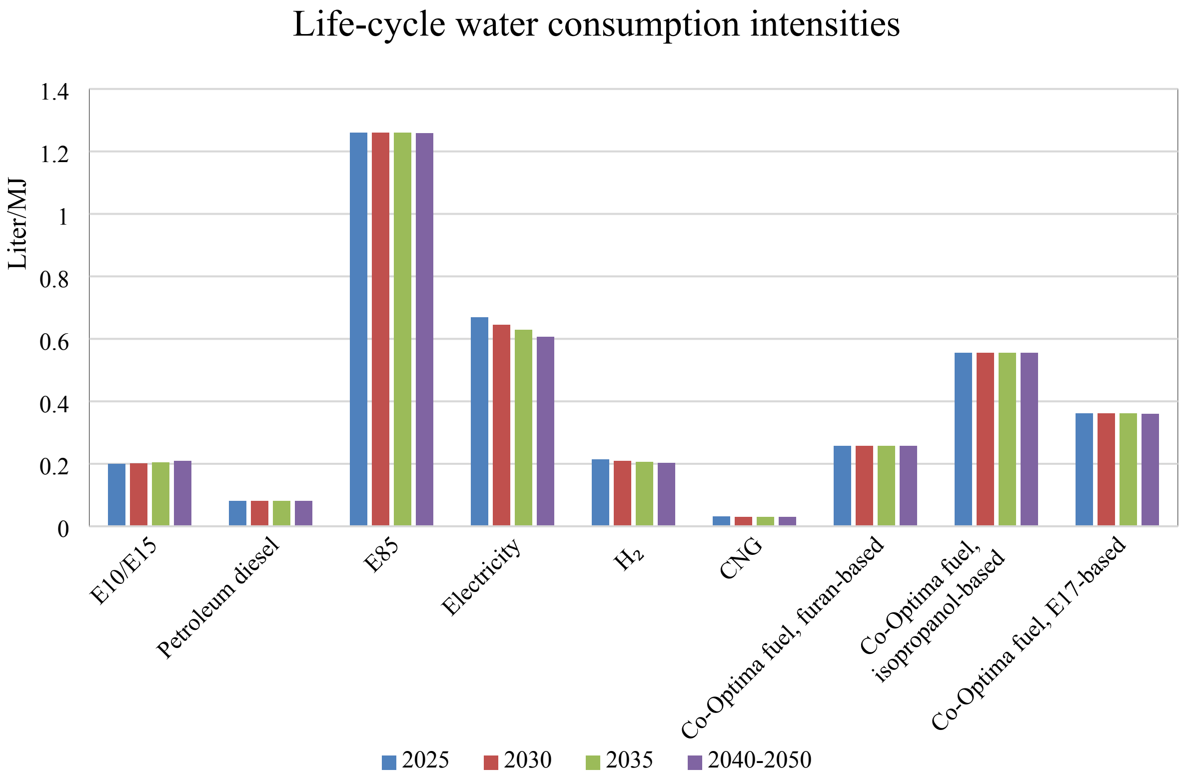

Figure S-5. Life-cycle water consumption intensities, in gal/MMBtu, of major fuels in 2025–2050.

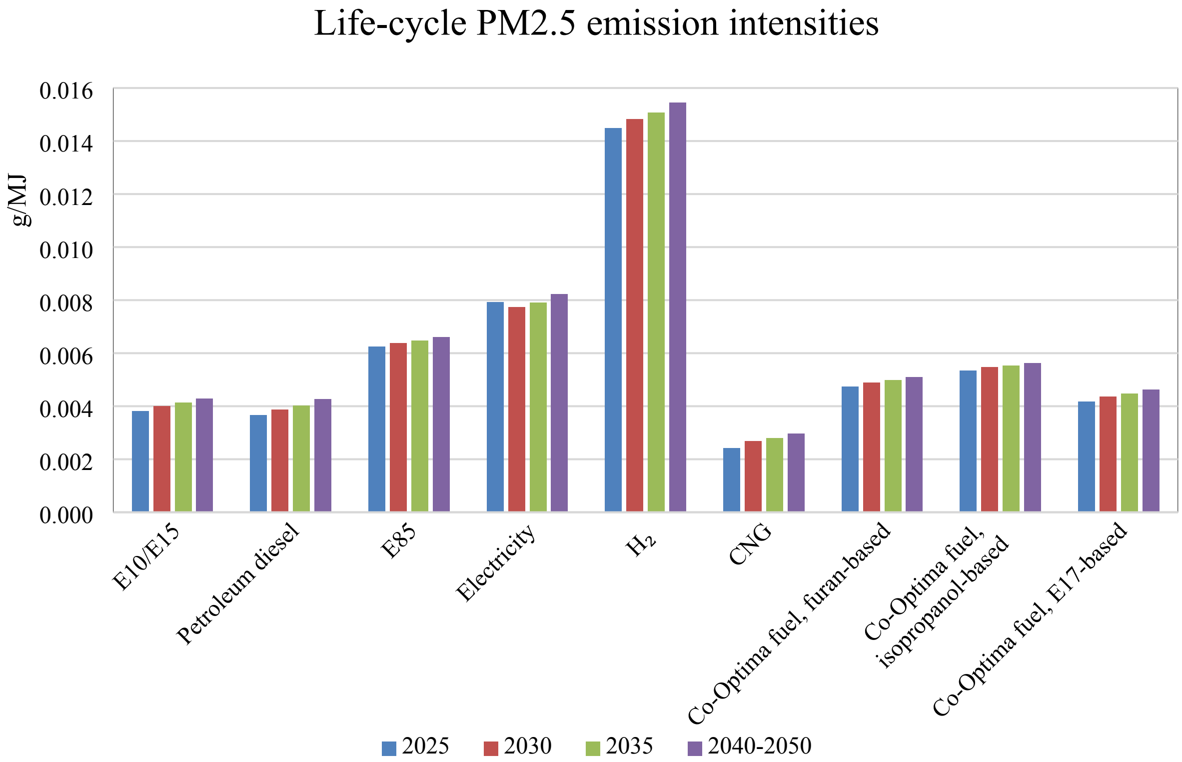

Figure S-6. Life-cycle $PM_{2.5}$ emission intensities, in g/MMBtu, of major fuels in 2025–2050.

Additional Information on Estimation of the Job Impacts on the Petroleum Industry

We use gasoline consumption estimates from NREL's Biomass Scenario Model (BSM), along with results from our model, to estimate how changes in domestic gasoline consumption affect employment in the U.S. petroleum sector. Our model utilizes regression analysis to link changes in U.S. gasoline consumption and employment in the petroleum sector through changes in domestic petroleum production. We utilize this two-step process to ensure that our estimates are in line with previous results. Our results suggest that the slight decrease in gasoline consumption in the scenarios we examined herein will have little to no impact on employment in the U.S. petroleum sector.

Our analysis estimates how domestic gasoline consumption affects U.S. petroleum production and how these changes in production affect the different types of employment represented by four NAICS codes. Upstream companies are represented by NAICS code 211, which includes jobs associated with oil and gas extraction. Contracted employees who assist in extraction are represented by NAICS code 213. Midstream companies are responsible for transporting and storing the crude oil before refining and are reflected in NAICS code 486.* Lastly, downstream companies focus primarily on refining the crude oil and distributing its byproducts. Employment in petroleum refineries and manufacturing is included in NAICS code 324.

Literature Review

Some studies have estimated the relationship between gasoline consumption and petroleum employment using crude oil price. Observational studies show that declines in crude oil prices seem to negatively impact upstream companies, primarily those involved in the exploration and mining phase, and benefit downstream companies which can now purchase crude oil at a lower price.[12,13] These observations are supported through data analysis provided by Brown and Yucel[14] , who used linear regression analysis to calculate the elasticity of types of petroleum employment and crude oil price. Their findings are in line with the idea that increases in crude oil price are beneficial to downstream companies and harmful to upstream ones. The elasticities they calculate for both are inelastic, meaning the percent change of employment will be smaller than the percent change in crude oil prices.

Since we hold prices fixed, we will estimate how gasoline consumption affects petroleum employment through petroleum production instead of price. We first need to estimate how changes in gasoline consumption affect petroleum production. A strand of economic literature has estimated how the crude oil market responds to demand shocks utilizing structural vector autoregressive analysis[15,16] . Both these papers suggest that the relationship between crude oil consumption and petroleum production is inelastic. Gunter finds that demand shocks only explain roughly 7–20% of the variance of crude oil production across countries[16].

Our second step is to estimate how changes in petroleum production affect employment in the petroleum sector. A study by Brown[17] relating employment to petroleum production estimated how petroleum employment responds to decreases in the number of oil rigs in a state. Brown's results are shown in the first three columns of Table S-1. The last two columns, highlighted in blue, are generated

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*Note that the midstream stage is often included as a part of upstream companies.

from our own calculations using petroleum employment from the Quarterly Census of Employment and Wages data on the four relevant NAICS codes. The last column shows the elasticities between oil rig count and petroleum employment by state. These values indicate an inelastic relationship between petroleum production and petroleum specific employment. Specifically, a 10% decrease in oil rig count decreases employment by 0.1–2.0%, depending on the state. Although we use a different measure of petroleum production, this result implies an inelastic relationship between domestic petroleum production and petroleum-sector employment.

Table S-1: Relationship between oil rig count and employment

	Change in rig counts (Sept 2014 to April 2015)	**Percent change in rig counts (Sept. 2014 to April 2015)**	**Predicted change in petroleum employment**	**Percent change in petroleum employment (versus Sept. 2014)**	**Elasticity between oil rig count and petroleum employment**
Arkansas	-3	-25.0%	-81	-1.2%	0.05
Colorado	-39	-51.3%	-1,114	-3.6%	0.07
Kansas	-13	-52.0%	-366	-3%	0.06
Louisiana	-45	-39.1%	-1,270	-1.9%	0.05
Montana	-7	-87.5%	-194	-3.6%	0.04
New Mexico	-50	-50.5%	-1,392	-5.8%	0.11
North Dakota	-102	-54.5%	-2,924	-10.2%	0.19
Oklahoma	-92	-43%	-2,603	-4%	0.09
Texas	-480	-53.2%	-13,762	-4.1%	0.08
Utah	-15	-65.2%	-438	-4.7%	0.07
West Virginia	-6	-21.4%	-172	-1.4%	0.07
Wyoming	-33	-56.9%	-928	-4.6%	0.08

With this literature as a benchmark, we expect our results to show an inelastic relationship between both U.S. petroleum consumption and production, as well as domestic petroleum consumption and employment in the petroleum sector.

Methodology

We analyze the effect of gasoline consumption on petroleum employment through changes in domestic production instead of price. We do this for a variety of reasons. First, there is very little evidence that changes in U.S. consumption alone affect overall global petroleum demand, and therefore U.S. consumption is unlikely to have a significant influence on crude oil price change[18]. Most importantly, crude oil prices are fixed across the BAU and co-optimized scenarios in the BSM analysis, which provided the gasoline consumption estimates. To maintain internal consistency with the assumptions about crude prices, which are used for BSM modeling, our analysis will estimate how changes in U.S. gasoline consumption affect domestic petroleum production and how these changes can then affect petroleum sector-specific employment while crude oil prices remain unchanged under both the BAU and co-optimized scenarios.

We utilize a two-step process to relate domestic gasoline consumption to U.S. petroleum employment so that we can verify each step using previous research. With the use of previous literature as a benchmark, our main contribution is primarily the linkage between the two stages, rather than a completely new model that links gasoline consumption to petroleum employment directly. We develop our model using U.S. national data from 2000 to 2016.

Consumption and Production

To determine the relationship between U.S gasoline consumption and domestic petroleum production, we estimate the following specification through ordinary least squares (OLS) analysis, where all non-stationary variables are first differenced to induce stationarity.

$$\begin{aligned}\triangle_t production \\ &= \beta_1 \triangle_t consumption + \phi X_t + \gamma_m + year2007 + year2008 + year2009 + year201 \\ &+ \epsilon_t\end{aligned}$$

Where:

- Production = the volume of crude oil produced from oil reservoirs and measured in thousand barrels per day. Provided by the Energy Information Administration (EIA).
- Consumption = the disappearance of petroleum products from primary sources, and approximately represents motor gasoline consumption. Measured in thousand barrels per day and obtained from EIA data.
- X_t includes all necessary controls to analyze the relationship between domestic petroleum consumption and production:
    - Unemployment rate, provided by the Bureau of Labor Statistics (BLS).
    - Futures contracts: agreements to buy or sell a certain number of barrels of oil at a predetermined date and price, provided by the EIA.
    - National Financial Condition Index (NFCI): measures national financial conditions of the U.S., provided by the Federal Reserve Bank of Chicago.
    - Russia and Saudi Arabia's GPR: measurement of geopolitical risk determined by counting the occurrence of words related to geopolitical tensions in newspapers[19]
    - World production: global oil production minus U.S. oil production. Measured in million barrels per day and provided by the International Energy Agency.
    - World consumption: global oil consumption minus U.S. oil consumption. Measured in million barrels per day and provided by the International Energy Agency.
    - Net imports: measured in thousand barrels per day and obtained from EIA data.
    - Fracking share: amount of petroleum extracted through hydraulic fracturing over the total amount of petroleum produced, to represent the share of petroleum obtained from fracking, obtained from EIA data.
- γ_m: monthly dummy variables, included to address seasonality of the data.

- Yearly controls:
    - 2007 and 2008 to control for the oil price shock during this time, which is said to be due to increases in demand and stagnant production[20].
    - 2008 and 2009 to control for the global financial crisis.
    - 2014 and 2015 to address the excess of supply that led to a sharp decline in crude oil prices.

Because petroleum production is influenced by multiple factors, it is important to control for factors other than domestic gasoline consumption that may also affect domestic petroleum production. The unemployment rate and NFCI are included to control for the economic climate. Futures prices, which are contracts to purchase oil at a specific price and time in the future, are included to address expectations about the crude oil market. Global variables are included since crude oil is a global commodity. Net imports and the share of fracking are included to account for changes to the crude oil market.

Production and Employment

The second step is to estimate the relationship between domestic crude oil production and U.S. petroleum employment. Brown[16]linked crude oil production to employment by estimating the relationship between oil rig count and employment using an autoregressive distributive lag (ARDL) model. An ARDL model, by including lags of both the independent and dependent variables of a regression, better addresses the dynamics of the relationship between the two variables. We take a similar approach and estimate the following specification through OLS:

$$\triangle_t employment = \beta_1 \triangle_t production + \beta_2 \triangle_{t-1} production + \sum_{n=1}^{1,2,or\ 3} \alpha_n \triangle_{t-n} employment$$

$$+ \phi X_t + \gamma_m + year2007 + year2008 + year2009 + year2014 + year2015 + \epsilon_t$$

Where:

- Employment = number of employees in NAICS code 211, 213, 486, or 324, depending on the regression. These values are collected from the Current Employment Statistics data provided by the BLS.
- Production is the same variable used in the previous stage, i.e., the crude oil produced, measured in thousand barrels per day.
- X_t includes a set of controls:
    - Unemployment rate: provided by BLS.
    - Futures contracts: provided by EIA.
    - Fracking share: obtained from EIA data.
- γ_m: monthly dummy variables, included to address seasonality of the data.
- Yearly controls:
    - Same as previous regression. These control for years of extreme variability in crude oil prices.

Again, we control for any other factors that could influence employment in the petroleum sector. We include the unemployment rate to address any changes in petroleum employment that are due to labor market conditions. Futures prices are included because many hires in the oil and gas sector take place earlier in the process, meaning that companies hiring employees will base decisions on the expectations of oil price in the future. We also include fracking share to address the changes to the crude oil market with the introduction of hydraulic fracturing.

Results

Relationship between gasoline consumption and petroleum production

The results of the first step imply that a decrease of one thousand barrels per day in U.S. gasoline consumption decreases petroleum production by 207–231 barrels per day. To put this value into context, a roughly 0.012% decrease in U.S. gasoline consumption decreases production by 0.0036%, suggesting an elasticity of 0.3. This inelastic relationship is consistent with previous work. Although neither Kilian nor Gunter looked directly at the relationship between U.S. demand shocks and U.S. production, both suggest an inelastic relationship between oil demand shocks and corresponding production responses. This implies that the 7% decline in gasoline consumption, due to increased biofuel utilization in the isopropanol scenario, would result in a decrease in petroleum production by less than 2%.

The results of the second step show that the only type of employment affected by changes in petroleum production is upstream employment, NAICS code 211. The other three types of employment—213, 486, and 324—yield insignificant estimates. Specifically, a thousand-barrel-per-day decrease in domestic production decreases upstream employment by 5.8 employees in the long run and has no effect on the remaining types of petroleum employment. This estimate suggests that a 0.016% decrease in production decreases employment by 0.004%. This implies an elasticity of 0.25, signifying an inelastic relationship. This elasticity is similar to Brown's[17] findings that there is an inelastic relationship between a state's petroleum production and its petroleum employment.

Using the co-optimized scenario results along with the first- and second-stage estimates of how gasoline consumption changes affect production, and how employment responds to production changes, Table S-2 shows the potential employment effects in response to the decrease in gasoline consumption in the co-optimized scenario. To put the employee estimates into context, there were 144,500 upstream employees (NAICS 211) in December 2017, according to the BLS. The results suggest a maximum 0.83% decrease in upstream employment due to increased biofuel utilization in the scenarios we considered, or a 0.23% % decrease in overall petroleum employment.

*Table S- 2: Employment effects under isopropanol scenarios compared to BAU scenario**

*Percent changes calculated using 211 employment in December 2017 (provided by BLS).

	Upper Bound: Full Fleet Turnover		Lower Bound: Market-Based	
Year	*Change in Number employees*	*% change in 211 employment*	*Change in Number employees*	*% change in 211 employment*
2025	1	0.00%	1	0.00%
2030	-30	-0.02%	-2	0.00%
2035	-44	-0.31%	-173	-0.12%
2040	-1053	-0.73%	-428	-0.30%
2045	-1199	-0.83%	-570	-0.39%
2050	-1090 -	-0.75%	-595	0.41%

Percent changes calculated using 211 employment in December 2017 (provided by BLS).

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Robustness Check

To test that our regression estimates are robust, we add more controls to the two specifications. First, we include stock of crude oil and crude oil price in both steps one and two. We include stock of crude oil because decisions may be dependent on how much crude oil is in inventory. We include price because the BSM/ADOPT model runs assume that oil and conventional gasoline prices do *not* change due to the production of new bio-blendstocks (refer to Caveats, Limitations, and Assumptions in the main text) and we want to analyze the changes in petroleum employment that are not due to changes in price. The only way to explicitly do this is to include price as a control. This causes econometric and interpretation issues, but we provide it for robustness. The inclusion of these additional controls has very little effect on our coefficient results.

Additionally, we want to account for the fact that employment in NAICS codes 211, 213, and 486 includes jobs related to both petroleum and natural gas. This fact can be problematic if changes in natural gas employment are driving the changes in our employment variables. To show that trends/changes in natural gas employment are not affecting our results, we add U.S. natural gas production as a control in our regression. Accounting for this issue has little impact on our estimates.

Limitations

As with all OLS analyses, there are limitations to the results. Specifically, coefficients provided by OLS estimation provide the effect of the independent variable on the dependent variable, holding all controls constant. Therefore, our estimates provide the predicted effect of consumption changes on employment, assuming no changes in any of the control variables. This assumption likely does not hold in actuality because of the complexities of the crude oil market. The analysis also assumes a linear relationship, which may not be a true representation of these two relationships.

Not only does OLS have its own limitations, but the data used in this analysis may also hinder the robustness of this study. We use a limited number of observations to focus specifically on the current U.S. petroleum market, which can lead to imprecise coefficient estimates. It is important to consider that the estimates generated in this study are derived from only about 200 observations. The limited availability and relevance of data make our estimates less robust than studies with more observations.

Another limitation is the complexity and inconsistencies of the crude oil market, and the U.S. petroleum sector specifically. The recent transformation of the U.S. petroleum sector due to fracking, and the limited time that has passed since, make it difficult to accurately estimate the relationships between these variables in the current market.

Although there are limitations to the analysis presented here, these inelastic relationships between gasoline consumption and production and crude oil production and petroleum employment have been demonstrated across a variety of studies. Our analysis further emphasizes the nature of these relationships. By tying the two stages together, our results suggest that the relatively small changes in U.S. gasoline consumption in the scenarios we considered will have minimal impact on U.S. petroleum employment.

Yearly changes in construction and operation-related jobs

Table S-3: Yearly changes in construction-related jobs when compared to the BAU (Annual jobs or the number of jobs for one year)

Years	Isopropanol market based turnover	Isopropanol full fleet turnover
2025	-2339	-2339
2026	-5992	-5992
2027	-9736	-9736
2028	-12564	-6505
2029	-9504	1985
2030	-5398	11252
2031	-3896	38009
2032	5534	63689
2033	22313	99069
2034	27457	114087
2035	19536	126053
2036	2258	125103
2037	4360	124398
2038	10369	123578
2039	17362	126926
2040	32937	128237
2041	46829	121040
2042	59948	100392
2043	47046	79941
2044	25266	64820
2045	5152	64863
2046	-1047	63017
2047	794	65390
2048	903	63358
2049	903	42437
2050	0	20697

Table S-4: Yearly changes in construction-related jobs when compared to the BAU (Annual jobs or the number of jobs for one year)

Years	Isopropanol market based turnover with all vehicles	Isopropanol full fleet turnover with all vehicles
2025	579	539
2026	-1016	-1120
2027	-2246	-2459
2028	-5520	-6036
2029	-6618	-7719
2030	-8525	-12237
2031	-6262	1272
2032	8987	27304
2033	7050	38200
2034	17202	68684
2035	37372	94598
2036	56176	118317
2037	67926	135870
2038	56811	159099
2039	43437	209765
2040	59139	250636
2041	72787	268413
2042	80843	280129
2043	75147	277267
2044	66422	288847
2045	63034	314535
2046	67447	340038
2047	93224	361221
2048	122528	373546
2049	106175	348373
2050	68504	329645

Electricity grid assumption:

In simulations, the U.S. average electricity generation mix comprising fossil and renewable sources is fixed at 2014 levels out to 2050 as in Table S-5.

Table S-5. 2014 Grid Composition

Component	**Share**
Residual Oil	0.7%
Natural gas	26.2%
Coal	39.8%
Nuclear	20.2%
Biomass	0.4%
Other (wind, solar, hydropower)	12.6%

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