MIT Joint Program Sponsors Webinar Series

March . 14 . 2013 10:30 am - 12:00 pm EDT

Biofuels in Commercial Aviation

Dr. Niven Winchester
Environmental Energy Economist, MIT Joint Program

Webinar Format:

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2. During the presentation, the Moderator/Host and Presenter will be taking questions *for clarity only* (first 45-50 minutes of the webinar). All other questions will be addressed during the Q&A period (second 40-45 minutes of the webinar).

3. If you have a question, you may either use the *hand icon* to "raise your hand", type a message in the *chat section* to the Moderator/Host, or ask your question *via the teleconference* if you have joined by phone. You will be recognized by the Moderator so that you may ask your question.

4. When asking a question, *please first identify yourself and your organization*, for the benefit of all attendees.

5. This webinar series is a service provided to the Joint Program Sponsor members only. On occasion, we may have prospective companies representatives attending for purposes of exploring membership with the Joint Program.

6. At the conclusion of the Webinar, online attendees will be presented with a brief survey. We hope that you will take a few minutes to provide feedback on today's session and make suggestions for future webinar topics.

We welcome your comments at any time to Frances Goldstein (fkg@mit.edu).

Thank you for participating in the MIT Joint Program Sponsors Webinar series today.

The webinar will begin shortly.

Biofuels in Commercial Transportation*

Niven Winchester (niven@mit.edu)

Co-authors: Dominic McConnachie, Christoph Wollersheim and Ian Waitz

March 14, 2013

* Winchester, N., D. McConnachie, C. Wollersheim, and I.A. Waitz (2013). Market cost of renewable jet fuel adoption in the Unites States, Joint Program on the Science and Policy of Global Change, Report 238, Massachusetts Institute of Technology, Cambridge, MA.

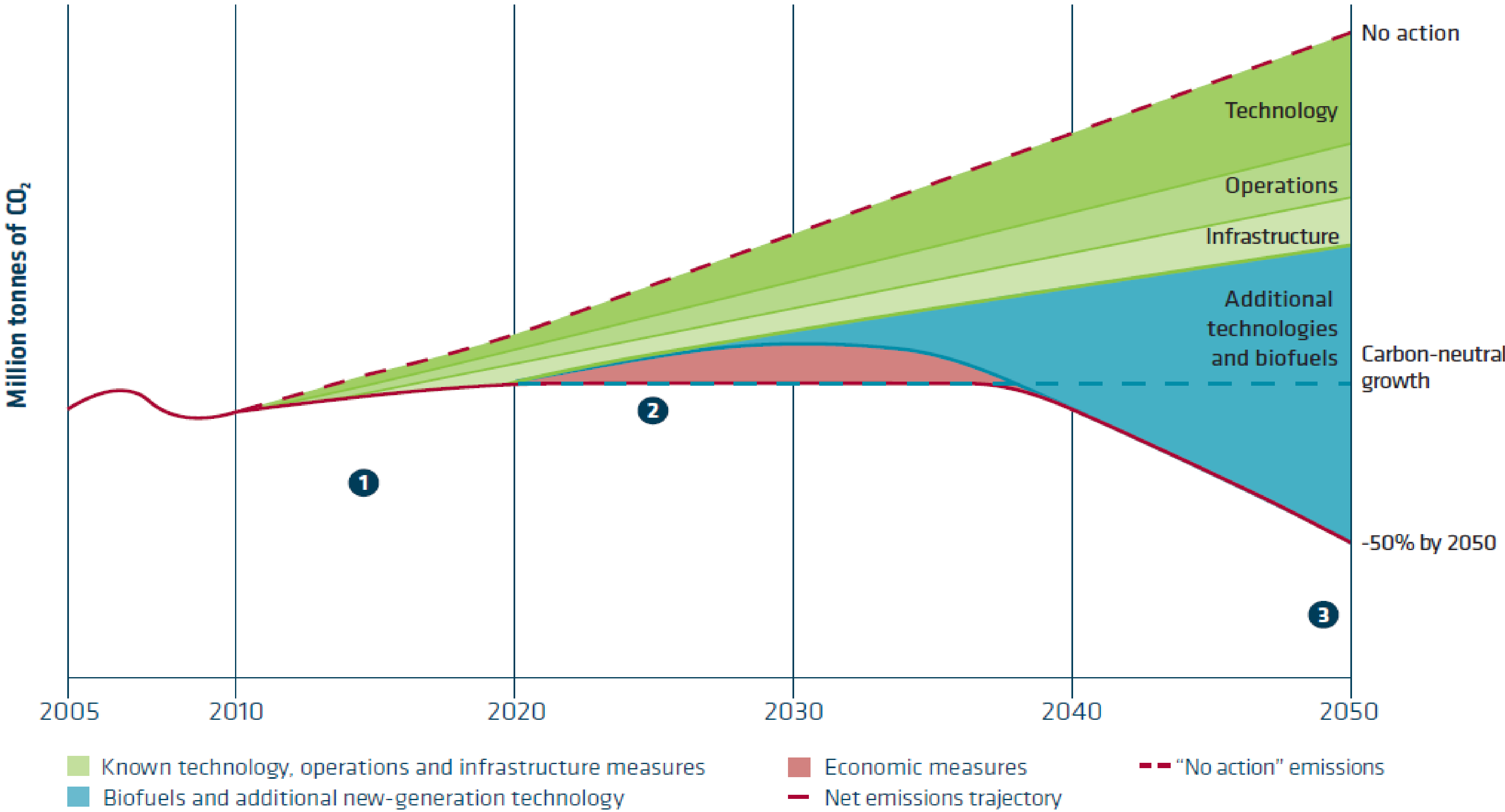
Outline

1. Introduction
2. The Renewable Fuel Standard II (RFS2)
3. Aviation biofuel pathways
4. Aviation goals under RFS2
5. Modeling Framework
6. Results
7. Conclusions

1. Introduction

- The global aviation industry is forecast to grow by 5% per year (Airbus, 2012) and aims to reduce CO_2 emissions by 50% relative to the 2005 level by 2050 (International Air Transport Association, 2009)

Emissions reduction roadmap



Note: Schematic, indicative only.

Source: Air Transport Action Group (2010, p.4).

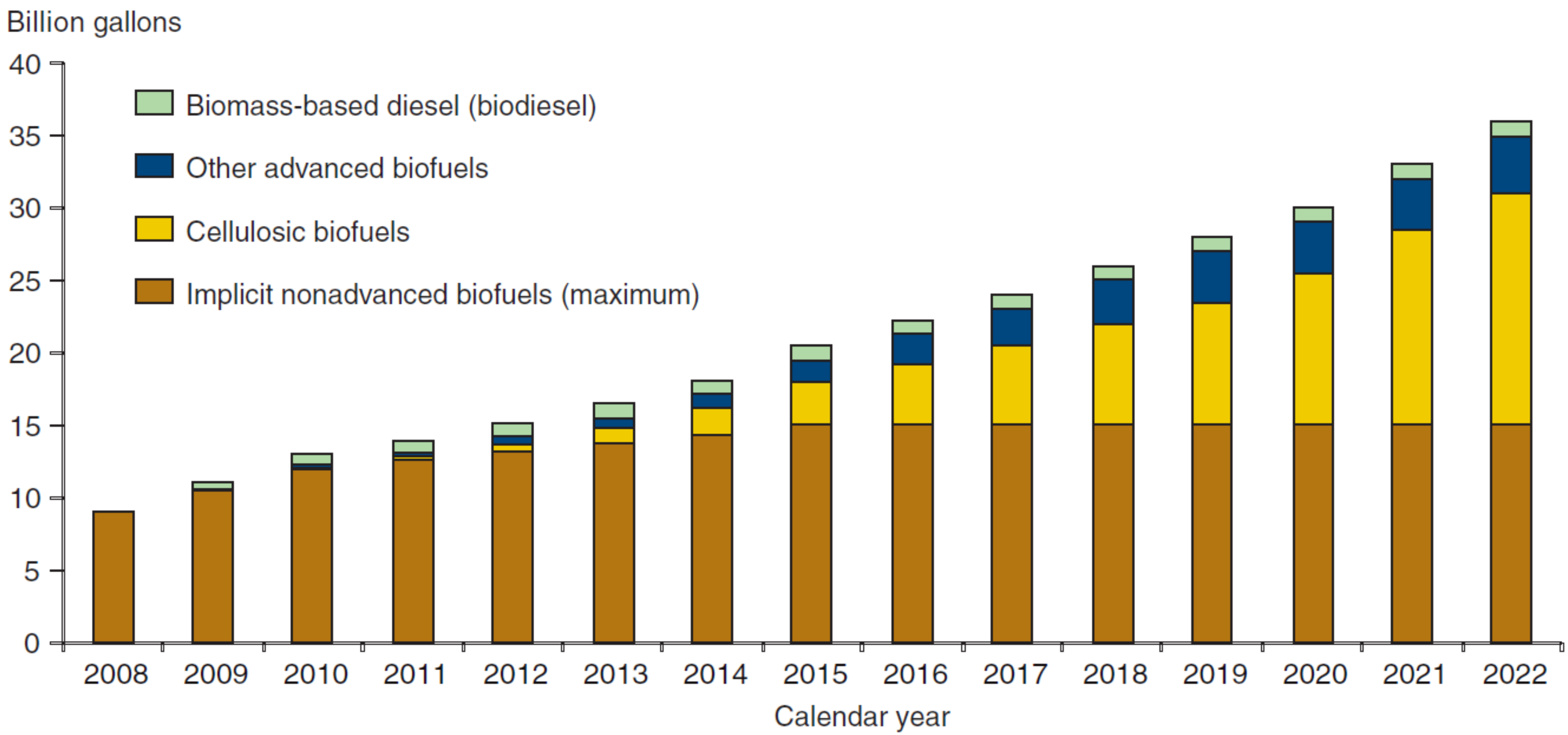
1. Introduction

- The industry believes that new technologies and biofuels will play a key role in reducing emissions
- In the US, the Federal Aviation Administration (FAA) has set an (aspirational) goal that one billion gallons of renewable fuel is used in air transportation each year from 2018 (FAA, 2011)
  - US Air Force: 50% of domestic aviation operations will use a 50:50 blend of renewable fuel from domestic sources by 2016 (0.37b gallons p.a.)
  - US Navy: 50% of total energy consumption from renewable sources by 2020 (0.28b gallons p.a.)
  - Commercial aviation: 0.35b gallons p.a.
- There are existing policies/mandates for biofuels used in ground transportation
- We assess the cost of meeting the commercial aviation goal under a specific pathway

2. The Renewable Fuel Standard II

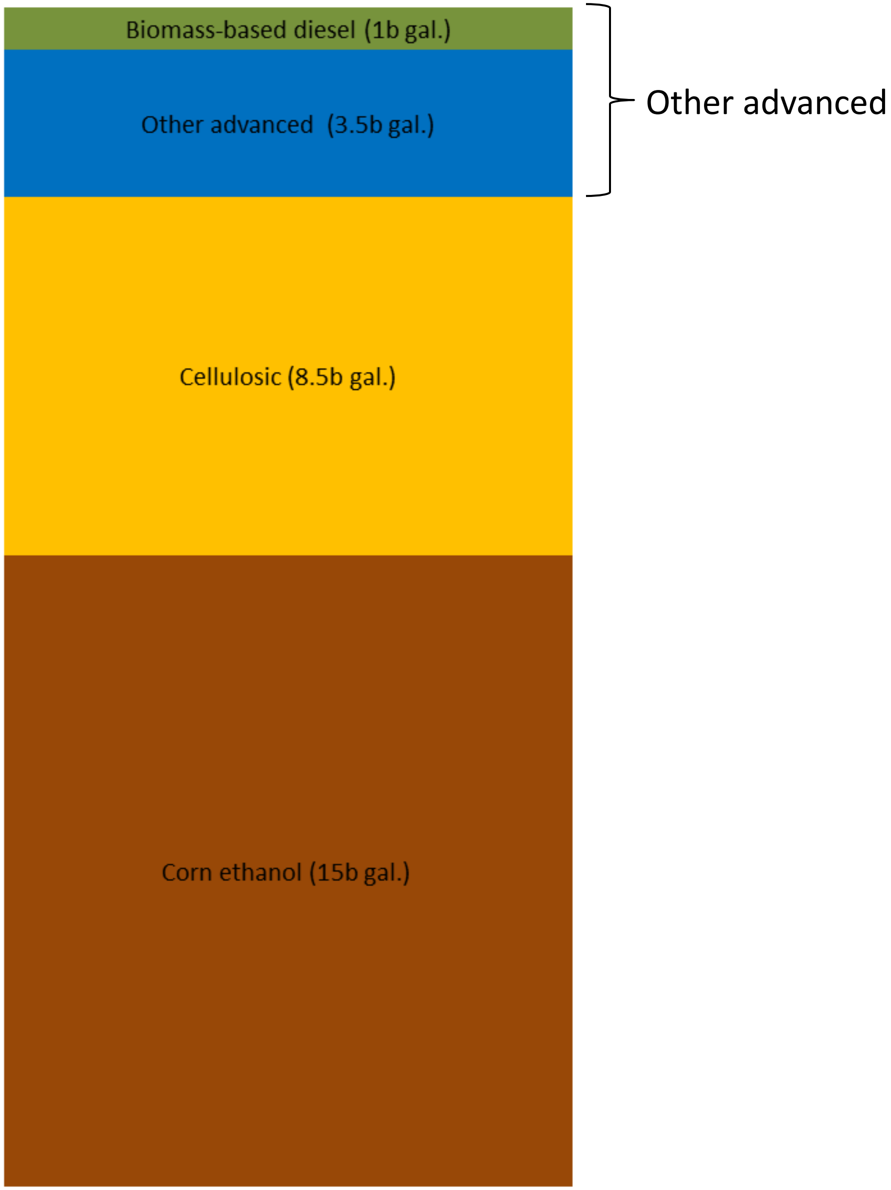
- Title II of the Energy Independence and Security Act of 2007 sets out conditions for the Renewable Fuels Standard II (RFS2)
- Sets minimum annual volume requirements (mandates) for (i) biomass-based diesel, (ii) cellulosic biofuel, (iii) advanced biofuels, and (iv) total renewable fuel that must be used in ground transportation
- In 2022, RFS2 stipulates that 36 billion gallons of transportation fuel must be sourced from renewable sources.

2. The Renewable Fuel Standard II



Source: US Department of Agriculture (2011, p.5).

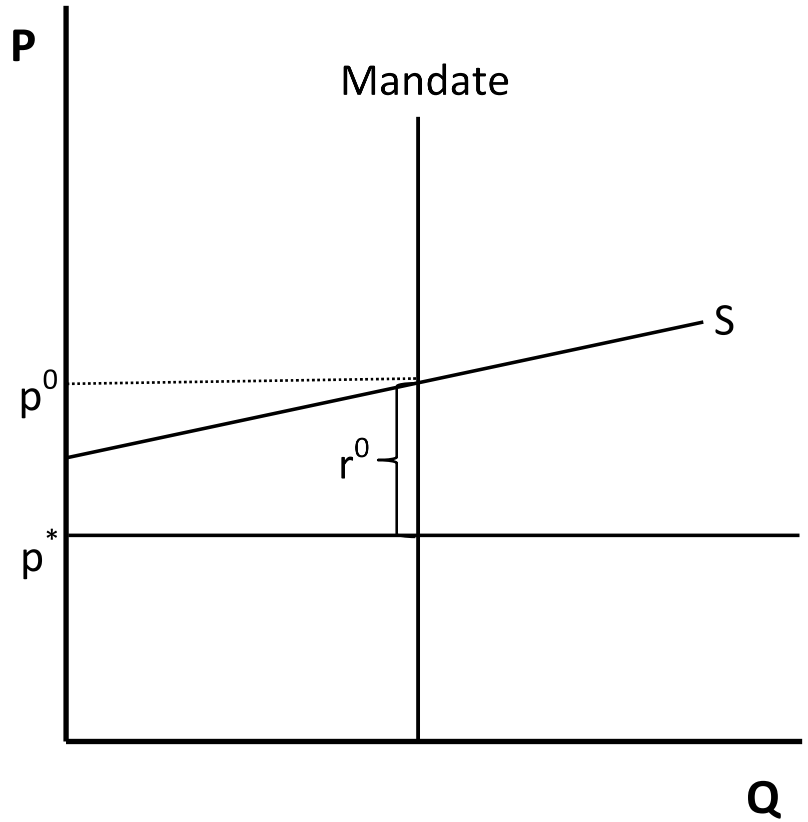
2020 RFS2 mandates



2. The Renewable Fuel Standard II

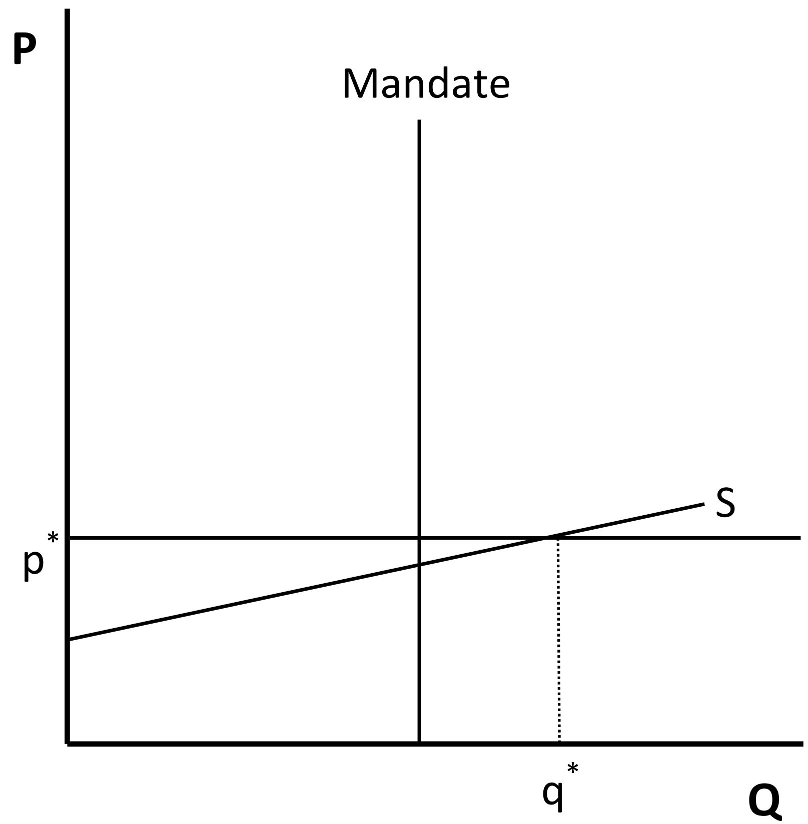
- The Environmental Protection Agency (EPA) ensures that the biofuel mandates are met by assigning each gallon of renewable fuel a Renewable Identification Number (RIN)
  - Different RINs are generated for each fuel category
- In November of each year, the EPA sets the number of RINs that gasoline and diesel producers (refineries) must surrender for each gallon of fuel sold
- There is no mandate for renewable jet fuel (producers of jet fuel are not required to surrender RINs), but renewable jet fuel can contribute to the RFS2 mandates
- For each fuel category, the RIN market value will evolve so as to offset the cost of producing renewable fuel relative to the price of conventional fuel

The market for biofuels



If the price of conventional fuel is p^*, a RIN price of r^0 is required to meet the mandate

The market for biofuels



If the supply of biofuels exceeds the mandate at the prevailing price, the RIN price will be zero

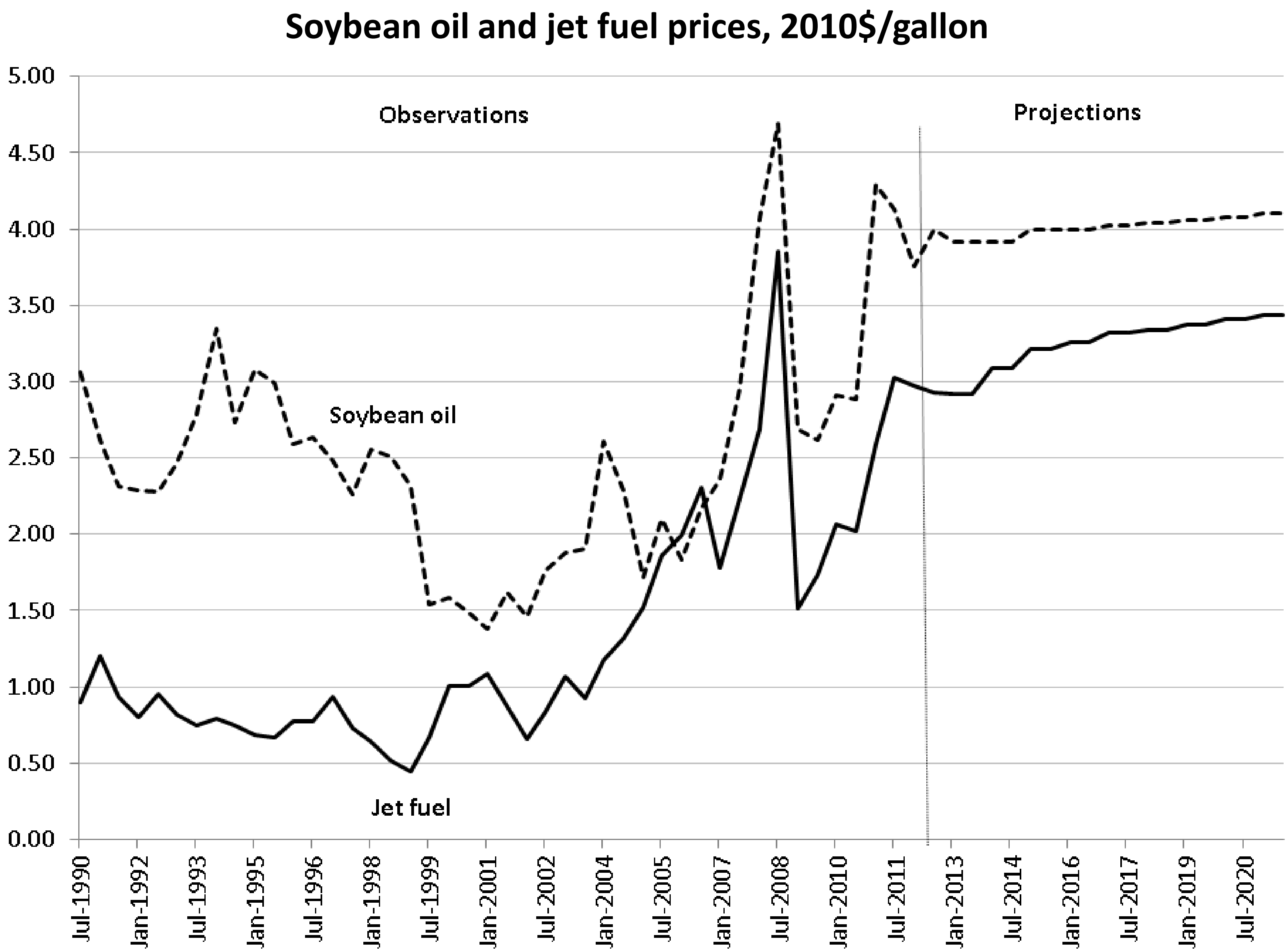
3. Aviation biofuel pathways

- Two biofuel pathways are currently approved by ASTM (American Society for Testing and Materials) International for use in aviation*
- Hydroprocessed Esters and Fatty Acids (HEFA)
  - Involves processing renewable oil (vegetable oils, animal fat, waste grease and algae oil) using hydrogen treatment (hydroprocessing)
- Biomass-to-liquid (BTL) via a Fischer-Tropsch (F-T) process
  - Involves vaporizing a combination of biomass and coal and converting the gas to liquid fuel via the F-T process
- Both processes produce a product slate that includes diesel, jet fuel and other co-products
- If renewable jet fuel production costs remain above the cost of conventional jet fuel, the aviation goal will be met by airlines voluntarily purchasing renewable jet fuel

*Other pathways expected to be certified in the near future include alcohol-to-jet and synthetic kerosene containing aromatics

3. Aviation biofuel pathways

- HEFA-derived fuels have been popular in demonstration flights and Bauen et al. (2009) estimate that the near-term uptake of biofuels will be greatest when oil crops are used in a HEFA process
- At maximum distillate, a HEFA process with a soybean feedstock produces, by weight, 76.9% diesel and 14.4% jet fuel (Pearlson, 2011)
  - Product slate tradeoffs are possible, but at a cost of reducing total distillate and increasing production costs
- HEFA jet fuel can be sold as diesel (but not *vice versa*) and separating jet from diesel requires additional capital costs
  - Renewable jet is likely to be sold as diesel under RFS2
- HEFA output qualifies for biomass-based diesel and undifferentiated advanced (other advanced) RINs under RFS2



Sources: Energy Information Administration (2021), US Department of Agriculture (2012).

3. Aviation biofuel pathways

- There is potential for rotation crops to be used as a HEFA feedstock
- USDA research suggests that the most promising rotation crop is Thlaspi arvense (pennycress)
  - Could potentially be grown in the Midwest in rotation with summer corn and spring soybean
  - Grown on land that would otherwise be left fallow
  - Requires minimal inputs of fertilizer, pesticides and water
  - Potential for 2.5 to 6 billion gallons of oil annually

- Other potential rotation crops include camelina, canola/rapeseed, flax, yellow mustard, safflower and sunflower
- Land used for rotation crops will have zero opportunity cost, if such crops do not have detrimental effects on pest control and the moisture and nutrient content of the soil, relative to leaving the land fallow

4. Aviation biofuels under RFS2

- Consider a biofuel pathway that produces 25% jet fuel and 75% diesel. If the price of both (conventional) diesel and jet fuel is $3 per gallon and it costs $4 to produce one gallon of biofuel, what subsidy is required to induce production of one gallon of jet fuel?

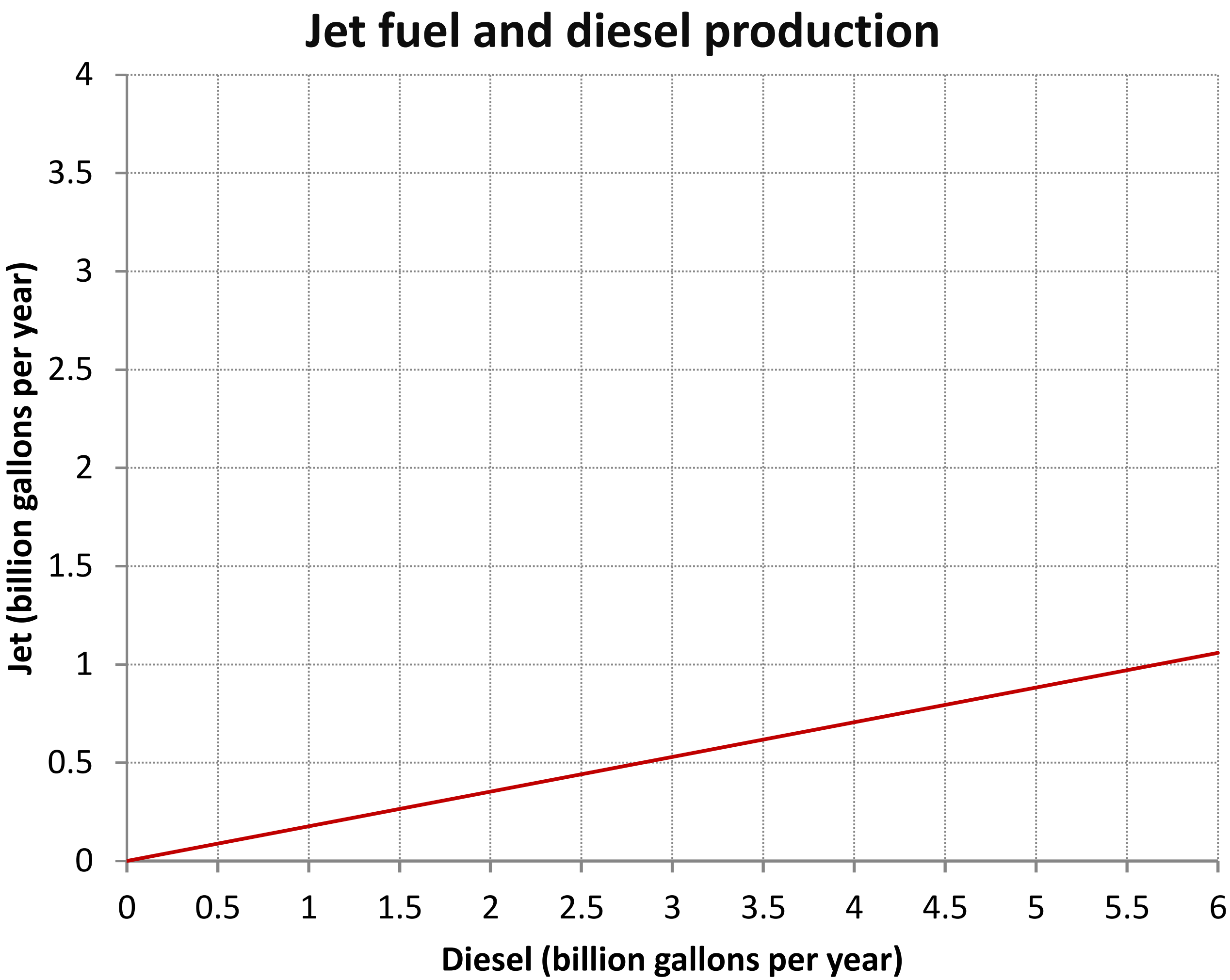
  Knee-jerk answer: $1 per gallon

  Four gallons of biofuel are needed to produce one gallon of jet. Producers lose $1 per gallon, so a subsidy of $4 per gallon is required

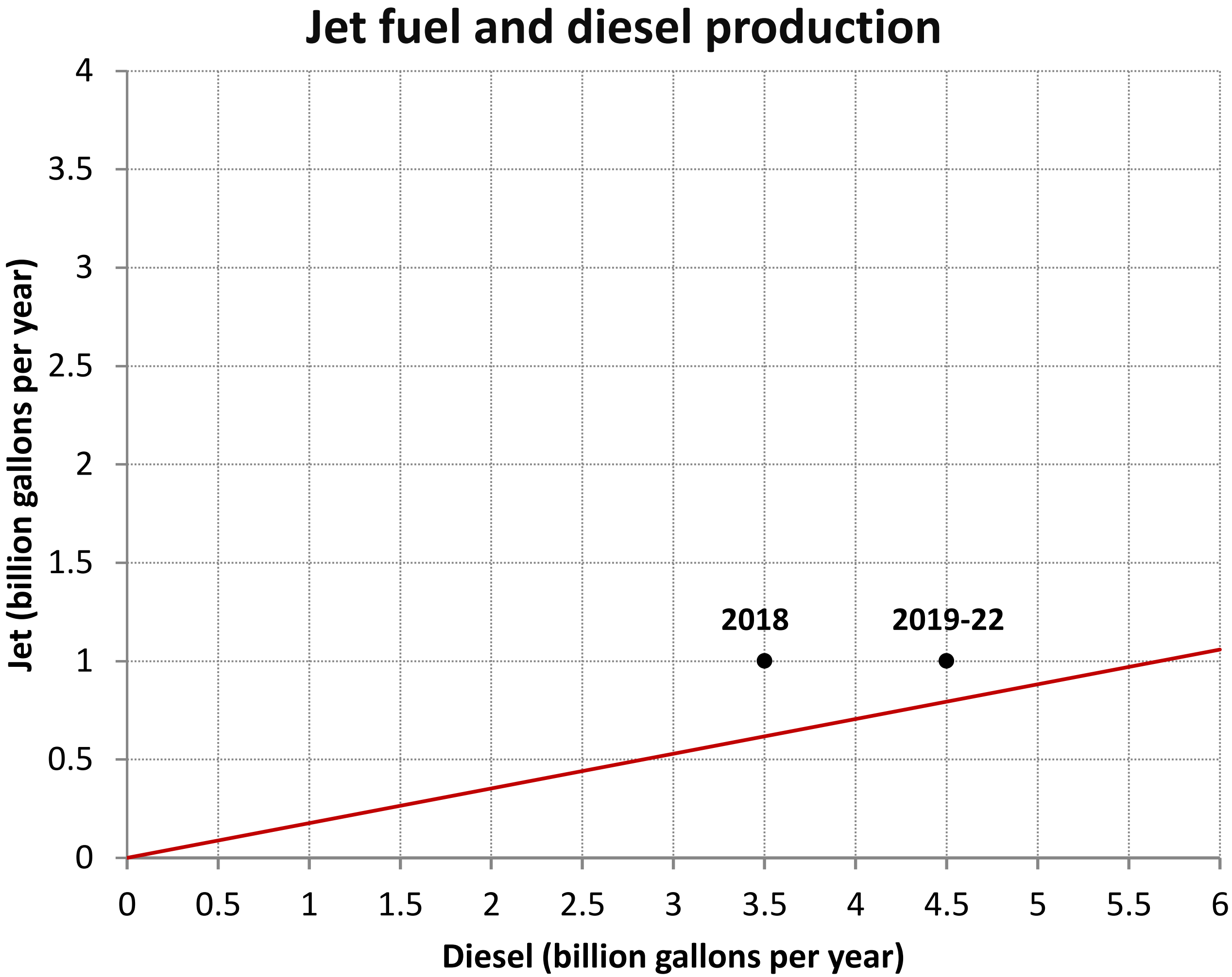
- The (implicit) subsidy required to induce jet fuel production will depend on the RIN value for other advanced fuels, which in turn will depend on the quantity of HEFA production

4. Aviation biofuel goals under RFS2

- Recall:
  - The HEFA pathway produces a product slate that, at maximum distillate, is ~ 15% jet fuel and ~85% diesel
  - Product slate tradeoffs are possible, but at additional costs and it is not possible to produce 100% jet fuel
  - HEFA output qualifies for biomass-based diesel and undifferentiated advanced (other advanced) RINs under RFS2



$$J = \frac{0.15}{0.85} D$$



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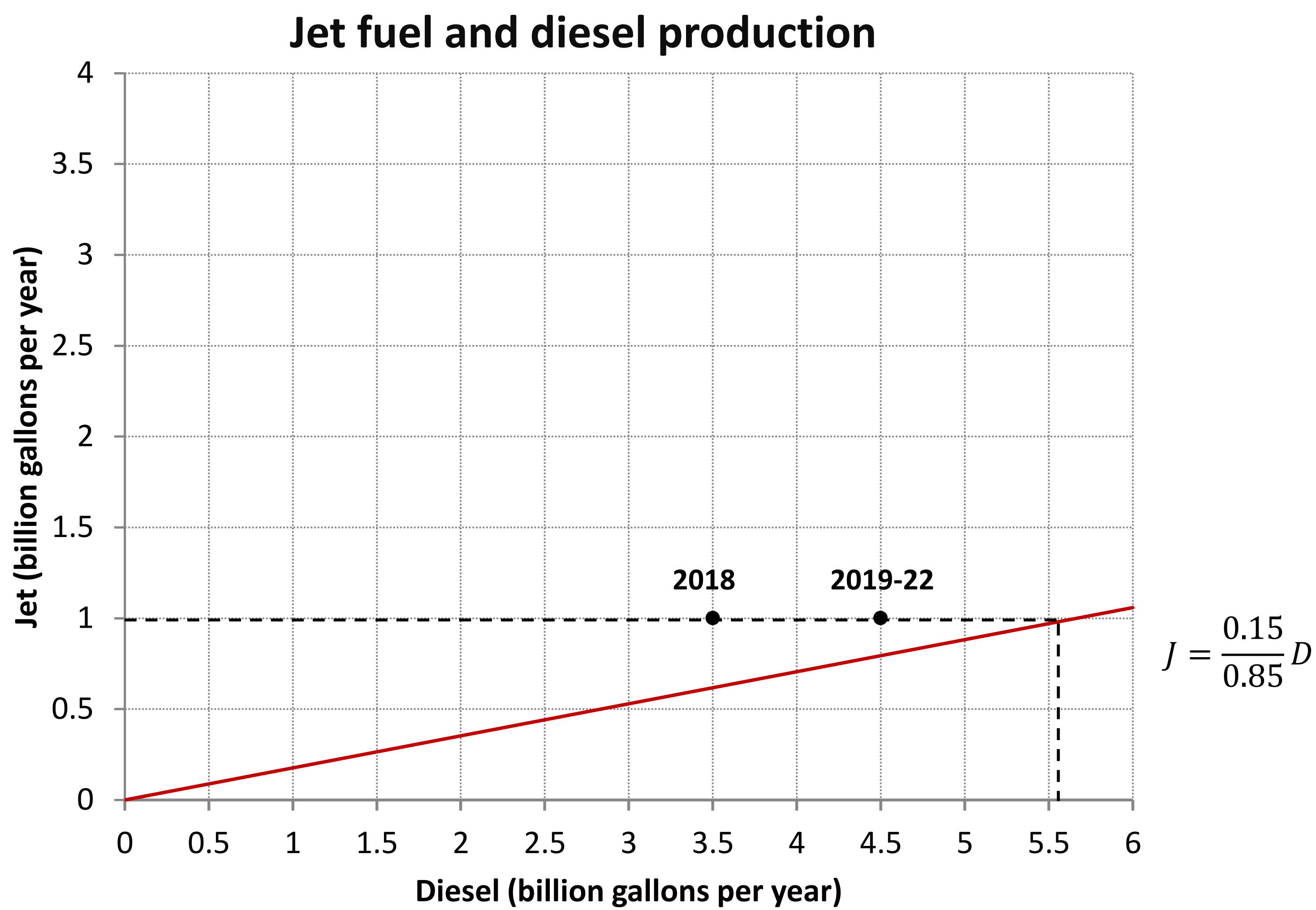
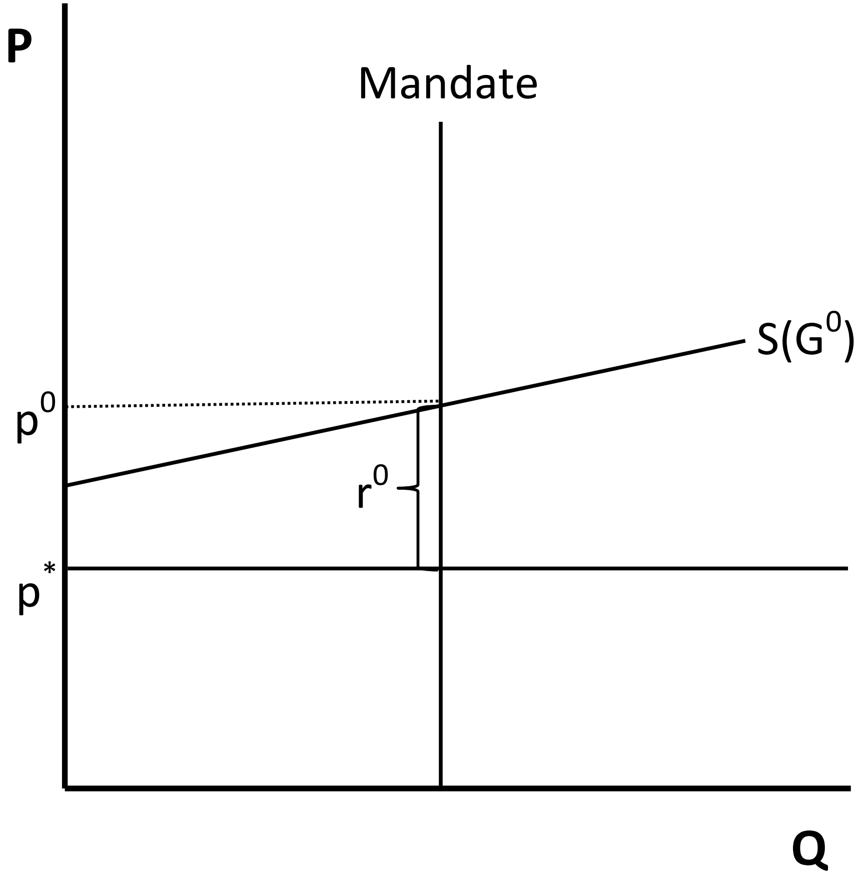


If HEFA jet fuel and diesel are produced in fixed proportions, meeting the jet fuel goal will result in the other advanced mandate being exceeded and the RIN price for this fuel will be zero (⇨ implicit bio-jet subsidy = $6.67 in our example)

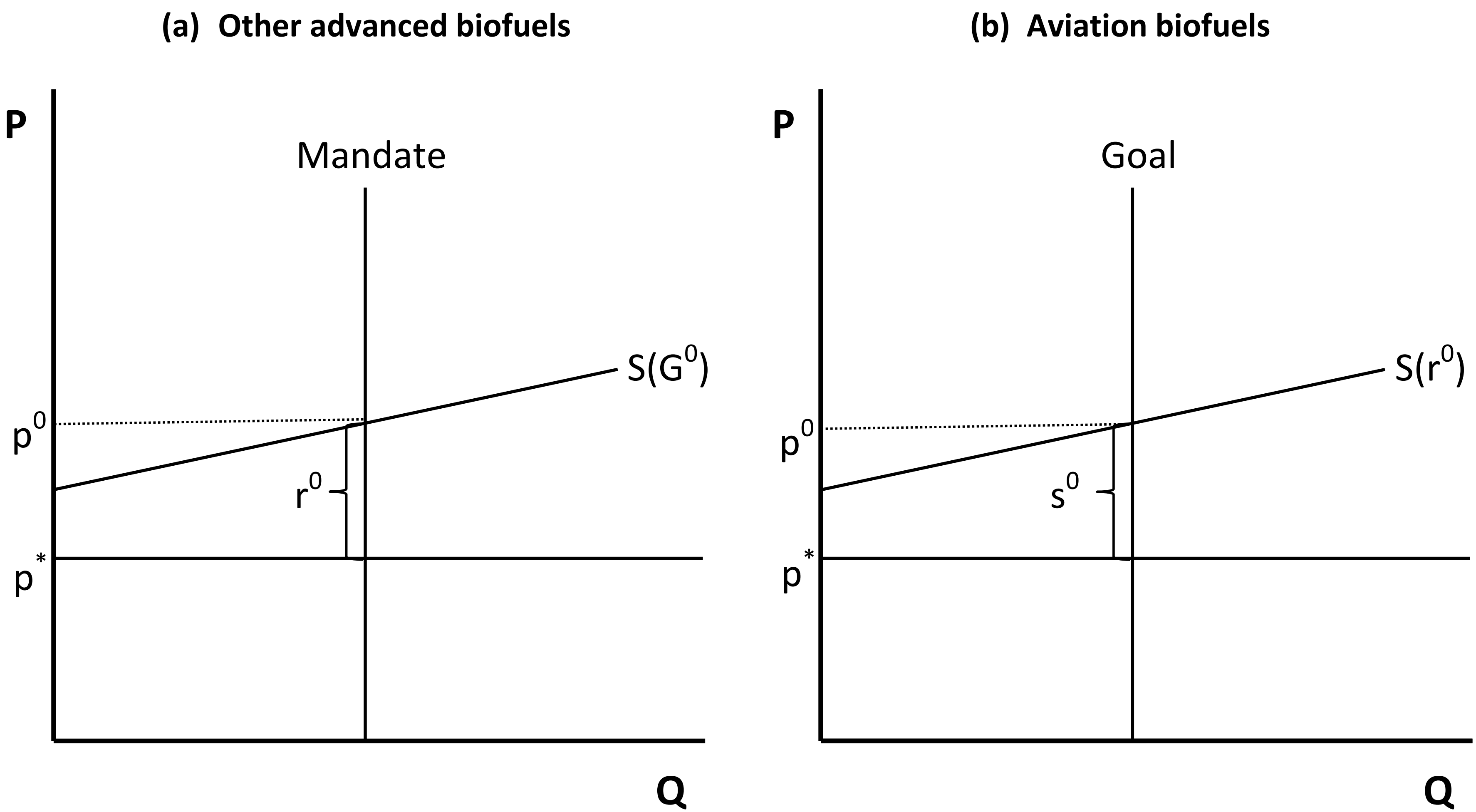
4. Aviation biofuel goals under RFS2

(a) Other advanced biofuels

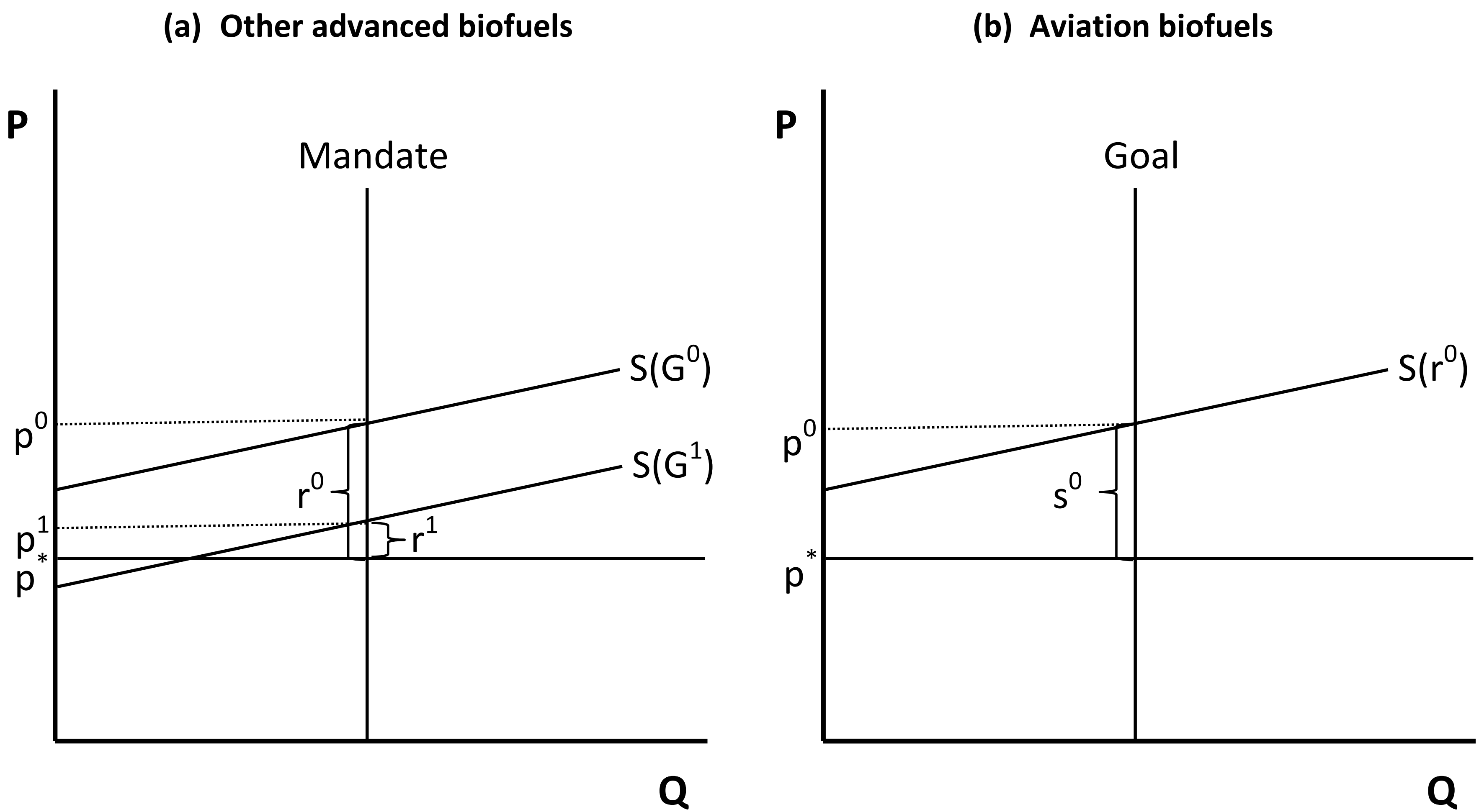


A RIN price of r^0 is required to meet the other advanced mandate

4. Aviation biofuel goals under RFS2

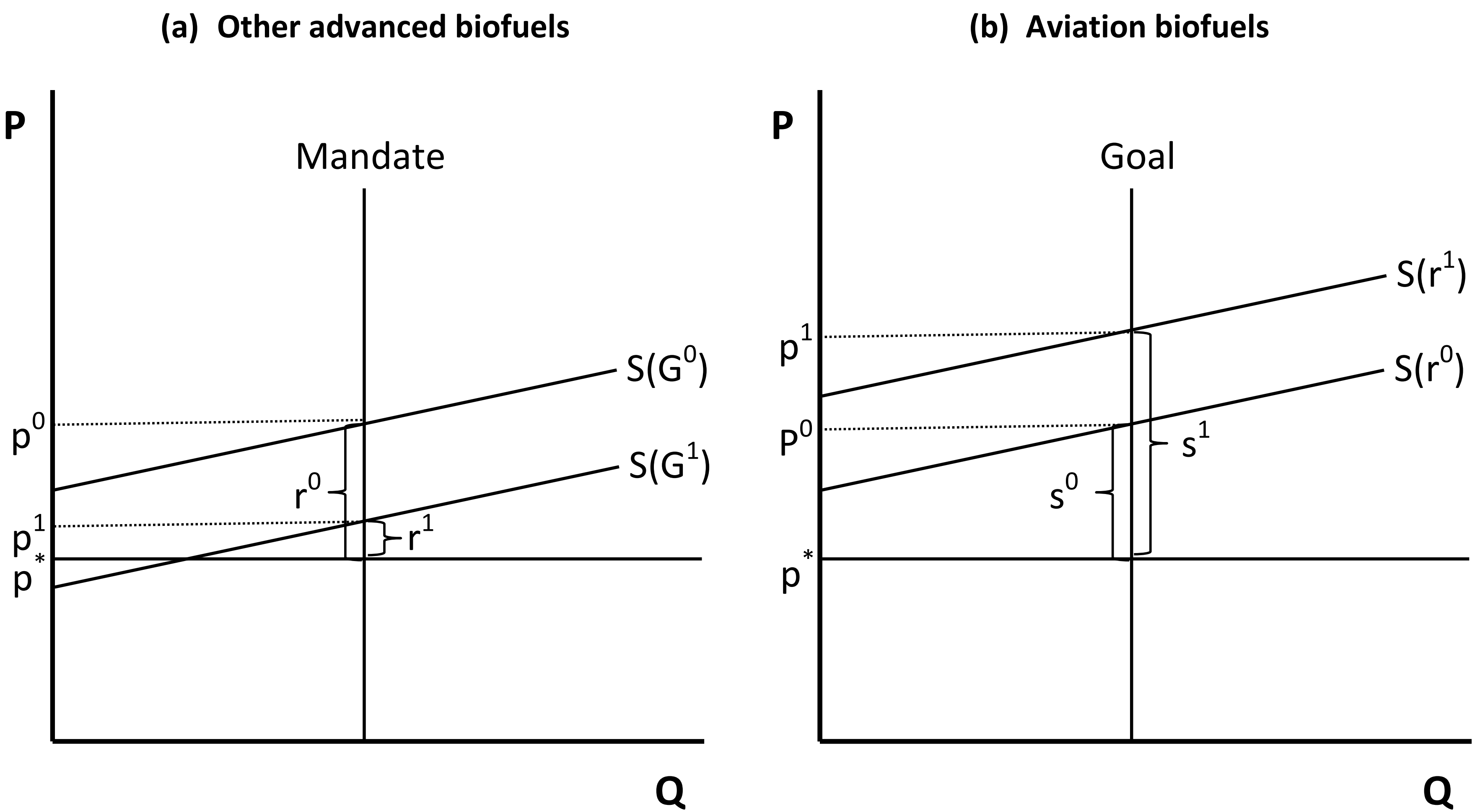


4. Aviation biofuel goals under RFS2



Inducing production of aviation biofuels increases the supply of other advanced biofuels and lowers the RIN price for this fuel…

4. Aviation biofuel goals under RFS2



… this will increase production costs for aviation biofuels, so a larger implicit subsidy is needed to meet the aviation biofuel goal

5. Modeling framework

- We use an augmented version of the MIT Emissions Prediction and Policy Analysis (EPPA) model to determine the impact of biofuels policies and goals on biofuel production and costs, RIN prices, fuel prices and GDP.
- Estimated changes in fuel prices, which are passed through to consumers, and GDP-induced changes in demand are then simulated using the Aviation Portfolio Management Tool for Economics (APMT-E) to determine changes in aviation operations
- The EPPA model is a recursive dynamic computable general equilibrium model of the global economy that links GHG emissions to economic activity
- APMT-E is a partial equilibrium model developed by the FAA and the Partnership for Air Transportation Noise and Emissions Reduction Center of Excellence

5. Modeling framework

- We extend the EPPA model by including several biofuel technologies and feedstocks
  - A corn ethanol pathway
  - A cellulosic pathway
  - A representative other advanced pathway
  - A HEFA pathway with a soybean oil feedstock
  - A HEFA pathway with a rotation crop feedstock (in some scenarios)

5. Modeling framework

Aggregation in the EPPA for aviation model

Regions	Sectors
United States (USA)	Crops
Canada (CAN)	Dedicated biofuel crops: corn, wheat, energy beet, soy beans, rape, sugar cane, oil palms, representative energy grass
Japan (JPN)	Livestock
Australia-New Zealand (ANZ)	Forestry
European Union (EUR)	Food
Eastern Europe (ROE)	Coal
Russia (RUS)	Crude Oil
Mexico (MEX)	Conventional crude, from shale, from sands
China (CHN)	Refined Oil
India (IND)	From crude oil, first generation biofuels, cellulosic biofuels
East Asia (ASI)	Gas
Rest of Asia (REA)	Conventional gas, from shale, from sandstone, from coal, synthetic gas from goal
Africa (AFR)	Electricity
Middle East (MES)	Coal, gas, refined oil, hydro, nuclear, wind, solar, biomass, natural gas combined cycle, integrated gasification combined cycle, advanced coal and gas with CCS
Brazil (BRA)	Energy Intensive Industry
Latin America (LAM)	Other Industry
	Services
	Aviation
	Other commercial Transportation
	Household Transportation
	ICE vehicles, hybrid vehicles, plug-in electric vehicles

5. Modeling framework

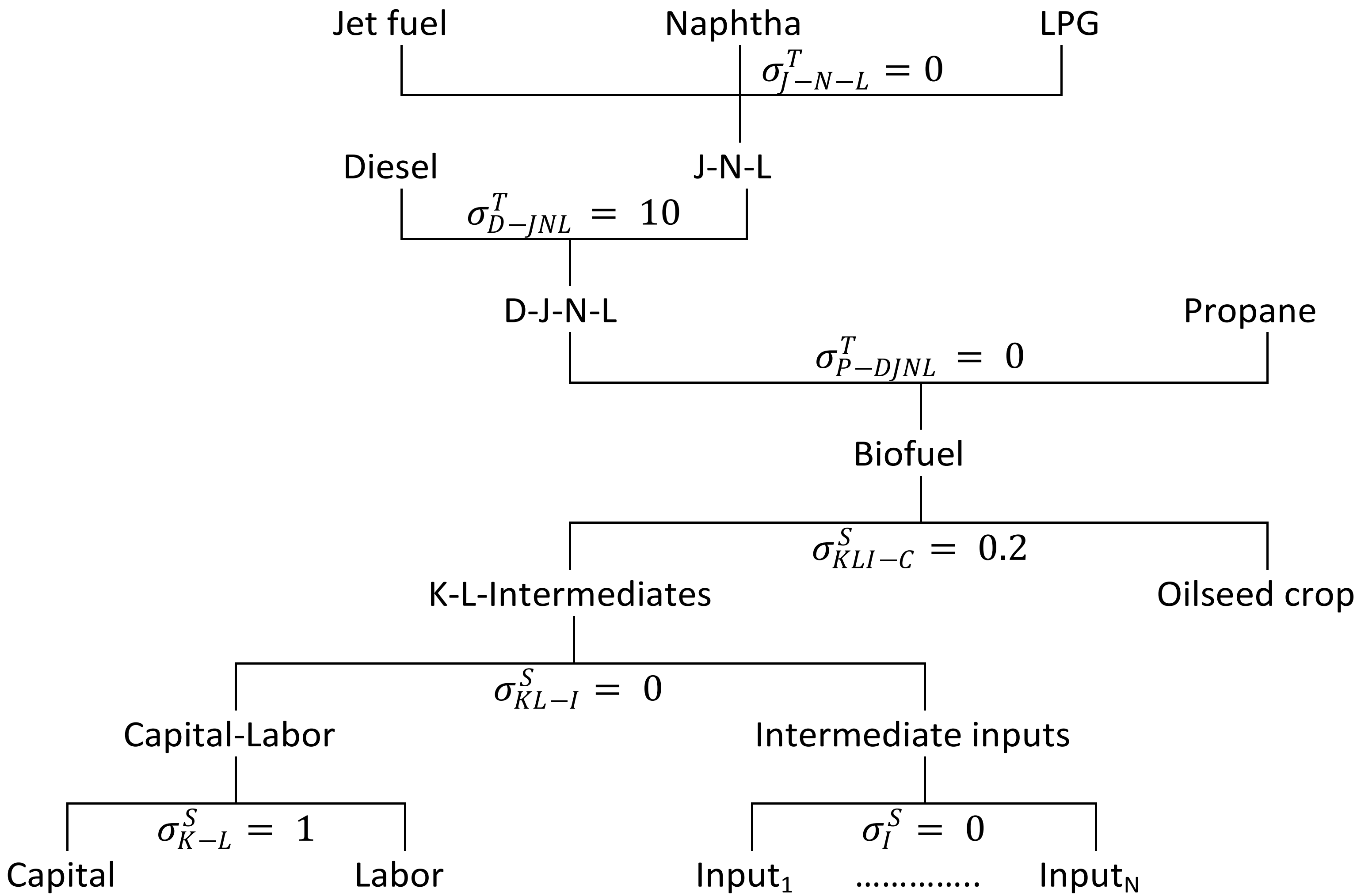


Figure 2. HEFA production

5. Modeling framework

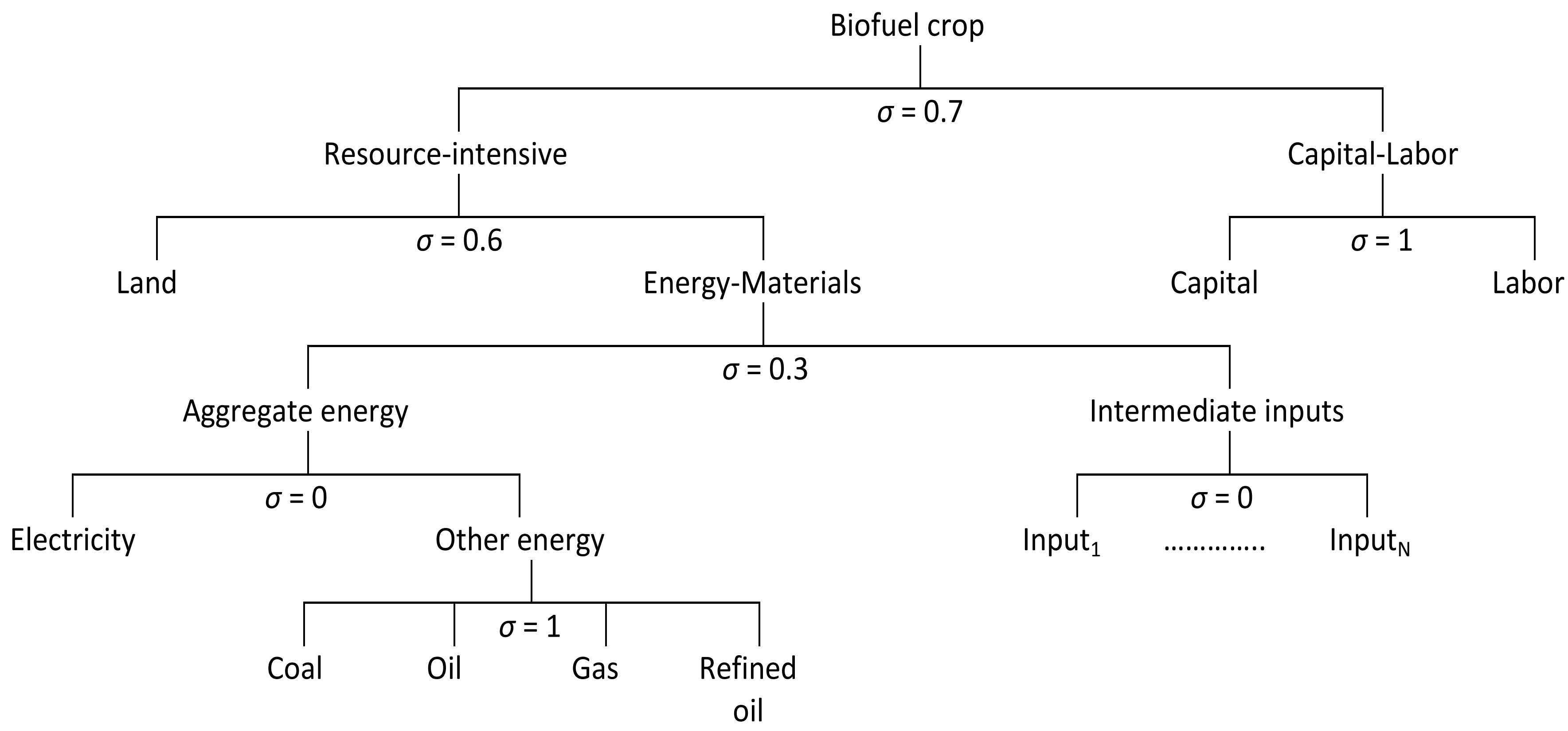


Figure 3. Biofuel crop production

5. Modeling framework

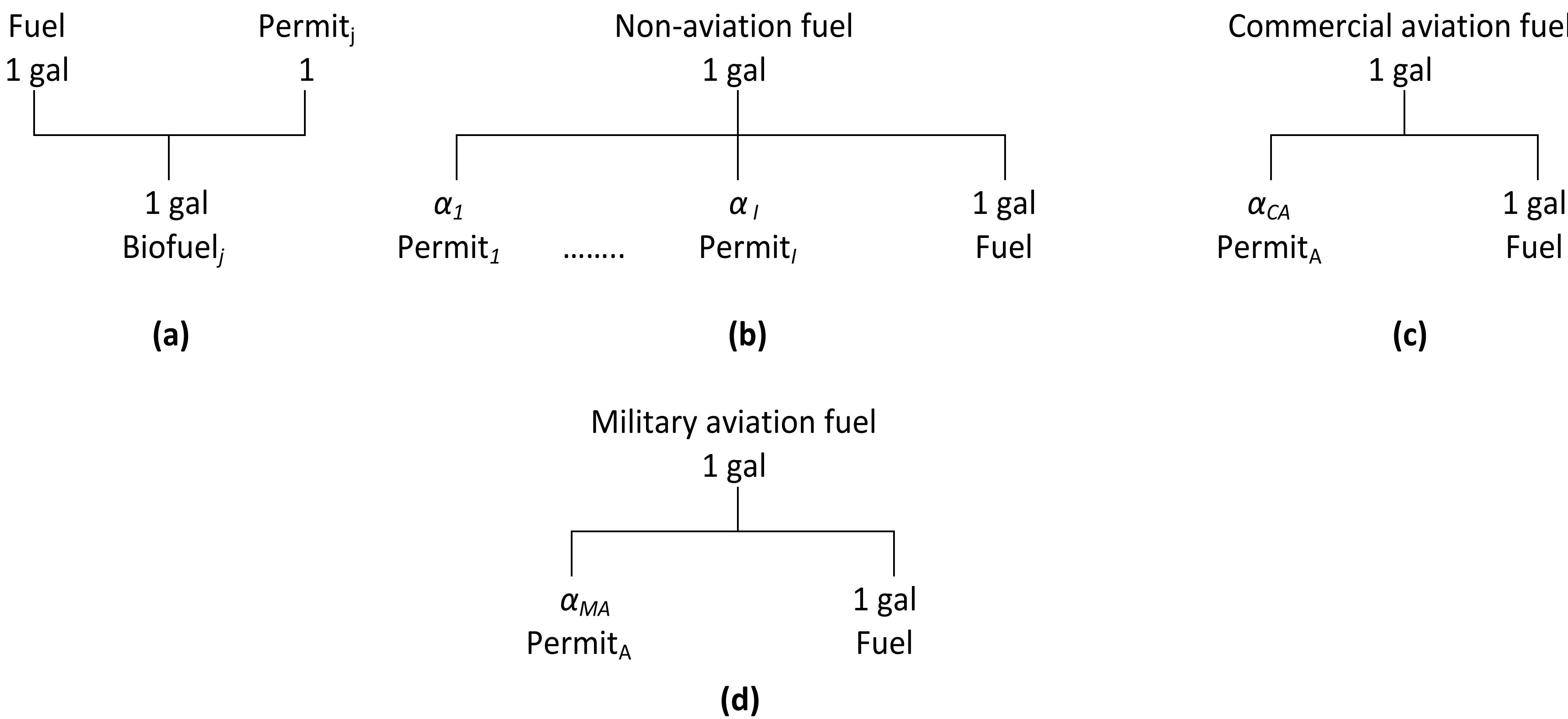


Figure 5. Implementation of RFS2 mandates and the aviation biofuel goal in EPPA-A **(a)** Production of permits, **(b)** Blending of permits into non-aviation fuel, **(c)** Blending of permits into commercial aviation fuel, and **(d)** blending of permits into services

5. Modeling framework

Scenario	Description
RFS2	RFS2 mandates (simulated in all scenarios)
Aviation*	Aviation goal (1b gallons/year) nested within RFS2 mandates
Rotation-Low	Include + a representative oil seed rotation crop, low availability
Rotation-High	Include + a representative oil seed rotation crop, high availability

Note: * Winchester et al. (2013) consider two aviation biofuel scenarios. The Aviation scenario reported in this presentation corresponds to the Include scenario simulated by Winchester et al. (2013).

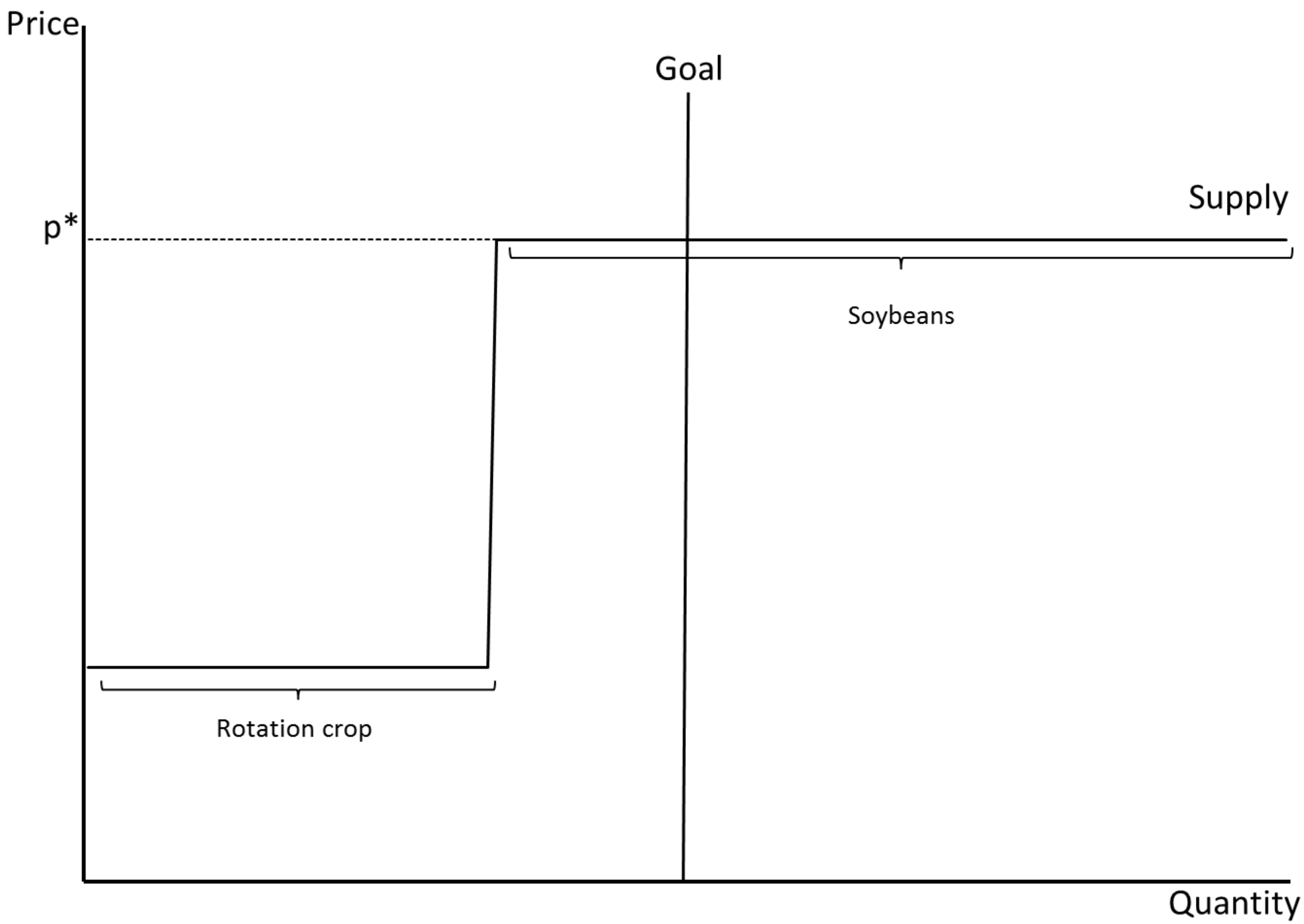
6. Results

Simulation results, 2020

	Reference	RFS2	Aviation	R-Low	R-High
GDP (% change relative to ref.)	-	-0.18	-0.18	-0.12	-0.08
Average price of jet (2010$/gal)	3.41	3.39	3.43	3.42	3.39
Price of HEFA jet (2010$/gal)	-	-	6.08	5.61	3.74
Implicit subsidy/RIN price (2010$/gal)					
Renewable jet subsidy	-	-	2.69	2.22	0.35
Other advanced RIN	-	1.88	1.68	1.29	0
HEFA jet production (gal, bil.)					
From soy	0	1	1	0.5	0
From rotation crops	-	-	-	0.5	1
Price of soy oil (2010$/gal)	2.99	4.25	4.39	3.97	2.49
Fuel use (gal., bil)	20.77	20.74	20.67	20.69	20.72
LC CO_2 (Δ relative to reference)	-	-0.18%	-1.34%	-1.30%	-1.23%
Due to biofuels	-	0%	-0.98%	-0.98%	-0.98%

6. Results

Bio-jet supply, low rotation crop availability



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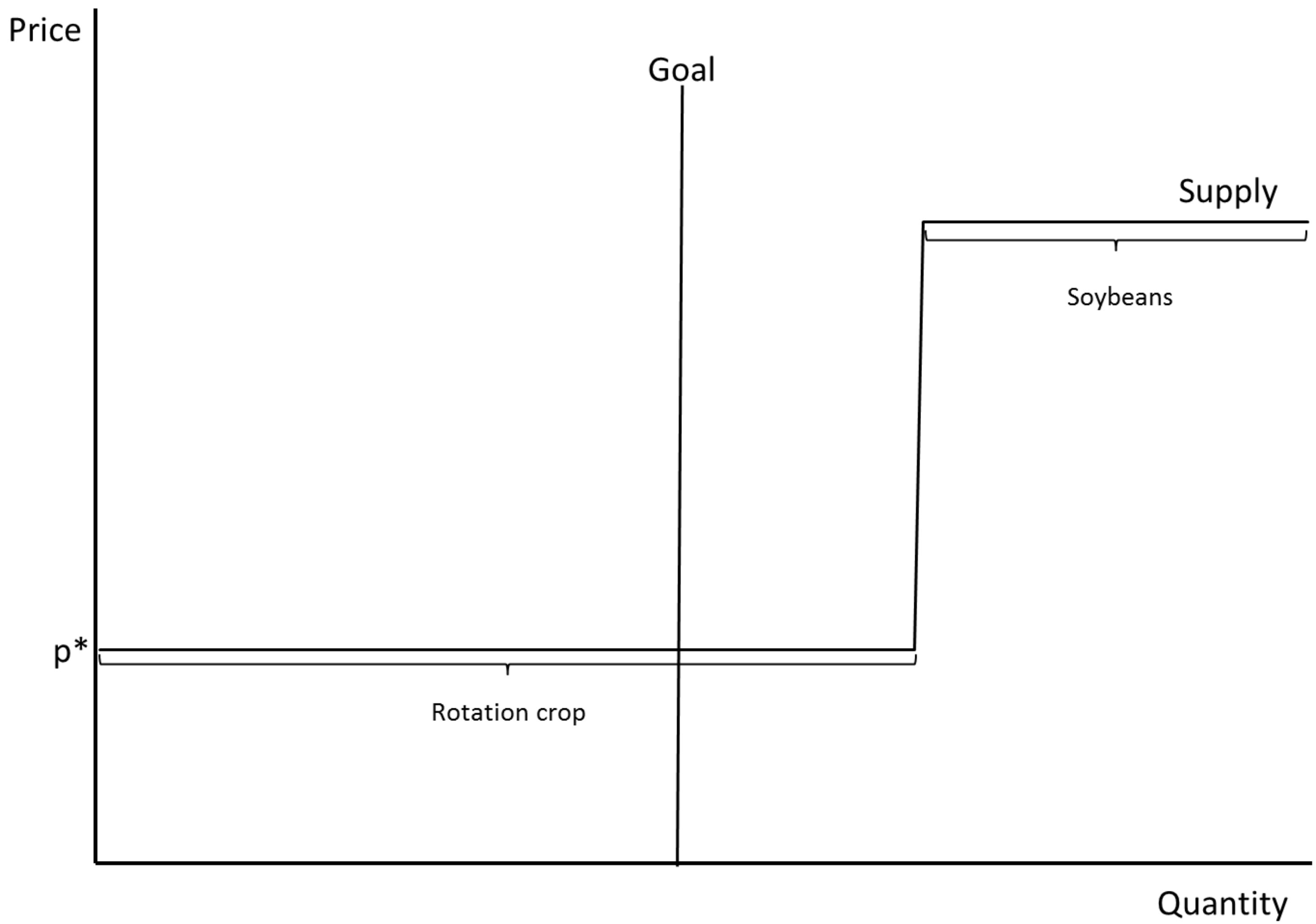
6. Results

Bio-jet supply, high rotation crop availability



7. Conclusions

- Under a HEFA pathway with a soybean feedstock, meeting the aviation biofuel goal requires an implicit subsidy of ~$2.70 per gallon and will increase the average price of jet fuel by ~$0.05 per gallon
- The FFA's aviation biofuel goal will reduce 2020 CO_2 emissions from commercial aviation by 1%
- There are important interactions between the aviation renewable fuel goal and mandates set out in RFS2
  - For aviation pathways that produce other advanced fuels, decreasing the aviation goal or increasing RFS2 other advanced mandate may lower the cost of meeting the aviation target
  - Cellulosic renewable jet fuel pathways with higher production costs than HEFA may be a less expensive option to meet the aviation goal (if cellulosic mandates are enforced)
- Production of a rotation crop grown on otherwise fallow land may significantly reduce the cost of producing renewable fuel

Biofuels in Commercial Transportation*

Niven Winchester (niven@mit.edu)

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March 14, 2013

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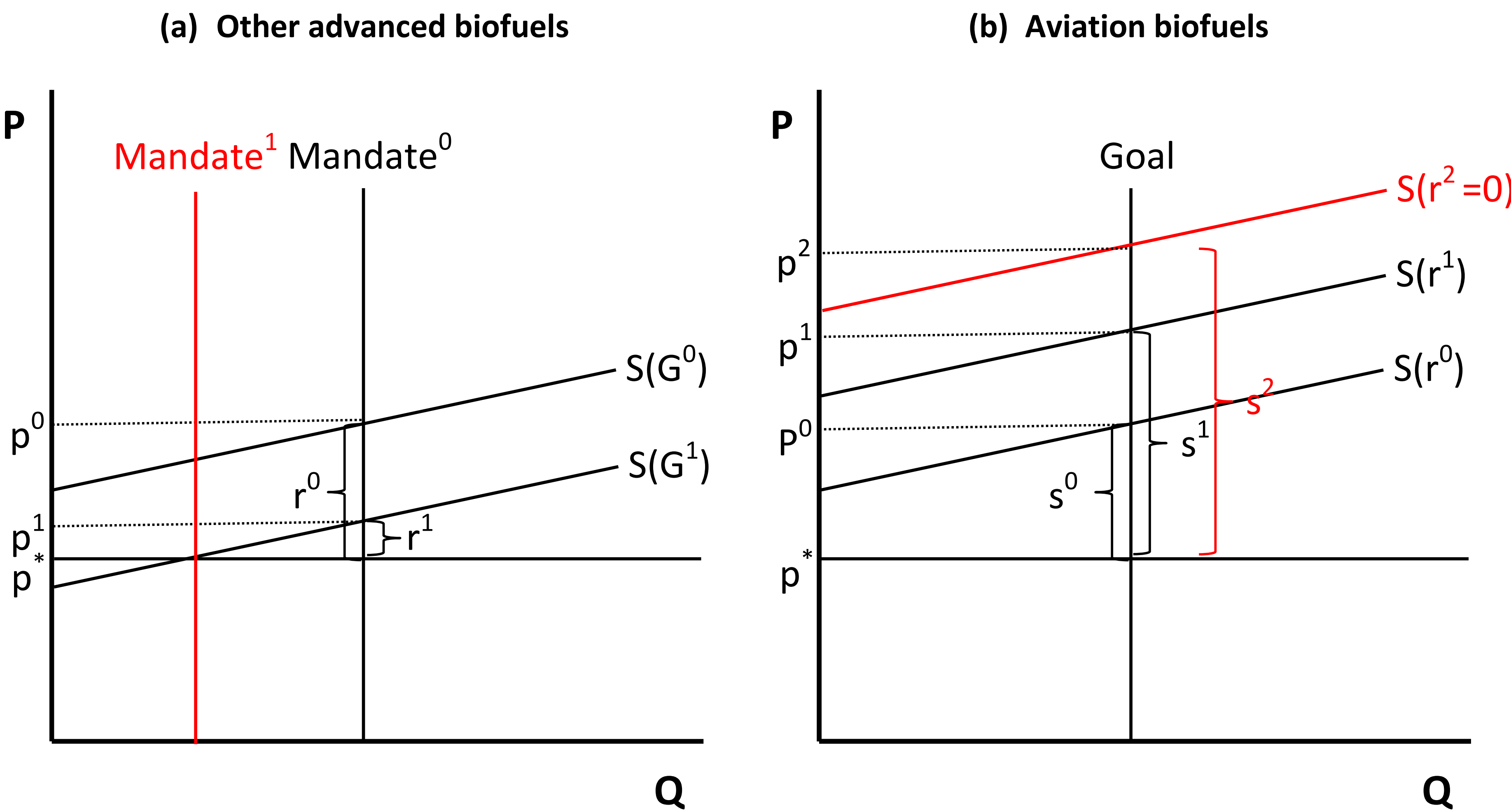
* Winchester, N., D. McConnachie, C. Wollersheim, and I.A. Waitz (2013). Market cost of renewable jet fuel adoption in the Unites States, Joint Program on the Science and Policy of Global Change, Report 238, Massachusetts Institute of Technology, Cambridge, MA.

4. Aviation biofuel goals under RFS2



Including the aviation goal within RFS2 reduces the effective other advanced mandate, further reducing the RIN price and increasing the implicit subsidy required to meet the aviation goal

5. Modeling framework

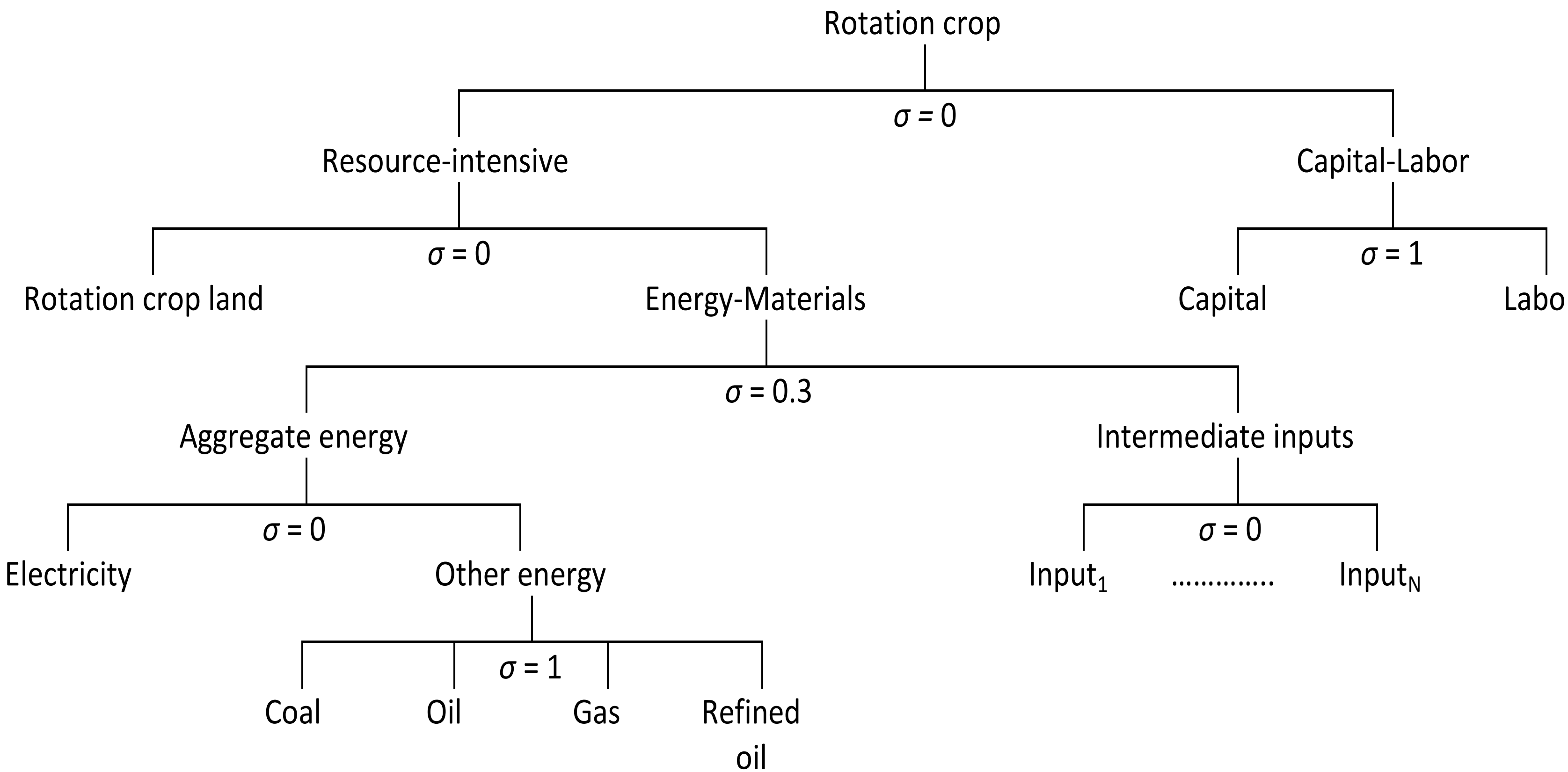


Figure 4. Rotation crop production

Table 2. Core simulation results, 2020.

	Reference	RFS2	Additional	Include	R-Low	R-High
GDP (Δ relative to ref.)	-	−0.18%	−0.20%	−0.18%	−0.12%	−0.08%
Average jet fuel price (2010$/gal)	3.41	3.39	3.43	3.43	3.42	3.39
Price of HEFA jet fuel (2010$/gal)	-	-	6.25	6.08	5.61	3.74
Implicit sub./RIN price (2010$/gal)						
Renewable jet fuel	-	-	2.86	2.69	2.22	0.35
Other advanced[a]	-	1.88	1.81	1.68	1.29	0
HEFA jet fuel (gal, bil.)						
From soy	0	0	1	1	0.5	0
From rotation crops	-	-	-	-	0.5	1
HEFA diesel production (gal, bil.)	0	1	1.5	1.4	3	4.6
Price of soy oil (2010$/gal)	2.99	4.25	4.45	4.39	3.97	2.49
Soybean biofuel land (acres, mil.)	0	13.3	70.1	58.9	23.5	0
Aviation metrics						
Operating costs ($2010, bil.)	267.5	267.3	267.6	267.6	267.5	267.3
Operating revenues ($2010, bil.)	276.3	276.1	276.4	276.4	276.3	276.1
Revenue tonne km (bil.)	283.4	282.9	282.1	282.1	282.2	282.5
Available tonne km (bil.)	350.0	349.2	348.6	348.6	348.7	349.0
Fuel use (gal, bil.)	20.77	20.74	20.70	20.70	20.71	20.72
Lifecycle CO_2 emissions (Δ relative to ref.)[b]						
Due to reduced fuel use	-	−0.18%	−0.36%	−0.35%	−0.32%	−0.25%
Due to biofuels	-	0%	−0.98%	−0.98%	−0.98%	−0.98%
Total	-	−0.18%	−1.34%	−1.33%	−1.30%	−1.23%

Note: [a] Other advanced biofuels are an aggregate of biomass-based diesel and undifferentiated advanced biofuels; [b] CO_2 emission calculations assume that lifecycle CO_2 emissions from HEFA production are 42% of those from conventional jet fuel.

Table 3. Sensitivity analysis results, 2020.

	Product slate trade-offs (Include)		Fertilizer for rotation crops	
	$\sigma^{T}_{D-JNL} = 5$	$\sigma^{T}_{D-JNL} = 20$	**R-Low**	**R-High**
Average jet fuel price (2010$/gal)	3.43	3.43	3.42	3.40
Price of HEFA jet fuel (2010$/gal)	6.24	5.92	5.61	4.39
Implicit subsidy/RIN price				
Renewable jet fuel (2010$/gal)	2.85	2.53	2.22	1.00
Other advanced (2010$/gal)[a]	1.67	1.68	1.29	0.07
HEFA jet fuel (gal, bil.)				
From soy	1	1	0.5	0
From rotation crops	-	-	0.5	1
HEFA diesel production (gal, bil.)	2.4	0.7	3.5	3.5
Price of soy oil (2010$/gal)	4.44	4.34	3.97	2.75
Soybean biofuel land (acres, mil.)	59.1	58.7	23.5	0

Note: [a] Other advanced biofuels are an aggregate of biomass-based diesel and undifferentiated advanced biofuels.

MIT Joint Program Sponsors Webinar Series

March . 14 . 2013 10:30 am - 12:00 pm EDT

Biofuels in Commercial Aviation

Dr. Niven Winchester

Environmental Energy Economist, MIT Joint Program

1. Thank you for joining us today at the MIT Joint Program Sponsors Webinar series.

2. At the conclusion of today's Webinar, online attendees will be presented with a brief survey. We do hope that you will take a few minutes to provide feedback on today's session and make suggestions for future webinar topics. For those participating by telephone only, we welcome your comments at any time to Frances Goldstein by phone (**+1.617.253.2682**) or email (fkg@mit.edu).

3. Today's webinar has been recorded, and will be available in our webinar archive in the 'Sponsors Only" section of the Joint Program website, at:
   http://globalchange.mit.edu/sponsors/sponsorsonly/webinars.html
   (Click on the "Archived webinars" tab)

4. The next webinar in the series will be:
   Date: **TBD**
   Time: **10:30 a.m. - 12:00 p.m. EST**
   Title: **TBD**
   Presenter: **TBD**

5. **XXXV MIT Global Change Forum, 4-6 June 2013, Cambridge, MA, USA**

We do hope you hold these dates on your calendar and plan to attend.
Details will be sent as we move closer to the events.

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