Global Hydrocarbons Supply Model

Biofuels Component Design Report

Prepared for

The Energy Information Administration

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Executive Summary

The expansion of the use of biofuels as a source of energy, and its identification by many as a key part of energy strategy for the future means that despite the fact that at the moment biofuels share is relatively small, its incorporation into the GHySMo modelling framework deserves careful consideration. In the Biofuels Component Design Report (BCDR) a suggested framework is laid out and the issues regarding the incorporation of biofuels in the GHySMo are addressed (from here on the biofuels module will be referred to as (BioGHySMo)). Choosing the appropriate specification of the biofuels model involves a unique set of issues:

- Biofuels have been produced from a wide variety of feedstocks. In 2014 fuels come mostly from grains and oilseeds. Competition with food uses and the subsequent impact on prices is a common criticism of biofuels, with policy makers typically now looking for alternative methods of sourcing feedstocks. Completely divorcing feedstocks from food markets is very difficult however. GyHSMo will need to incorporate some representation of agricultural markets. It is suggested that key relationships are incorporated through reduced form equations based on existing, more comprehensive agricultural models or through parameterization using estimates available in the literature.

- Large scale biofuel production is a relatively recent phenomena in many countries and this presents some challenges for modelling. Going beyond a 10-year horizon raises issues of technological advancement, and the development of new fuels and processes that might change central relationships. In the BCDR key areas of uncertainty are identified.

- In the BCDR the key relationships between the biofuels and fossil fuels markets are identified. These can be complex, with biofuels being both a compliment and a substitute for fossil fuels in some instances. Biofuels are also linked to energy markets through their cost of production, through key inputs into the production of the raw material such as fuel and fertilizer. These links become crucial if in the longer term a more significant share of energy comes from biofuels.

- Until now most production has been concentrated in a small number of regions, Brazil, Europe, the U.S. and Malaysia/Indonesia. In the short run these regions will continue to be the most important producers. But BioGHySMo must consider the development of different producers –

these are not easy to predict, however, as they will be tied to policy, feedstock viability and technology used.

- Until now, there has been a large overlap between regions producing biofuels and those consuming them given that a large motivation for the policies has been energy security and the support of domestic industries. Over time this link is likely to be broken as other policy objectives increase in importance (e.g. climate change) or markets develop based on their competitiveness with fossil fuel equivalents.

- Policy has played a key role in the sector's development. Much of this policy has operated on the *demand* side of the market. Nonetheless the impact of the policy has also been felt on the *supply* side as evidenced by the fact that the three big consuming regions are also the three big producing regions. The guarantee of market for product has undoubtedly helped facilitate investment in the U.S. and the EU in particular. Incorporating this effect into the supply side is a challenge.

- Given the importance of agriculture, and the uncertainties of how the biofuel sector will develop in terms of fuels, place of production and use, and their interaction with the fossil fuel complex, it will be important to build a network of experts. Also it will be necessary to revisit the model frequently to incorporate changes in policy and technology. Associated with this will be the need to make the workings of the model transparent in particular the assumptions that are made regarding the nature and operation of policy and the progress of technology.

In the first part of the BCDR an overview of the model and the key interactions with the other parts of GHySMo are identified. The key links are with the transport fuel sector – although power generation could become more important in the future. In the second part the key parts of a potential BioGHySMo are outlined through a system of equations that could be incorporated into a more linear programming framework, or estimated as part of a dynamic partial equilibrium approach. Suggestions for parameterizing the model in the absence of data are included. Data sources are discussed in light of the need for a consistent set of easily updatable data. Finally, a framework for the identification and presentation of policy assumptions is developed.

The model framework is based on a simple set of equations that can be implemented in all the regions to be modelled, and adapted for important countries where necessary. For biofuels, the challenge for the model is the parameterization of the model and the correct incorporation of policy, and a simple underlying model structure would facilitate this.

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1. Overview

The Energy Information Administration (EIA) is exploring the development of a dynamic representation (referred to here as GHySMo) of the global production, processing, transport, distribution, and storage of natural gas and liquid fuels. The ultimate purpose of this project is to improve EIA's capability to represent international markets (i.e., prices and commodity flows) for liquids and natural gas under a variety of assumptions. The primary function of the model will be to replace the existing upstream and midstream models of petroleum and natural gas within the World Energy Projection System Plus (WEPS+) used to produce EIA's International Energy Outlook. A secondary function of this development project is to identify a reasonably seamless process, based on GHySMo or its results that will allow for a consistent international representation of the gas and liquids markets to be incorporated within EIA's National Energy Modeling System (NEMS) used to produce EIA's Annual Energy Outlook.

This document is one of several overlapping Component Design Reports covering the different aspects of the GHySMo, dealing with the biofuel component (BioGHysMO). The GHySMo system will operate in standalone fashion, with the objective that improved tractability will facilitate rapid turnaround of development, validation, and analyses. The aim is to minimize dynamic feedback from outside the liquid and gas markets. The challenge for the BioGHysMO is to produce a framework that allows the envisioned deep-dive analysis of specific countries, regions or policies through the specification of the appropriate economic and biological relationships without over-burdening the effort with excessive data requirements of difficult parameterization or validation issues.

The modelling of the biofuels sector provides some unique challenges. The market for biofuels has changed dramatically over the past decade. It is likely that markets will continue to evolve, and in ways that are hard to anticipate, both in the development of new market and new fuels. Renewable fuels of all types are typically identified as potential sources of energy with attractive characteristics for policy makers, including environmental benefits of improvements in energy security. Biofuels are sourced from feedstocks that are linked either directly (through competition in markets such as the corn market) or indirectly (through competition through land, such as growing grasses on pasture land) and if these important interactions are not considered then the costs of any biofuel related policy (or the competitiveness of biofuels at high levels of output) will be overstated.

Given the sector has grown largely as the result of national (or regional in the case of the EU) policy, then it is no surprise that the evolution of the sector in the important regions largely reflect the policy objectives and economic characteristics that prevail there. In the **U.S.** a mixture of farming interests and energy security objectives resulted in the introduction of an amalgamation of incentives including tax credits, imports tariffs, and a renewable fuel mandate. Ethanol from corn production increased rapidly, partly in response to these incentives (and the security that they offered) but also to economic incentives as the rise in oil price made corn ethanol competitive. Corn ethanol remains the dominant fuel in the U.S., mostly consumed in the form of low level (10 percent or less) blends. A variety of other feedstocks are also used such as soybean oil, rapeseed oil, wastes fats and oils from livestock or commercial food sectors, and other grains in small quantities. Other fuels that are consumed are in low level biomass based diesel blends, high level ethanol blends (such as E-85 or E-15) and in certain other small sectors such as military use.

Brazil is the second largest ethanol producer as a result of competitive sugar based ethanol and government policy that has sometimes supported the biofuels industry in order to support the sugar industry that underlies it. Brazil operates a mandate for ethanol blending in gasoline (currently standing at 25 percent but with proposals for this to increase), and use is split between this fuel and hydrous ethanol that can be consumed in Brazil due to the existence of a large flex fuel enabled fleet (in contrast to the U.S., where the flex fuel fleet is small). The price of gasoline in Brazil is regulated, and is adjusted according in part to objectives related to inflation, or the needs of the sugar sector. Brazil production and use is almost entirely sugar based ethanol and soybean based biodiesel.

Brazil has, in the past, been a major supplier of both the U.S. and EU markets. In the **EU** biofuels policies are often driven by environmental concerns (particularly to meet greenhouse gas emission targets) and energy independence. As concerns regarding the actual environmental impact grow, enthusiasm for biofuels has waned. In the EU biomass based diesel is the prominent fuel and is made mostly from rapeseed, with ethanol coming from wheat and corn. Barley, other cereals, sugar, soybean oil and other fats and oils are also used, with the EU using a wider variety of feedstocks than other major producers. The wide array of feedstocks reflect member state level policies that favor domestically produced crops, in association with policies regarding consumption that include sustainability objectives.

The brief introduction to these major biofuel producers outlined above is included to illustrate some key issues for model specification:

- Policies are different in each of the regions and therefore the model structure should be flexible enough to represent these differences.
- Policies change over time as policy objectives change or markets move. Selection of the appropriate policy assumptions that underlie the model is a crucial part of the process. In some cases the policy, especially in the long term, can be viewed as endogenous to the broader energy sector.
- Demand for biofuels has stagnated in many of the regions - in the U.S. due to filling the low level blend market, and in the EU due to member states' reluctance to pursue the ambitious targets that the EU set out. In Brazil, investment in the sugar/ethanol sector has slowed as commodity prices fall, but also as the potential U.S. and EU markets shrink due to policy changes. In this climate investment in new production facilities has fallen.
- In both the U.S. and the EU the failure to reach targets that had been established comes in part as a result of the failure to develop commercially viable advanced fuels that are not produced from "food crops". In part this reflects overly optimistic projections of their viability, but it also illustrates the uncertainty surrounding the viability of these fuels.

So the current situation can be characterized as one where the drivers of the recent "boom" in biofuels are no longer inducing expansion in the major three regions. Other major users of biofuel, such as Canada and some Asian countries have consumption linked to mandates. Changes in demand for transport energy can therefore have an impact on biofuels demand but the current structure of the biofuels industry could therefore be derived fairly simply from a modelling perspective. The example of the U.S. shows, however, that under high enough oil prices, ethanol can be competitive with fossil fuels in low level blends. The model needs to be able to capture this effect as it is a potentially large market, but logistical concerns and fuel specification regulations in different countries will impact on the development of that market.

Global production of fuel ethanol is shown in Figure 1 as sourced from FO Lichts. The U.S. was the major source of growth in ethanol production over the last decade, but since 2010 growth in production has slowed in both the U.S. and globally. Production is dominated by the three producers discussed above. Regional disaggregation in BioGHySMo however would need to consider regions where production could occur in the future as well. The biggest uncertainty in this regard is probably **China**, where history

dictates that agricultural policy has a strong element of food security. As the country grows, and moves to more open markets, it could be that this objective is weakened and biofuel production be pursued for other reasons – environmental or energy security for example. Given the huge potential market and the continuing central control, production could expand rapidly. China is currently the second largest producer of corn, and the fourth largest producer of soybeans globally.
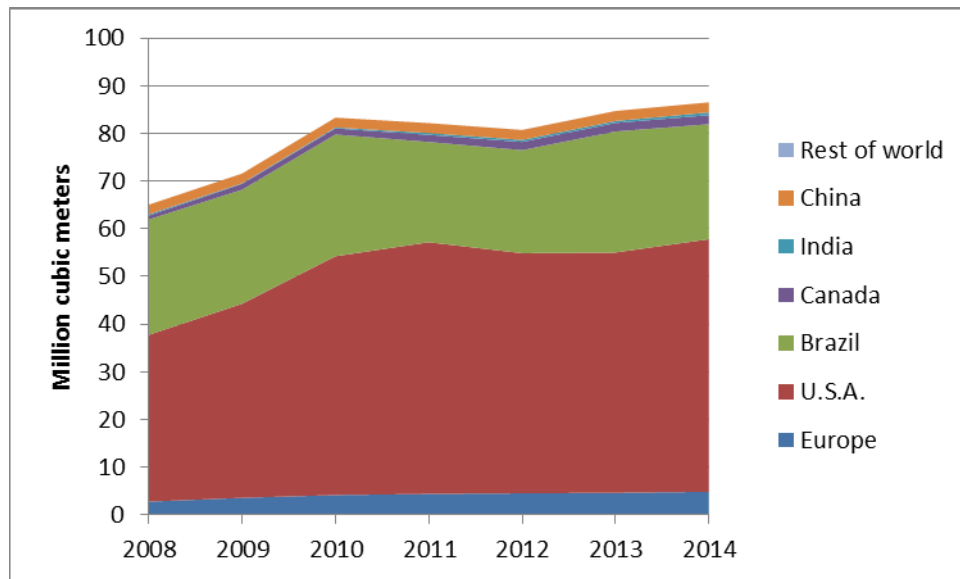
Figure 1:Global production of fuel ethanol. Source: F.O. Lichts.

African production of ethanol is expanding, albeit from a very low level. As in China, food security considerations are important. But countries might still implement policies to increase production, in South Africa, for example, policy to increase ethanol from sugar is being proposed as a way to help producers in that sector. As well as being very influential in energy markets, **Russia** and **Ukraine** are increasingly important suppliers of grain and oilseeds onto the world market. Some of these products are exported to Europe and potentially used to produce biofuels. These countries therefore potentially face a choice, export raw commodities (grains, oilseeds), or lightly processed versions (such as vegetable oils), biofuels or presumably in the case of Russia, blended fuels. At present biofuel production in those countries is minimal, but could evolve in the future if there was an effort to capture some of the upstream value added.[1] The model structure that is proposed in section 2 of the BCDR will include representations of these regions, but it is a mix of policy and economics that is likely to result in the

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[1] Note that the U.S. exports raw commodities, biofuels, and blended products.

development of biofuel generation in these regions so it will be necessary to monitor policies in particular on at least an annual basis.

The situation is similar for biodiesel, FO Lichts estimates of production of FAME is shown in Figure 2. There is a strong link between policy and production. The U.S., EU and Brazil are major producers. For biodiesel, in contrast to ethanol, Europe is the dominant producer. Production is spread over more countries than is the case for fuel ethanol, with several Asian countries producing biodiesel from palm oil. Production is centered in the large oilseed producing areas. Potential new entrants into production would again include **China** or **Russia/Ukraine** for the reasons that have been outlined for ethanol.
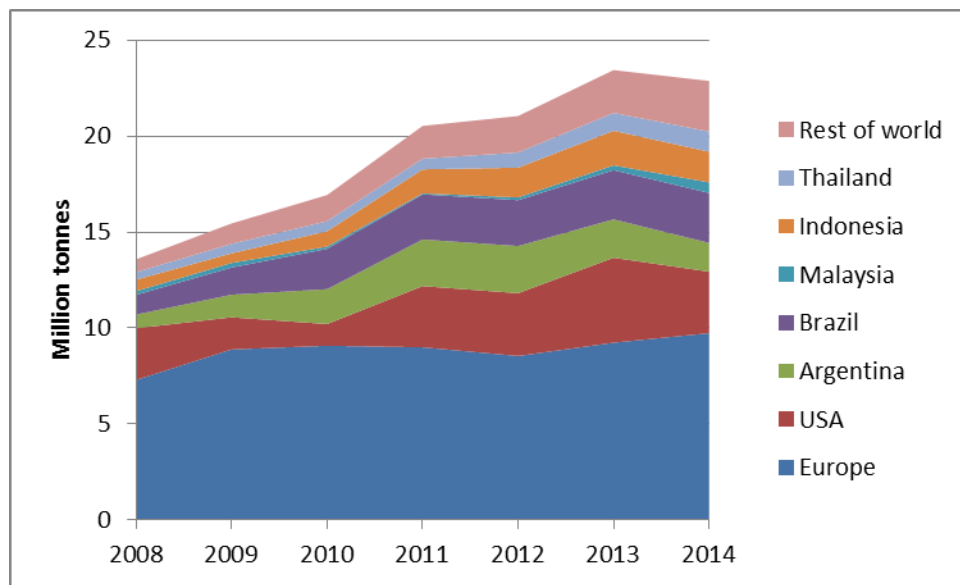
Figure 2: Production of FAME. Source: F.O.Lichts.

Looking forward, the mix of biofuels is likely to diversify away from "first-generation fuels" (from food crops such as grain or vegetable oil), such as what is termed "conventional" ethanol in the U.S., and toward the next generation of advanced biofuels including cellulosic biofuels despite the former's lower costs. These fuels could be subject to similar blending limitations as current biofuels, or produced in the form drop-in fuels produced from emerging technologies that could avoid current blending limitations.

In addition, the interaction between biofuels and petroleum fuels will depend in large part on the role of developing economies around the world and their effect on crude oil and petroleum fuel demand which will impact fossil fuel prices and the competitiveness of biofuels. As more countries may begin playing greater roles in the global biofuel market, and trade flows will change. New uses for biofuels could also emerge or expand, such as for aviation fuel or military use in a variety of vehicles.

In this report a global modeling framework that can accurately represent the current state of the biofuel market yet be flexible enough to account for the market's evolution in the medium- to long-term future is developed. The goal of the Biofuels Component Design Report (BDCR) is to describe a global biofuel supply model that can fit within the within the GHySMo framework (i.e. BioGHySMo) and interact with other modules within GHySMo, including upstream production, downstream processing, and logistics/distribution of natural gas and liquid fuels. The following two sections will outline the overall BioGHySMo design as well as the specific connections to the other GHySMo modules.

1.1. Overall BioGHySMo model design

Biofuel models within the academic literature come in all shapes and sizes (de Gorter et al., 2011; Du and Hayes, 2009; Thompson et al. 2011). Based on the needs of the current project, we recommend BioGHySMo take the form of a partial-equilibrium structural model that is dynamic, flexible, and can be adapted to LP-style solutions that fit well with the current modeling structure used by EIA for the *Annual Energy Outlook* and *International Energy Outlook* publications. In this section BioGHySMo's general structure and interaction with the overall GHySMo/WEPS+/NEMS structure is examined. A detailed specification of the biofuels component is outlined in Section 2.

Product coverage

A key issue in the specification of the model is the granularity of product coverage. Increasing the number of fuels results in a greater level of analytical ability but at the cost of additional data requirements which are often the constraint in biofuel models. The Statement of Work identifies five fuels for consideration into the model; ethanol, biomass based diesel, and biomass to liquid (BTL) fuels. Other fuels for consideration would be jet fuels or those used in energy generation. One issue is whether or not each category should be disaggregated further by feedstock. For example, the FAPRI-MU biofuel model currently disaggregates U.S. ethanol production into four sources: corn, non-corn grains (e.g. sorghum), sugar, and biomass. Likewise, biomass-based diesel is modeled according to soybean oil, non-food grade (i.e. distillers) corn oil, other fats and oils (including canola), and cellulosic feedstocks. In some respects this is a more disaggregated approach than NEMS, with a different breakout of biofuel

feedstocks in other regions (Table 1 and Table 2). From a flexibility standpoint, it would be advantageous to settle on a general framework, perhaps more similar in scope to NEMS that, regardless of feedstock, can be applied within each region subject to data availability

Table 1: Important ethanol feedstocks by region.

Region	Barley	Cassava	Corn	Molasses	Rice	Rye	Sorghum	Sugar beets	Sugar cane	Tapioca	Wheat
United States			X								
Brazil									X		
OECD Europe	X		X			X	X				X
Other Non-OECD Europe and Eurasia	X		X			X	X				X
China		X	X								X
Canada			X								X
Other Central and South America			X						X		
Other Non-OECD Asia		X		X					X	X	
Australia/New Zealand			X								
India				X			X				X
Japan			X			X					X
Africa											
Mexico											
Middle East	Very little production/feedstock information not available										
Russia											
South Korea											

Source: F.O. Lichts, USDA-FAS GAIN reports (various issues)

Aggregation of feedstocks in most cases is possible. As noted above, countries that are large producers of biofuels are largely large producers of the feedstocks that they use, and therefore tend to trade those commodities and are linked to world markets. That means that for grains, there are strong links between the price of the corn that producers in the U.S. pay and the price of wheat that producers in the EU pay. Using a single representative price or production method for "grain" or "vegetable oil" is defensible. In other cases, such as the use of cassava in developing countries this would not be so appropriate.

Table 2: Important biomass-based diesel by region.

Region	Corn oil	Inedible fats/tallows	Palm oil	Rape oil	Soy oil	Vegetable oils
OECD Europe		X	X	X	X	
Other Non-OECD Europe and Eurasia		X	X	X	X	
United States	X	X		X	X	
Brazil					X	
Other Central and South America			X			
Other Non-OECD Asia		X				X
China		X		X	X	
South Korea		X			X	
Canada		X	X			
India		X				
Australia/New Zealand		X				
Japan						
Africa		Very little biodiesel production/				
Mexico		feedstock information not				
Middle East		available				
Russia						

Source: F.O. Lichts, USDA-FAS GAIN reports (various issues)

Biofuels and fuel demand

The responsiveness of biofuel supply to blend component and product demands depends, in large part, on assumptions made regarding transportation and energy policies. Tax credits and subsidies have, historically, played a large role in supporting biofuel production in the U.S. For the most part, those production incentives have given way to more demand-driven support from oxygenate replacement and the Renewable Fuels Standard (RFS), and those are expected to play a continued role for the medium-term future at the very least. One outcome is that, barring rapid deployment of drop-in fuels or a cheaper source of octane, ethanol blends are unlikely to fall much below 10%, and ethanol demand will be tied to motor gasoline consumption to an extent. Under current Corporate Average Fuel Economy (CAFÉ) standards, ethanol consumption would be expected to fall unless there is an expansion of mid- to high-level blends (i.e. E15-E85)[2]. Such expansion is still possible under certain policy assumptions which,

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[2] Some would consider E-15 a low level blend.

in addition to a global export market, could imply a level of support for ethanol production near current levels.

The U.S. experience is mirrored in the EU where mandated blend rates are the preferred policy used by member states to meet biofuel objectives. These blend rates are typically below the 10 per cent that prevails for ethanol in the US, and there is therefore probably some possibility for these rates to rise. But biofuel use will remain tied to fuel demand. For the EU, discriminating between gasoline and diesel markets is important as in some cases the mandatory blending rates is different for the two fuels. Also, it could be that consumption of the fuels could take different paths in the future. The increase in diesel cars means that gasoline use is likely to continue its downward trend. Overall fuel use has stagnated in recent years for the EU-28, but it is likely that this is in part due to the recession. Income growth could see fuel use (and therefore diesel use) rise in the coming years, especially in the new member states where incomes will rise fastest from the current levels of low income.

Conversion rates

Yields based on mass and energy balance are quite appropriate in models of petroleum product refineries, but are perhaps impractical for biofuel production models. As these are generally mature production processes in which yields are unlikely to change from current levels (e.g. ~2.8 gallons of ethanol/bushel corn, ~0.13 gallons biodiesel/pound oil), it might be more practical to assume fixed yields or a slight trend increase to account for marginal improvements in efficiency. One exception to this rule might be related to cellulosic biofuel production. The cellulosic industry is still in its infancy, so production efficiencies and substantial yield improvements cannot be ruled out entirely. In that case, yield estimates would need to be limited by theoretical yields based on mass and energy balances.

The role of processing and production costs will be further elaborated in the discussion on capacity expansion. In general, existing biofuel production capacity and capacity utilization will be influenced by the net returns beyond the costs of processing and production. Two important components of the net returns are the input costs related to agricultural feedstocks, which should come from the reduced-form agricultural models, and the natural gas input costs, which should come from the natural gas module of

GHySMo. Increases in technology can be incorporated through conversion rates in the returns calculations used in the production equations.

Regional Representation

In reality, all of the above features are likely to differ between each of the regions represented in the model. Feedstocks, policies, yields, and costs will all reflect local idiosyncrasies further highlighting the advantage of having a flexible framework for each representative biofuel that can be applied within each region being modeled. For maximum flexibility, each country (or, in some cases, sub-region) would be modeled independently and results would be aggregated to the appropriate regional level to interact with WEPS+ and NEMS. Only a select few regions, or countries therein, have had dominant roles in the global market for traditional biofuels to date (Table 2). One option might be to continue modeling at a broader granularity and make use analyst judgment to make disaggregation assumptions that would allow WEPS+ and GHySMo to connect more readily. It is possible conditions in those other regions (Table 3). It is possible conditions could change over time, and non-traditional fuels like BTL could become more prevalent in non-traditional areas as those industries mature.

Table 3: WEPS+ regions and dominant biofuel comparison.

Region	Significant role in biofuels at present?
OECD America	
United States	Yes
Canada	No
Mexico/Chile	No
OECD Europe	Yes
OECD Asia	
Japan	No
South Korea	No
Australia/New Zealand	No
Russia	No
Other Non-OECD Europe and Eurasia	No
China	No
India	No
Other Non-OECD Asia	No
Middle East	No
Brazil	Yes
Other Central and South America	No
Source: EIA-International Energy Statistics	

Another option might be to include much of same general modeling framework across all the regions and use simplifying assumptions to streamline the models in the low-key regions. This option has the benefit of maintaining adequate flexibility in case future market conditions change. There would be a higher upfront cost, however, in the form of the overhead necessary to incorporate the framework as well as identifying, obtaining, and maintaining the appropriate data, if they are available

In practice the disaggregation of the model depends on data availability and the resources that are available to monitor policies in those regions. It should be possible to obtain production data from any of the countries producing commercial levels of biofuels and so regional representation could be determined by that used in related modules. In Table 4 a manageable break out of regions that would capture the major producers is shown, with shaded areas signifying which commodities would be covered in each region. One important question would be whether the EU should be broken out into different member states. Although the EU determines overarching policy, member states in practice set their own legislation for the implementation for broader targets. Data for different EU member states supply and use of biofuels is available so in principle more disaggregation is possible, although price information for the different member states is harder to source.

Table 4: Example regional coverage in BioGHySMo, supply driven.

	Ethanol	Biomass based diesel
United States		
Canada		
Other North/Central America		
EU*		
Other Europe		
Malaysia	Not significant	
Indonesia	Not significant	
Thailand	Not significant	
China		
India		Not significant
Other Asia		
Brazil		
Argentina		
Columbia		
Other South America		
Rest of world		

*EU could be disaggregated if necessary as data is usually available

Environmental discharges resulting from biofuels production and use

The environmental impact of biofuels has been a very contentious issue. There are plenty of estimates of, for example, the greenhouse gas (GHG) implications of certain biofuel production processes and it would be a simple matter to use these conversions to recursively produce estimates based on the model projections of production. The impact on land use change has attracted a lot of attention, but determining the extent of the change due to biofuels production is difficult as the impact of increasing production of any particular biofuel will depend on the feedstock, the region where the increase takes place, and prevailing market conditions. Policy makers in both the EU and California have struggled with the land use issue regarding the impact of changes in policy. Even production using feedstocks that are targeted to use "marginal" land also impact commodity markets and therefore the production of feed and animals through indirect competition, for example through the reduction in pasture area triggering a substitution for grain based feed.

In certain scenario analyses, details regarding plant-level environmental discharges would be ideal. The availability of these data, as they relate to individual biofuel production facilities, presents a challenge. As in the previous point, certain simplifying assumptions could be made to streamline the modeling process while ensuring adequate flexibility if and when data become available. Aggregation across regions, or at least across some countries, may be feasible in the short-term using information from existing life-cycle analysis (LCA) literature or models (e.g. GREET).

Representation of policy

In most cases, it would be feasible to represent renewable laws and regulations on a country-by-country basis where they exist. Similar policies could share a common framework across countries/regions that would provide flexibility and require minimal changes within the model as policies change. The model would require a database of such policies be maintained, but here it would be useful to form links with one of the other modelling systems that use such information such as FAPRI or the OECD/FAO both of whom have global representations of biofuels (or private institutions such as LMC or FO Lichts). This would help to ensure that the database be kept current with up-to-date information.

One concern would be the determination of the appropriate framework for a complicated policy, such as the RFS in the U.S. Although it seems unlikely that the renewable fuel volumes contained in EISA will be implemented by EPA, an analyst could make such an assumption in developing the framework. To the extent such an assumption seems unreasonable, other assumptions will have to be made regarding the implementation strategy in the future. FAPRI-MU has struggled with this issue in the past, as well. Previous FAPRI-MU Baselines have incorporated assumptions regarding EPA's utilization of the waiver authority granted in EISA and, more recently, EPA's proposed methodology for setting the 2014 RFS requirements (including within-year percent standards rather than fixed volume requirements). More details regarding the determination of policy are included in the Knowledge Management System section.

Chemical and energy characteristics of liquids produced

This feature of the model will depend, in large part, on the available data and the desired format of the output. The chemical and energy units will need to be standardized across the representative frameworks to facilitate model interaction within BioGHySMo, other GHySMo modules, and in relation to WEPS+ and NEMS. One option might be to use native units (metric or English) within each regional model and convert volumes to standard units as the information is passed from one model to another. Final output can be standardized to common units for reporting purposes. This has the benefit of allowing unit familiarity to assist in model development and troubleshooting. However, it increases the likelihood of mismatched units and model communication issues. The other option would be to convert all the data to a common standard to be applied in each regional model. In this case, model interaction might be more streamlined, but there's an upfront cost in terms of data management. Conversion factors consistent with those used in WEPS+ and NEMS will be necessary to ensure consistent results.

Capturing industry changes

In the FAPRI-MU model, biofuel production is determined by operable capacity and the associated capacity utilization rate. Both are endogenously determined as functions of the net returns to production. Operable capacity expands as net returns increase, and it declines to some extent as production facilities age. Utilization rates are modeled as a logistic curve bound between 0 and 1. This

framework can easily be extended across biofuel types and across regions within BioGHySMo. Careful attention must be paid to the parameters to ensure the appropriate expansion response within each region. This framework should not present any issues in aggregation to match the reporting levels of WEPS+ and NEMS.

For short run analyses it is necessary to represent capacity constraints. In the U.S. for example, a short run large increase in ethanol production would be difficult given high levels of capacity utilization, and so an increase in demand could push ethanol prices higher, especially given the current slow-down in Brazilian production facility expansion. For biodiesel, however, excess capacity in the U.S. and the EU means that production can respond more quickly to an increase in demand. In analyses that look at the longer run the issue of capacity constraints are not so important.

Modeling new biofuels, fuels or production processes

The general framework used for established biofuels in BioGhySMo can be extended to other technologies – both those that are currently operating at a demonstration level and those that are yet to be developed but are anticipated to emerge over the projection period. Approaches that have been taken in other energy areas could inform the approach here. In the current form of WEPS+ for example, CTL and GTL are produced in the Coal and Natural Gas modules, respectively. The supplies of CTL and GTL are inputs to the Refinery module of WEPS+ as both would be considered substitutes for petroleum based liquid fuels. With respect to BioGHySMo, there are elements of CTL and GTL estimation that can be carried over to new biofuel technologies.

To estimate the expansion of CTL and GTL, the current WEPS+ framework uses an "optimism" factor that is, essentially, a cost multiplier to account for the unexpected costs that tend to occur in emerging technology industries. The idea is that this multiplier as an additional hurdle to initial capacity expansion. The optimism factor is endogenous and declines to unity (i.e. no multiplier effect) as the industry matures and more capacity is built.

A similar mechanism can be put into place on a regional level as entirely new biofuel industries (e.g. second-generation biofuels, BTL, etc.) emerge in traditional biofuel production regions or as traditional biofuel industries emerge in new markets. For instance, the cellulosic biofuel industry in the U.S. continues to face this hurdle as the first commercial plants have experienced unexpected technological and financial setbacks. Likewise, one might expect even a conventional ethanol refinery to experience

difficulty if it is the first such foray into biofuel production within a given region. In a medium- to long-term outlook, the hurdles will either prove too much for the industry and capacity will never really expand, or the industry will be profitable enough to mature and allow capacity expansion to occur. Relative prices among the competing fuels and feedstocks become very important in this type of representation, so having the appropriate feedbacks to an agricultural model and the other GHySMo modules becomes imperative.

The magnitude of the optimism factor will likely vary according to production technology and region. Established biofuel production technologies emerging in new regions will not require as large a multiplier as new production technologies. Analyst judgment will play a key role in determining the appropriate level and the rate at which the optimism factor declines.

Time in BioGHySMo

The linkage of an agricultural model raises issues regarding the appropriate time periods to be modelled. In agriculture modelling is often carried out on a crop year basis, the definition of which will vary among commodities. Synchronizing these years, with each other and to calendar years or financial years to link with other sources of data takes careful consideration. For BioGHySMo the fact that only a reduced form representation is used should simplify this and FAPRI, for example, is moving to a system where biofuels are solved on a calendar year basis. Since the world prices can be calculated on a calendar year basis from monthly data this should not be a problem. Of course whatever model is chosen to calibrate the feedstock part of BioGHySMo will likely be on a crop year basis but the parameters derived should be transferable. With care projections of crop year prices can be converted to calendar year for the calibration of a baseline outlook if needed. One area of concern could be the sourcing of feedstock use by calendar year.

Seasonality of production is a feature of agricultural systems, and higher frequency models are often used for different applications in agricultural economics. Problems with data and the complexity of the modelling system probably make this outside the scope of GHySMo. One important consideration is that sometimes policy is made on a crop year basis (e.g. Brazil). If fuel production moves away from grain and vegetable oil to other agricultural products this issue might become more pronounced, given the high

costs of storing such products. If an issue arises that requires different accounting periods or higher frequency models these could be developed outside of the BioGhySMo framework.

1.2. Connections between upstream module and other GHySMo modules

BioGHySMo will have few, if any, direct links with the upstream module, but there will likely be several links with the downstream liquids, logistics, and gas market modules (Figure 3). The extent of these links will depend of the structure of the model for liquid fuels. There are three options. If the modelling of "supply" lies at the production of liquid fuels then use of fuels is not needed. If "supply" is taken to be the supply of liquid fuels delivered then blend rates and the policies that decide them will need to be considered in GHySMO somewhere. This could occur in the biofuels model – which could provide the "supply of fuel in blends" or in the refinery model or similar which will effectively provide the demand for biofuels for blending. In Figure 3 arrows are multidirectional where such uncertainty exists. In practice it will be difficult to model biofuel use in blends in isolation from other modules – and this needs to be considered in the model specification.

To a large extent, biofuel blend rates within each region will be determined by policy assumptions. These policies could include regional or sub-regional blending or use mandates. In some cases the blending rates may adjust to market conditions. As was mentioned in the previous section, the current state of the liquid fuels market in the U.S. is such that ethanol blends are unlikely to fall much below 10% unless there is rapid expansion of drop-in fuels or a cheaper source of octane. In other words, under some circumstances ethanol and motor gasoline seem to have a substitute relationship (i.e. increases in the price of one could increase the demand for the other) as long as the RFS is effectively non-binding. When the RFS is effectively binding in the future, the relationship between ethanol and gasoline becomes complementary (i.e. increases in the price of one good decrease demand for both goods) in nature. Similar relationships could exist in other regions, as well.
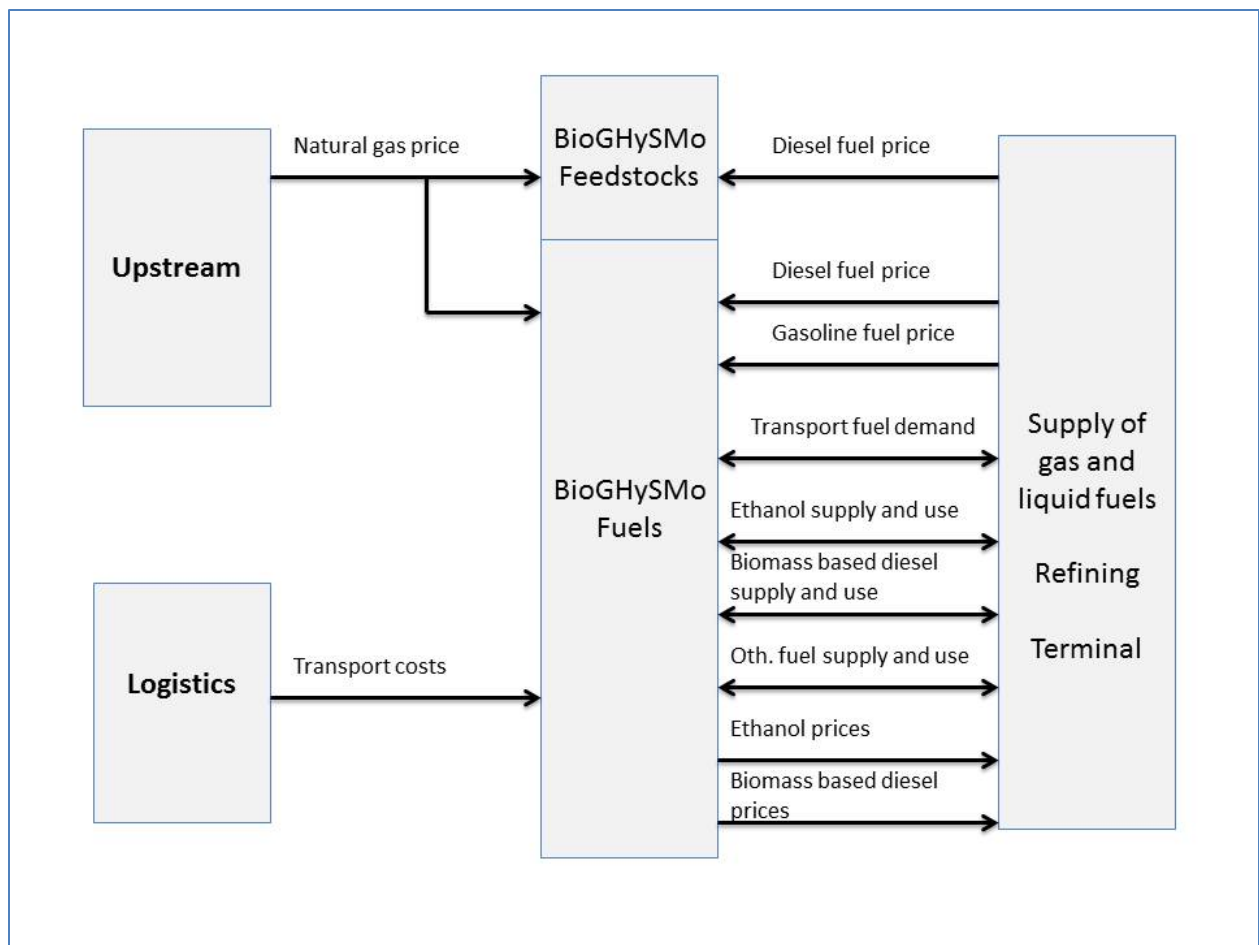
Figure 3: Module linkages for BioGHySMo.

Underlying the model would be certain key relationships between prices across modules – and validation of the model will necessarily incorporate monitoring of these. Figure 4 to Figure 6 below show historical prices for conventional ethanol (Omaha rack), gasoline (Omaha rack), crude oil (WTI), corn (FOB Gulf), sugar (No. 11), and sugarcane ethanol (Sao Paulo). In the first chart, ethanol and gasoline prices tend to have similar price movements, particularly in 2010 and 2011. At that time the RFS was relatively easy to meet, as very low RIN prices at the time would indicate. It would appear that ethanol and gasoline acted as substitute goods over that period (Whistance and Thompson, 2014). After 2011, the RFS became somewhat more difficult to meet (i.e. RIN prices increased along with the RFS requirements), so ethanol became somewhat more of a complementary good relative to gasoline and their price movements became less synchronised. It should be noted that while the relationship might have shifted slightly between those two "regimes", ethanol consumption as a share of the motor

gasoline pool remained close to 10%. A price linkage equation in the model could represent this relationship, but would not be able to capture all of the policy detail and behavior exhibited in recent years, behavior that would be more likely to be captured if prices were solved endogenously (see section on prices below for more discussion).
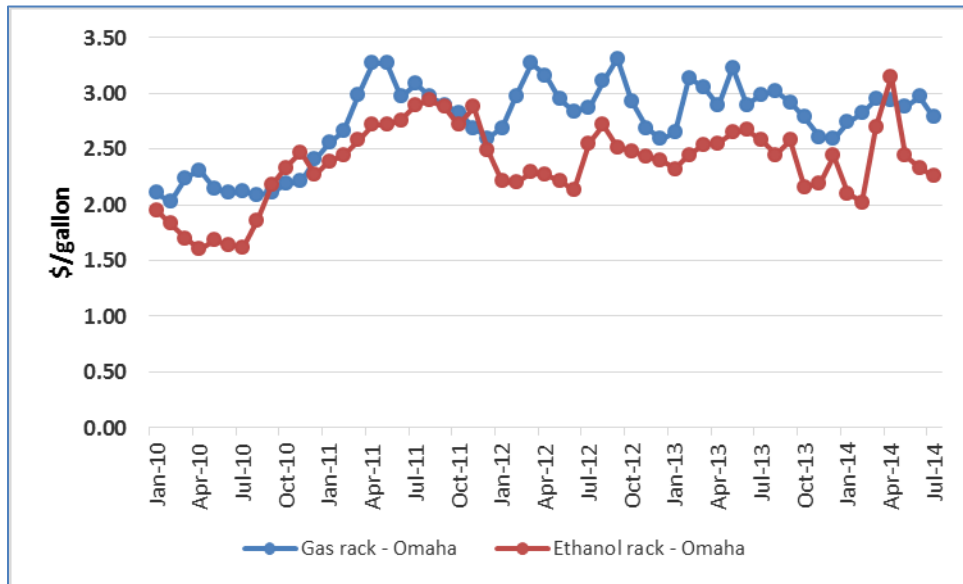

Figure 4: Gasoline-Ethanol price comparison.

Source: Nebraska Department of Energy

The link between ethanol and gasoline might imply a link between the primary ethanol feedstock in the U.S. (corn) and crude oil. This potential relationship has been examined closely in academic literature (Du and McPhail, 2012; Serra et al., 2010; Whistance and Thompson, 2014; Zhang et al, 2009). Although the crude oil and corn prices follow the same general movements (Figure 3) as ethanol and gasoline in Figure 4, they do not appear quite as coordinated. A drought year in 2012 resulted in corn prices rising relative to oil prices, but that reversed when yields recovered this year. In the long run agricultural commodity prices and energy prices are linked, not just by biofuels market but also through input markets. In the long run a simple relationship between feedstock prices and the energy prices that come from the other parts of GHySMo might be sufficient, but this would miss important movements in the short run.
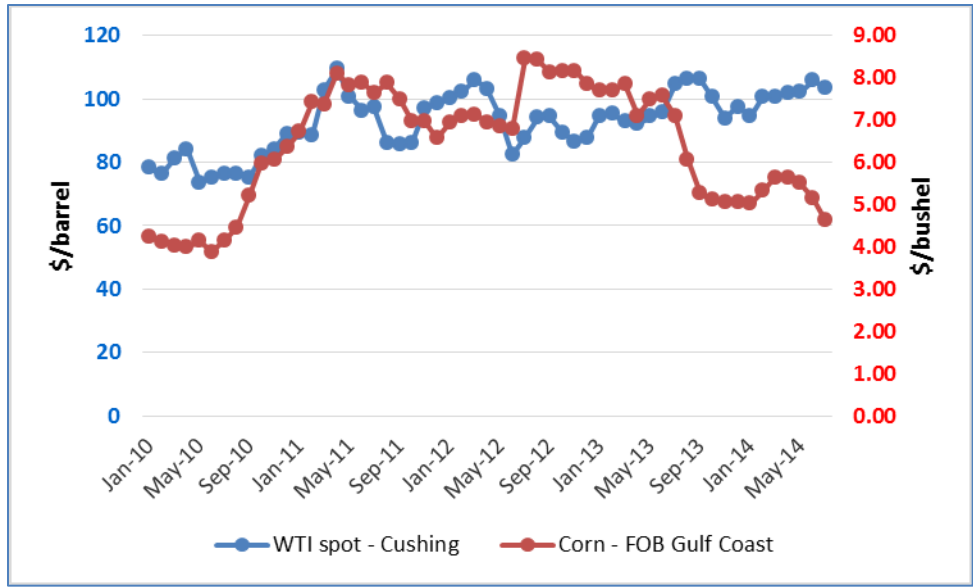
Figure 5. Crude oil-Corn price comparison.

Sources: EIA, USDA-ERS

In Figure 6 shows the strong link between sugar prices and anhydrous ethanol prices in Sao Paulo, Brazil. This relationship makes sense as sugar mills in Brazil choose to either refine sugar or distill ethanol from the same sugarcane feedstock. Most of the time, the split is roughly 50% of the feedstock processed into sugar and 50% processed into ethanol (UNICA). It is simple to switch production at the margin between sugar and ethanol and given Brazil's important role in world markets for each product mean that these prices move largely together. Given Brazil's large flex fuel fleet, substitution between ethanol and gasoline is easier than in other markets. That strengthens the link between feedstock and energy markets. For Brazil, however, the price of gasoline is administered and this provides an added complication regarding the transmission of prices through the system.
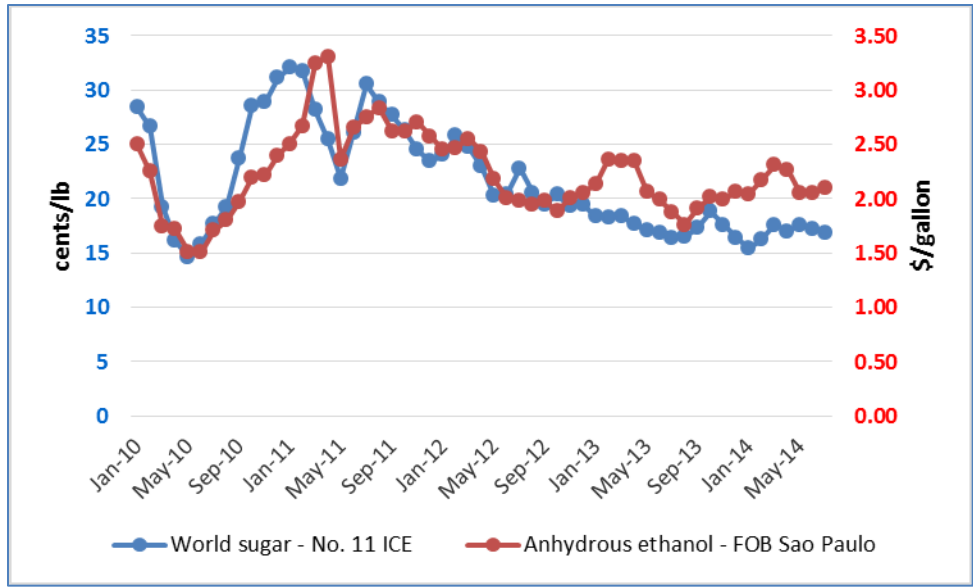
Figure 6: Sugar-Ethanol price comparison (Sao Paulo).

Sources: ICE, UNICA

Ideally, BioGHySMo will capture these and other biofuel-petroleum-feedstock price effects not only in the major biofuel markets but in the emerging biofuel markets as well. This is one reason why reduced-form agricultural models are suggested to be included with BioGHySMo. Those models can provide important feedback effects that can improve the way BIoGHySMo interacts with other modules within GHySMo. In the long run the prices outlined above are likely to have strong linkages as energy, biofuel and agricultural markets are ever more closely integrated.

Liquid fuel demand will be driven primarily by consumer response to motor fuel and biofuel prices determined within BioGHySMo and economic factors determined elsewhere in the WEPS+ model. This will be the case across all regions, although the level of demand response will likely vary across regions. A factor to keep in mind during the model development phase is the role of other transportation/energy policies. As another example from the U.S., fuel economy and GHG emission standards are expected to result in lower motor fuel demand in the future. This will affect the quantity of biofuel used domestically and, through trade effects, the supply of biofuels produced and consumed in the rest-of-world.

The gas market module will be primarily responsible for providing the supply curve for natural gas used as a GTL feedstock and the prices faced by other biofuel producers that use natural gas as an input. Those prices will also play a role in the reduced-form agricultural models through their effect on

fertilizer prices and subsequent crop supplies. Again, this framework can be extended across the regions that are represented in the model.

2. Methodology description

The rise in the importance of biofuels in energy markets, but particularly for food markets has resulted in a range of different approaches in modelling the sector. Models have been developed using linear programming, general equilibrium, or partial equilibrium dynamic models (see von Lampe, 2006 and Golub 2010 for examples of a partial equilibrium model developed by the OECD and a general equilibrium model used as part of GTAP respectively). Given the nature of agricultural markets and the way that policies are often implemented, the bias of the author is towards partial equilibrium models that solve for each year. These are superior especially where the time frame of the model is ten years or less. The extended range of the GHySMo may make the generation of each year impractical, however, and the modelling representation below is presented in such a way that it could be parameterized in a number of different frameworks.

2.1. Model objective

The goal of the Biofuels Component Design Report (BDCR) is to describe a global biofuel supply model that can fit within the within the GHySMo framework (i.e. BioGHySMo) and interact with other modules within GHySMo, including upstream production, downstream processing, and logistics/distribution of natural gas and liquid fuels. The model attempts to strike a balance between the complexity of the policy in place and importance of agricultural markets in determining fuels' competitiveness, for the need for a tractable model that is just part of a much wider effort to model energy markets.

In the author's opinion the three major considerations for the model are:

    i)   The correct incorporation of the supply of currently commercially produced biofuels and the policies that influence them

ii)   The consideration of developing markets for those fuels shown by the blending of biofuels if that is considered within the scope of the model

iii)   To ensure that if scenarios call for the rapid expansion of either first generation fuels or other fuels based on biomass the costs of that expansion are reflected in the prices of those fuels and their feedstocks

Variable name structure

A list of variables is contained in Appendix I. The first two letters of the variable name refer to the product, the second three to the activity, with country identified by the first sub-script, and further commodity disaggregation denoted by the second sub-script. For example:

$ETPRD_{US,ADV}$

denotes the total production of advanced ethanol in the U.S.

Parameterization

The recent development of the biofuels sector in many regions means that there is usually not a large amount of data from which to mine information as to the likely value of parameters. The estimation of the BioGHySMo is not an option in most cases given this lack of data. Even where there are time series available, the change in the structure of the industry and policies would make any estimates unreliable.

In such a situation the next best option is to consult the literature for information that might guide decision making. There are a variety of models currently being used and the parameters from those would give some useful information. Nonetheless, parameters will have to be selected on the basis of economic theory, ability to fit the data that is available, and validation through scenario work and consultation with experts.

2.2. Model structure

The structure of the model that is outlined below is for a core model that would contain the important linkages necessary for the generation of estimates of the supplies of biofuels globally. As with any modelling exercises this entails a trade-off between the granularity of the model and the requirement that the model be tractable and updated easily. It reflects judgments as to the importance of different policies for overall hydrocarbon markets. Though the structure below is simple, the challenge will be its parameterization given short or non-existent data series.

Feedstock representation

The basic structure of the feedstock component of the BioGHySMo model is shown in the flow diagram in Figure 7. It is recommended that a feedstock component is developed in conjunction with those who have a large scale international modelling system (FAPRI, OECD/FAO, USDA or private company), or using parameters that have been determined from those models. Within BioGHySMo a reduced form would be parameterized using one of these agricultural models.[3] Natural gas prices are an important part of the costs of agricultural production given their use in the production of fertilizer. Gas prices plus fuel prices would come from other parts of GHySMo, (along with the GDP deflator as a simple way of capturing other costs, if these macroeconomic variables are endogenised in the system. To keep the model simple, a simple production cost index based on these variables would be generated. These costs would feed into a system of reduced form equations that would determine indicative world prices of feedstocks:

- US fob gulf price of corn for grain
- Hamburg soybean oil price for vegetable oils and other fats
- No. 11 sugar price
- Tallow, US, cif Rotterdam
- An index price for cellulosic material

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[3] An alternative to this approach is to simply use elasticities for the supply of agricultural commodities available from the literature such as in Roberts *et al*, 2013.

These prices are selected on the basis that they are generally available and widely reported and updated, they are viewed as indicator prices for world markets for the products concerned, and they represent the main feedstocks currently used in biofuels production. They are port prices given that the model is international in scope. Corn is the leading grain used for ethanol. Northern Europe prices are generally used as indicator world prices for oilseeds and their products. A logical addition here might be to use a palm oil price as well. Given the volume of other oils and fats used for the production of biofuels the Rotterdam tallow price is suggested, although given the range of products that are used for these types of fuels there will probably be bigger differences here between this price and the price that those fuel producers pay for their feedstock in reality. For cellulosic materials an index constructed from a weighted average of feedstock prices currently used is suggested.
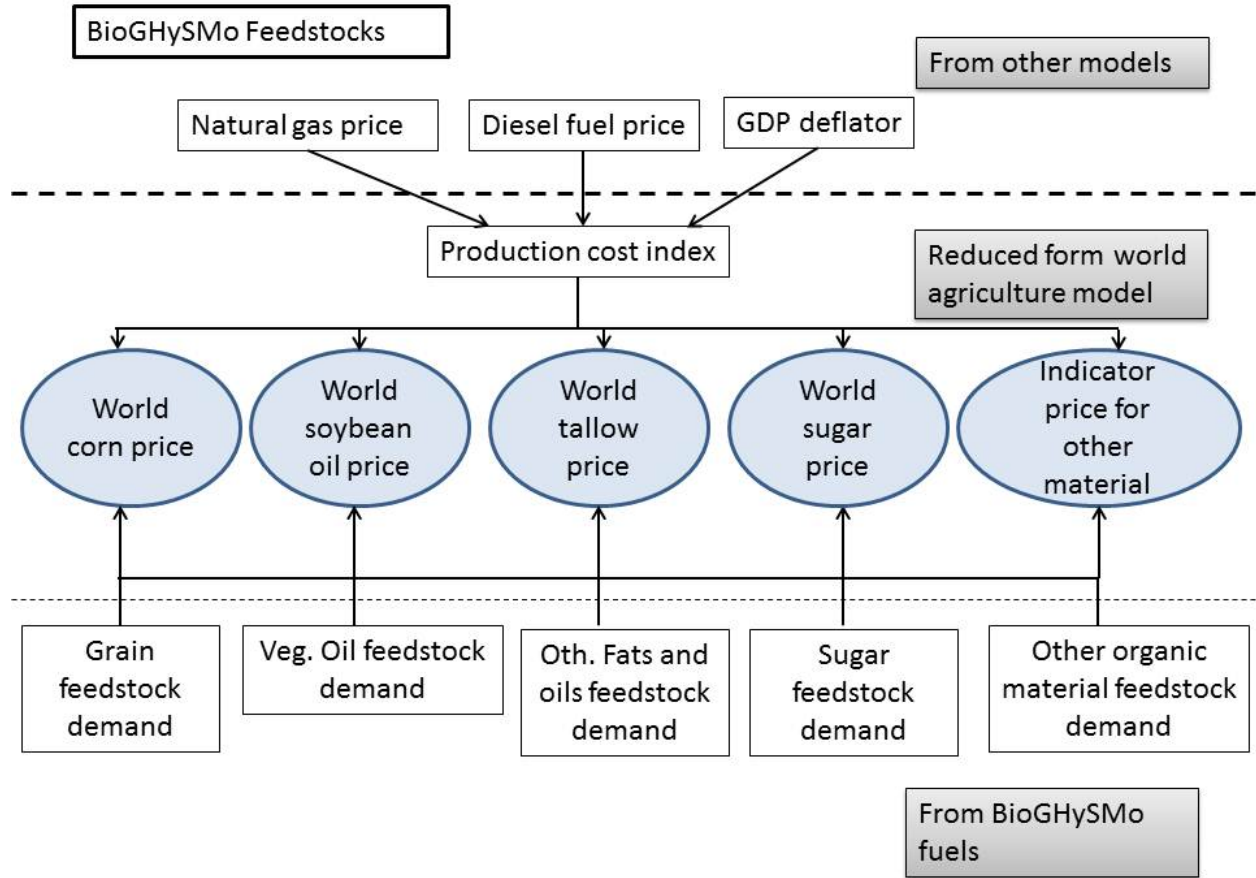

Figure 7: Structure of the feedstock component of the BioGHySMo.

The actual cost of feedstocks at any given plant could differ considerably from these world prices in reality. In principle feedstock prices could be generated for each of the regions, and for different basis in

these regions, but this level of detail is probably not wise, given the additional data requirement. If specific agriculture related scenarios are to be attempted then more detail would likely be required, however. Likewise prices for the different types of grain could be generated. Prices for materials for emergent technologies could be added if required. When considering what level of disaggregation regarding prices the model should aspire to it is also necessary to consider how the prices will be generated in practice. If a large regional network of prices are incorporated, given the resources available it is likely that these prices will be projected through simple price linkage equations, in which case one would need to consider the additional benefit the incorporation of more price detail would provide. A similar argument could be made for including different feedstock prices, since in the long run there would be expected to be strong relationships between, say different varieties of vegetable oil.

World agriculture models external to the GHySMo system could be simulated to generate price responses to changes in demand for different feedstocks and these estimates can be used to parameterize BioGHySMo. Most of the agricultural modelling systems have some form of land representation and the suggestion here is that for non-food crops volumes of biomass material be converted to land use equivalent and aggregated. This is a very simple approach and misses much of the detail that is inherent in biomass markets, both in the wide variety of inputs expected and regional variation. But it is important to balance the needs of the system with the cost of implementation. The main requirement is that if policy (or other shocks) are carried out that increase energy costs these are reflected in the costs of feedstocks for biofuels. Also, that emergent technologies that use land also have the appropriate impact on other feedstock prices, and that large volumes of biomass cannot be transformed without impacting commodity markets.

Equations specification for the reduced form feedstock model would be (note that variables and their definitions are in Appendix 1 of this document):

$COPRW = f(COCST, GRFSK_{WD}, VGFSK_{WD}, OXFSK_{WD}, SUFSK_{WD}, OTFSK_{WD})$

$SOPRW = f(COCST, GRFSK_{WD}, VGFSK_{WD}, OXFSK_{WD}, SUFSK_{WD}, OTFSK_{WD})$

$XOPRW = f(COCST, GRFSK_{WD}, VGFSK_{WD}, OXFSK_{WD}, SUFSK_{WD}, OTFSK_{WD})$

$SUPRW = f(COCST, GRFSK_{WD}, VGFSK_{WD}, OXFSK_{WD}, SUFSK_{WD}, OTFSK_{WD})$

$OMPRW = f(COCST, GRFSK_{WD}, VGFSK_{WD}, OXFSK_{WD}, SUFSK_{WD}, OTFSK_{WD})$

Given this structure, changes in the demand for, say, vegetable oil, will have a knock on impact in the price of grains, even though the competition for land is not explicitly determined in the model. Feedstock demand is defined in the section below.

In the initial baseline of the model these equations could be calibrated to externally determined projections of commodity prices produced from the modelling processes identified above.

Biofuel supply

The supply of biofuels can be divided into fuels that are already being produced and used, and those that are yet to be produced in commercial quantities. The approach here is based on that used by FAPRI-MU (Whistance and Thompson, 2014). The basic structure is presented in Figure 8, simplified to show an example biofuel. In practice equations would be generated for each disaggregated fuel type considered. Feedstock prices come from the feedstock component of BioGHySMo. Estimates of other components of the cost of production would come from other part of the GHySMo system.
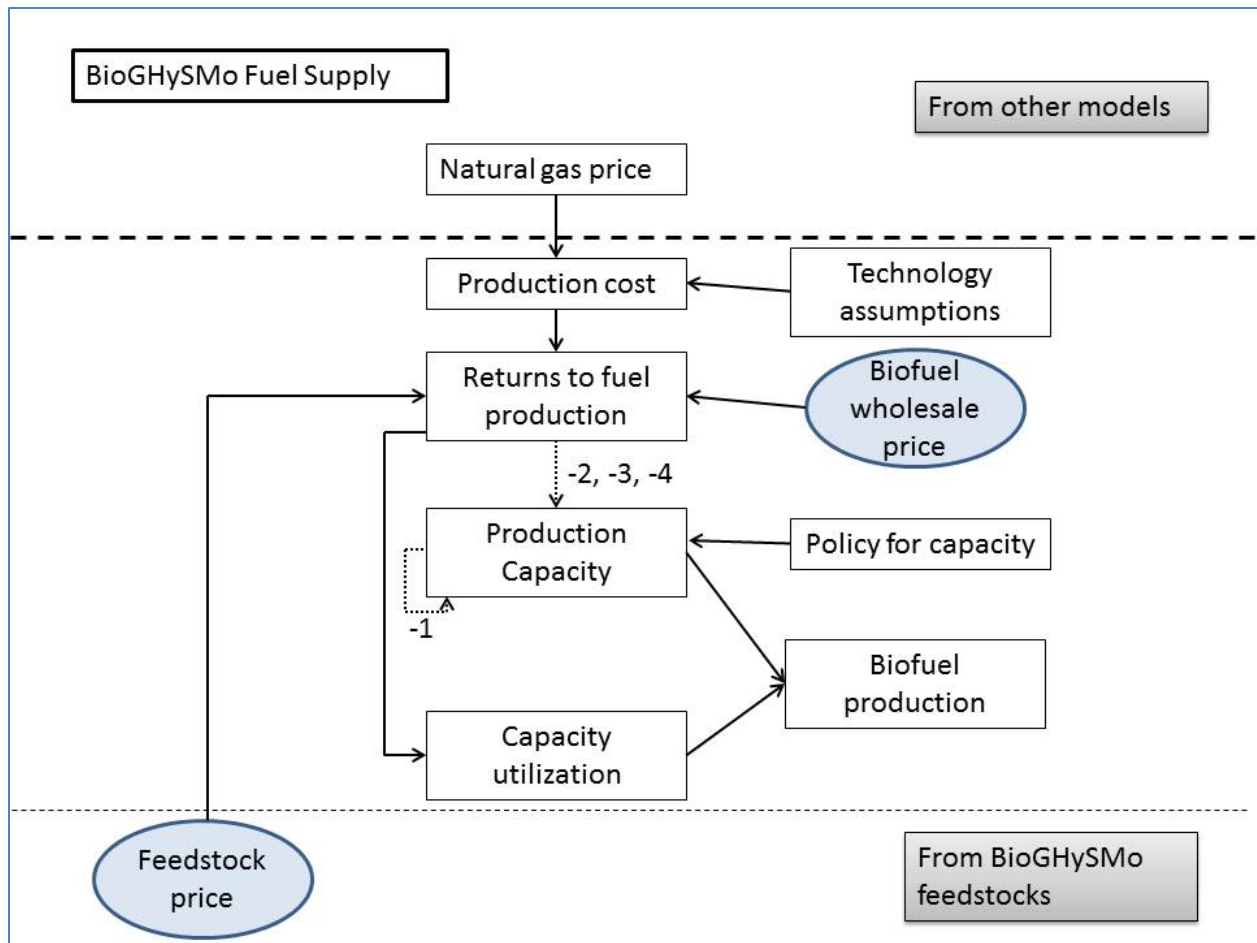
Figure 8: Structure of the supply component of the BioGHySMo.

Wholesale fuel prices and assumptions regarding conversion rates are then used to calculate a return to production. Where there are a variety of different feedstocks or processes used to produce a particular biofuel, then the dominant system would be used as a representative return.[4] For example, in Brazil sugar from ethanol process will be used, with the return calculation based on industry sources. For Europe, a maize based production system can be used – although in practice other cereals are used their returns should be strongly correlated with maize. Improvements in technology that increase conversion rates can be incorporated in the cost term, on the basis of industry input.

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[4] As with all of these specifications a more disaggregated approach could be considered. If information of the different costs of the processes is readily available then either the processes themselves could be split out, or a representative return could be weighted from the relative importance of the different processes. For most of the regions, however, a dominant production system can be identified.

Fuels that are not currently produced in commercial quantities can also be incorporated using this framework – the returns calculation will be negative. Estimates of technological improvement can be incorporated and when returns are positive capacity will result. This is broadly the approach that FAPRI employs with respect to cellulosic ethanol production from sources such as forestry waste, or corn stover.

Using the example of ethanol, equation structure is shown below. Capacity depends on returns, and any subsidies that might be available:

$$ETCAP_j = f(ETCAP_{ij}(-1), ETPRR_{ij},(-2,-3,-4),ETCSB_{ij})$$

Lag structure is important here, if a model framework enabling yearly solution. Typically capacity building occurs where there are several years of positive returns. Having capacity depend on returns 2 through 4 years previously ensures that there are different reactions to changes in market conditions in the short run than in the long run, where production of biofuels is effectively more elastic. Positive returns trigger additional capacity building. Equations can also include a component that can retire capacity after some period of time to mimic obsolesce.

Derivation of the returns variable is the most important part of the model. The proposed set up here uses a naïve expectations framework to the incorporation to investment behavior. In practice the construction of biofuel production capacity is based on expectations. An alternative would be some sort of calculation regarding net present value of investment, perhaps in a way that is comparable for the decisions made in the other part of the model.

Clearly, expectations regarding the path of future policy play a role in capacity decisions. Sometimes policies are in place that specifically subsidize the construction of capacity, but investment decisions can also be driven by the presence of policy that works on the demand side. By appearing to guarantee a market, policies such as mandatory blending rates or target volumes can spur investment as has probably happened in the U.S. and the EU in particular. The approach suggested here is to incorporate policies directly related to capacity in the returns equations themselves. Information about existing and capacity under construction is available from the data sources listed elsewhere, so this can be used to calibrate the short run. In the longer run the model can determine capacity given the estimates of the variables that make up returns but the modeler may need to adjust equations on the basis of policies that impact other parts of the market for biofuels, either demand or trade. More discussion of this process is carried out in the knowledge management part of this report.

Ethanol utilization is also determined by returns to production, but in the current year:

$ETUTZ_{ij} = f(ETPRR_{ij})$

Which is then used to calculate production:

$ETPRD_{ij} = ETCAP_{ij} * ETUTZ_{ij}$

Using average coefficients of conversion of fuel from raw material, feedstock demand can be calculated:

$GRFSK_i = ETPRD_{iGR} * etgr$

$SUFSK_i = ETPRD_{iSU} * etsu$

$OTFSK_{iET} = ETPRD_{iOT} * etot$

Technological progress can be incorporated by changing these coefficients, with the volume of feedstock needed for a given output of fuel. The different country feedstock requirement can be summed across country to determine the raw material demand that is the input to the feedstock demand model:

$GRFSK_{WD} = \Sigma\ GRFSK_i$

$SUFSK_{WD} = \Sigma\ SUFSK_i$

$OTFSK_{WD} = \Sigma\ OTFSK_{ij}$

Biofuel demand

The increase in demand for biofuels has largely been driven by government policies, but markets and the competitiveness of biofuels also play a role. The challenge for the demand system is to capture both these. The basic structure of the demand component of BioGHySMo for biofuels used in transport energy is shown in Figure 9. Here it is assumed that gasoline use and diesel use are going to be available from other sub-modules of GHySMo. Segregation of the market between diesel and gasoline is preferable given the way that policies work in most regions and the different feedstocks that are typically used.
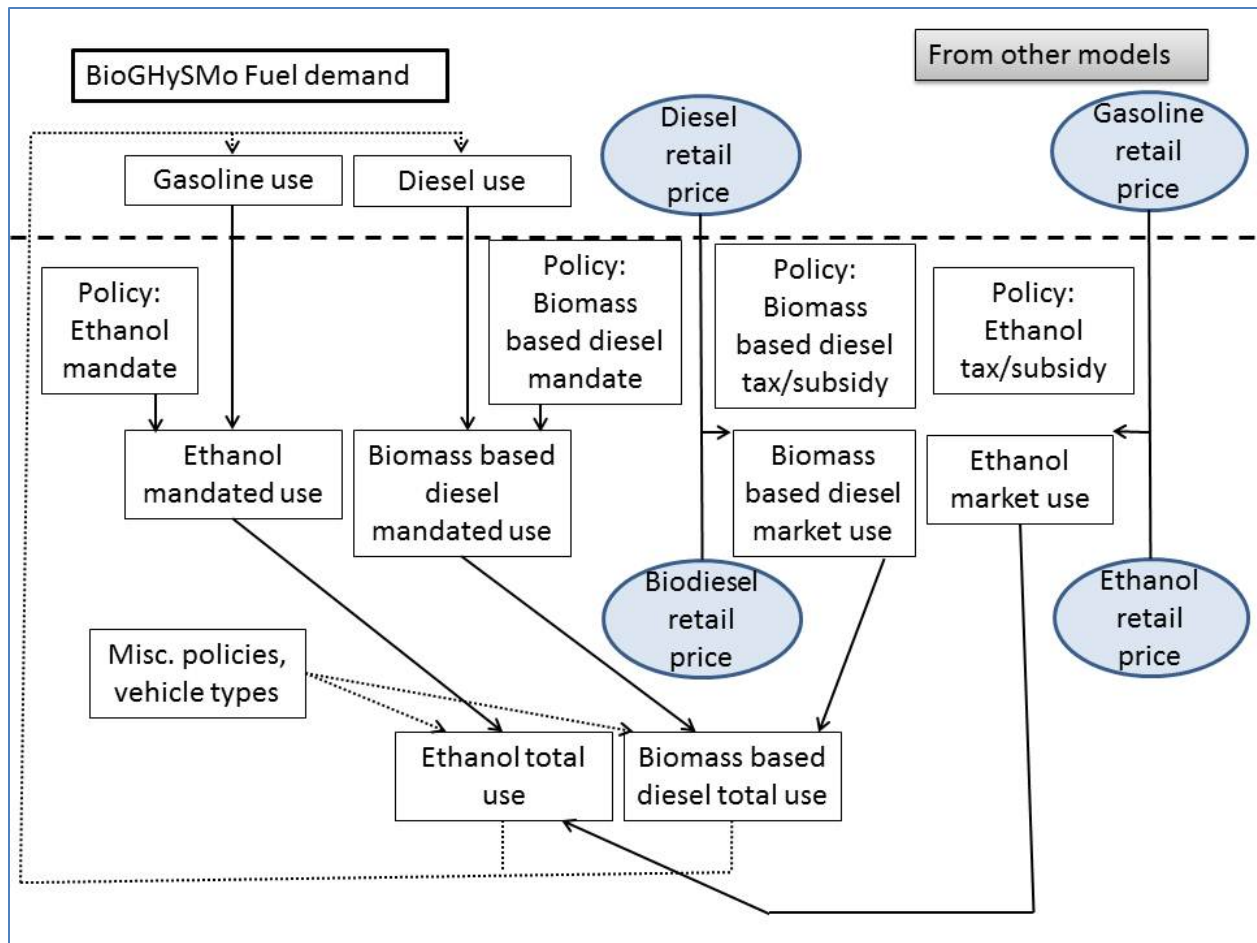
Figure 9: Structure of demand component of BioGHySMo.

The challenge for the modelling of the demand for biofuels is to capture the different segments of the market. There is a segment that is inelastic with relation to relative fuel prices:

$ETUSM_i = ETMAN_i * GSUSE_i$

$BDUSM_i = BDMAN_i * DSUSE_i$

Given that ethanol is also a substitute for fossil fuels it is necessary to capture also this competitive relationship:

$ETUSK_i = f(ETPRR_i/GSPRR_i, ETUSB)$

$BDUSK_i = f(BDPRR_i/DIPRR_i, BDUSB)$

The equation can be structured such that if the price of biofuels falls below that of the fossil fuel equivalent then consumption can expand more rapidly.

With total use then given by:

$$\text{ETUSE}_i = \text{ETUSM}_i + \text{ETUSK}_i$$

$$\text{BDUSE}_i = \text{BDUSM}_i + \text{BDUSK}_i$$

subject to market specific conditions that dictate the maximum volume of biofuels that can be utilized.

Biofuels are also used for other purposes, and those demands can be incorporated into the structure. At present many of these fuels are used even though they are not competitive with their equivalents. The model therefore needs to make the same distinction for these fuels as that above with a component largely based on judgment that represents the policy or public relations justification and another. For example fuel use by airlines would be represented by:

$$\text{ETUSE}_{i\text{AV}} = \text{ETMAN}_{i\text{AV}} + f(\text{ETPRW}_{\text{AV}}, \text{AVPRW})$$

Another important source use of biofuels in the energy sector is for electricity generation. Particularly in the case of vegetable oils, the ability to substitute vegetable oils for fossil fuels not only in the case of transport fuels (biomass based diesel) but also in other sectors. Where prices of vegetable oils fall significantly oil prices provide a floor. This was evidenced in 2013 when an expansion in supply in the palm oil sector caused prices to crash. In 2014, favorable weather has led to record corn crops and the potential for a large soybean crop, causing prices of vegetable oils to fall dramatically. Figure 10 shows the evolution of both oil prices and soyabean oil prices in Argentina over the last 12 months. The fall in prices meant that in Argentina biodiesel has become competitive with diesel and use has exceeded mandates. That part of the demand response would be captured in the structure outlined above. There is also a response in the use of vegetable oil in other uses:

$$\text{BDUSE}_{i\text{EG}} = f(\text{BDPRW}_i, \text{DIPRW}_i)$$
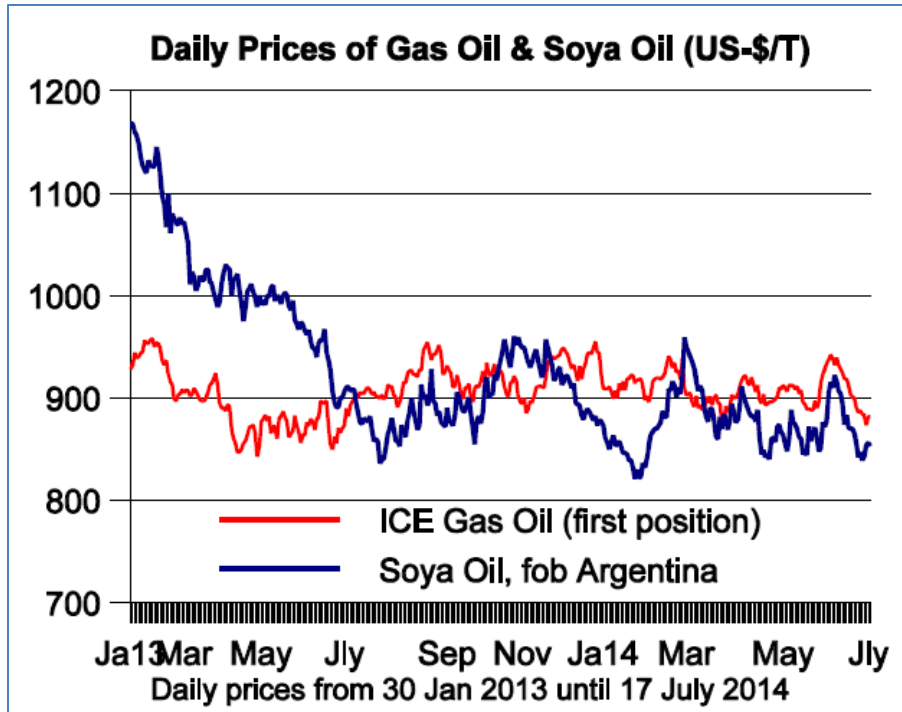
Price determination

What is suggested here is that the model is solve for a representative world price of ethanol and biomass based diesel and that this price feed recursively back into country models. The price can be determined through the clearing of supply and demand in each of the markets as in Figure 11, or alternately if only the supply side is used then a price linkage with energy prices can be considered. The inclusion of both wholesale level prices (that drive production decisions) and retail level fuel prices (that derive consumption decisions) should be considered. The evolution of markets beyond those mandated will depend on the competitiveness of ethanol to its fossil fuel equivalent. This is also the case in the current Brazilian market where this relationship already determines the volume of ethanol consumed.
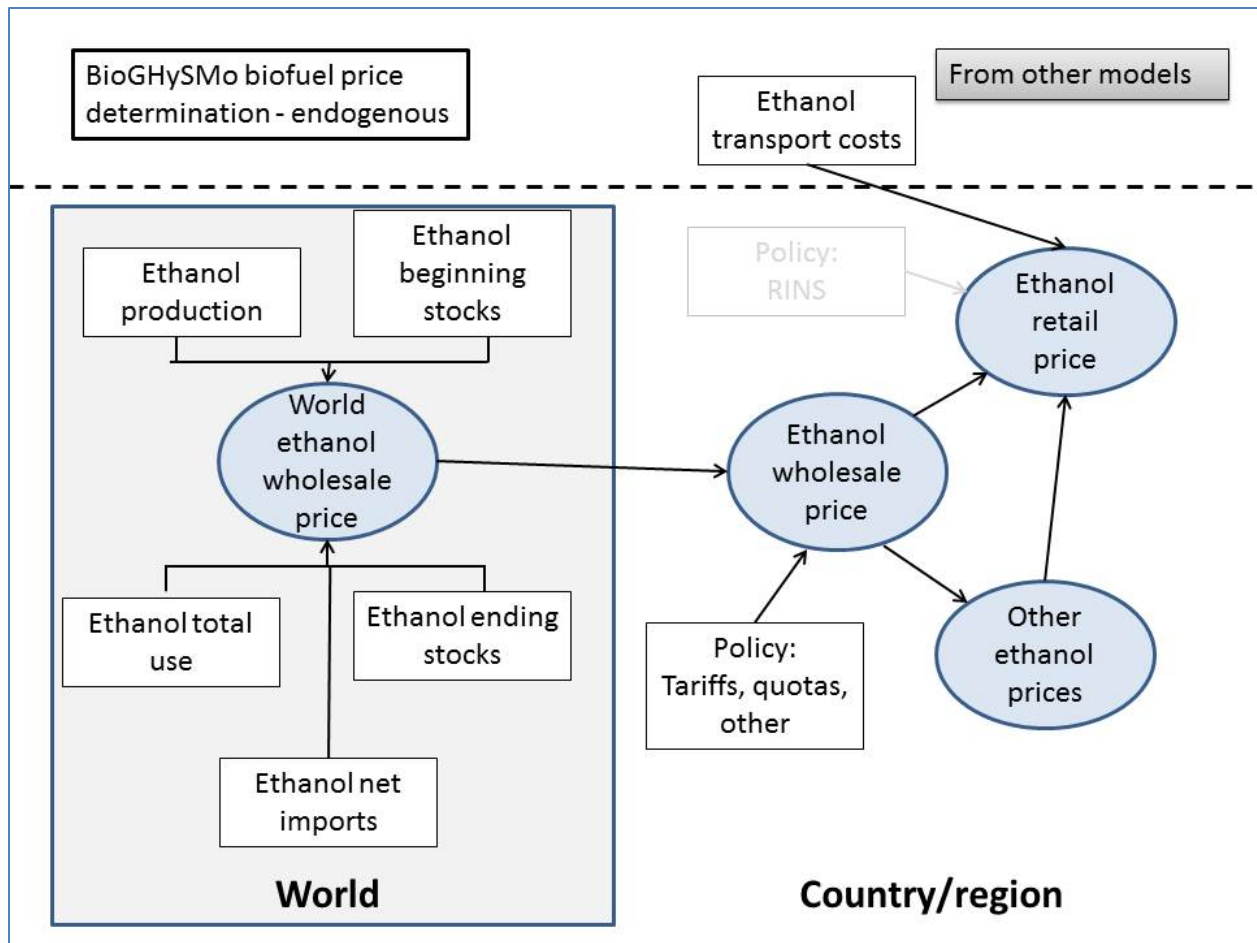
Figure 11: Endogenous price determination in BioGHySMo.

Using the example of ethanol, the model would solve for a Brazilian anhydrous Sao Paolo (or Santos) price where:

$ETPRD_{WD} + ETSTK_{WD}(-1) = ETUSE_{WD} + ETSTK_{WD} + ETNIM_{WD}$

FAPRI uses a very primitive iterative process to solve their partial equilibrium model in Excel, whereby the model determine supply and demand for a given price, and if the market does not balance then a new price is selected and the process continues until a solution is found. This can be rather unwieldy for larger models and the general preference for the kind of agriculture sector models outside of FAPRI is to use software that solves through an algorithm, such as in SAS, GAMS, or Troll for example.

Having determined the lead world prices, domestic prices can then be calculated from the world price where they are available, alternatively the world price could just be converted into local currency:

$ETPRW_i = f(ETPRW_{BR}, ETTAR_i)$

Other domestic ethanol prices can then be determined from the wholesale price, such as those of other fuels or retail level prices as appropriate. Retail level prices could include information that comes from the logistical model, along with taxes as appropriate for the major countries. The country detail to include here would be highly dependent on availability of data. Data for the U.S. and Brazil is available, but the situation for the EU is a little more complicated given that the industry and usage is spread over a number of member states.
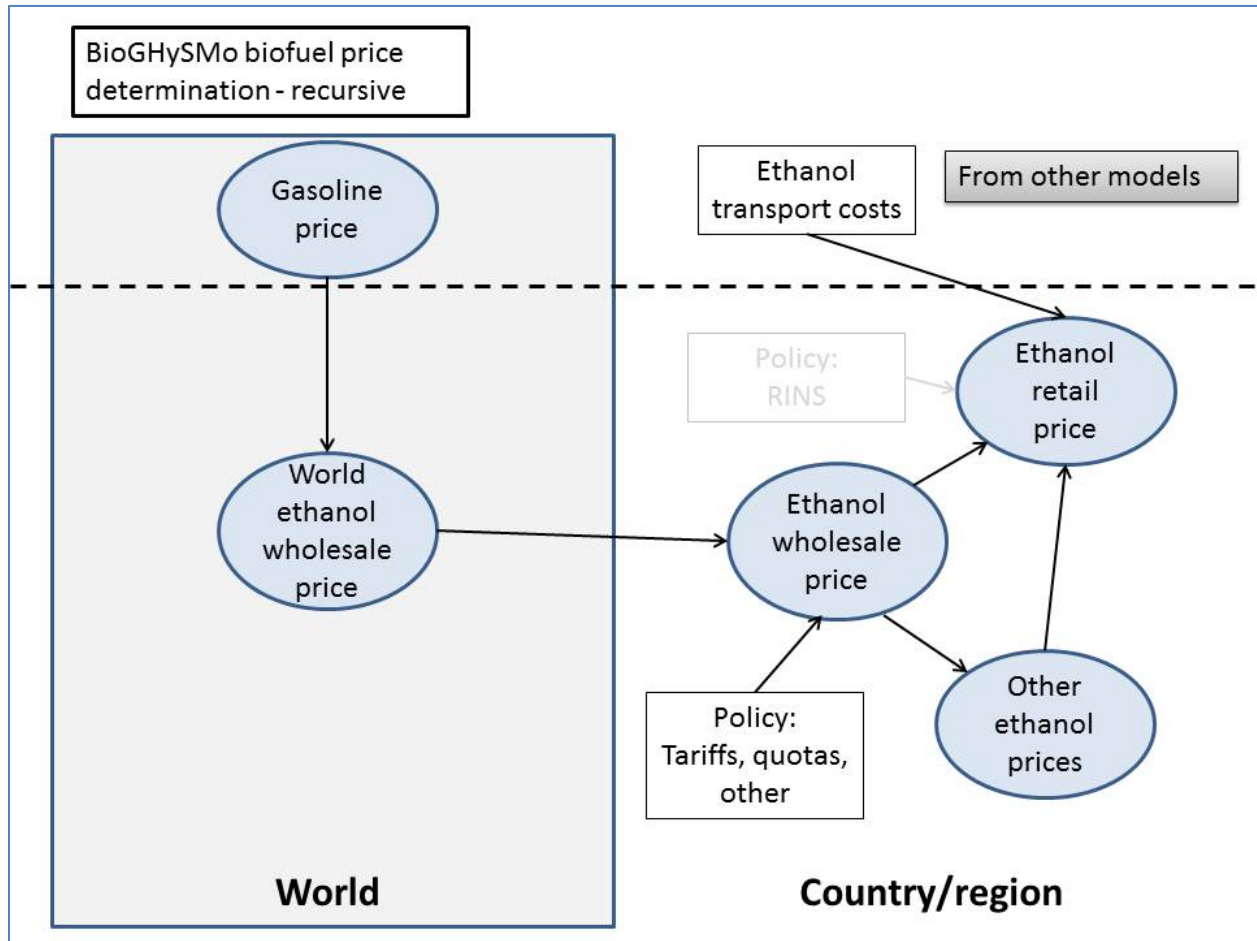
Figure 12: Recursive price determination in BioGHySMo.

The above framework relies on the simulation of a full supply and demand balance for both ethanol and biomass based diesel, and the solution of the system of equations to determine the market clearing price. An alternative is to use a simple series of price transmission equations to derive world prices. In the long term ethanol prices are likely to be related to oil prices (and by extension gasoline prices). This relationship could be replicated in one equation as in Figure 12. If a purely supply side model were to be

specified then this could be used to define prices. As discussed above however, this would not capture all the dynamics of the system especially in the short run where the price relationships have often not held.

2.3. Model design considerations

The most important decision regarding the model is the scale of the modelling effort to be undertaken. It is possible to build a model with a large number of countries (and regions within countries, such as breaking out California from the rest of the US). Prices and policies could be collected for all of the countries but the resources needed for this would be very large. It is probably better to concentrate on the most important markets and ensure that they are modelled correctly. The simple model outlined above is suggested, with the flexibility to incorporate different features from different countries or regions. The main regions are discussed below.

USA - model idiosyncrasies

It is possible to develop a very complex of just the biofuels sector in the U.S. as a result of the way that policy operates there. For example in the U.S. ethanol is treated differently in the RFS structure depending on the way that it has been produced, with the result that ethanol produced from different feedstocks can almost be treated as different fuels with different prices. Also, the use of RINS, and in particular the way that they have different vintages, has meant that in order to capture the full complexity of the policy the market for RINS, as well as the market for the fuels themselves had to be modelled in the FAPRI framework. In the diagrams above RINS are greyed out to reflect that simplifying assumptions may be needed rather than complicated specification, given the resources available.

However, given the way that it appears that the EPA will implement the RFS2 in 2014, it may be possible to make some simplifying assumptions as to the way to incorporate the model in BioGHySMo. It seems that the EPA will waive down the requirements to approximately blend wall levels. Therefore the U.S. ethanol sector could be modelled as if it has a 10 percent mandate (this mandate could be increased

over time to reflect any belief that E-15 blends would become more prevalent). Assuming that biomass based biodiesel will be consumed at the mandate level appears to be justifiable, even if in some years it has deviated from it. The EPAs behavior could be interpreted as setting the level of mandates in order to keep compliance costs within a certain range, resulting in an assumption setting RIN prices at a certain level. This approach would govern use, but production could still vary given the structure of the model and trade could occur, so the dynamics of the model on the supply side could be preserved.

In both the biomass based diesel and ethanol sector it would be important to make sure that if biofuels prices were below their fossil fuel equivalents then use could expand. For ethanol the appropriate lag structure would need to be imposed in order to reflect the fact that it would take time for the fleet of flex fuel vehicles to expand to absorb more ethanol. Calibrating this part of the model will be difficult as there is no experience for how a flex fuel market might emerge, and what prices would be required to make it happen. It seems reasonable to assume that prices of ethanol in the US could not spend long periods under their energy equivalent with fossil fuels without sparking growth in this market.

EU - model idiosyncrasies

With the EU a key question is the level of regional disaggregation. If for other parts of the model the EU is split into its member states then this can be considered for BioGHySMo. This would facilitate more precision in the estimates of biofuel use given that blending mandates are set at a member state level and can vary considerably. Germany is a major biofuel user, with high mandate levels, and a very large fuel market. If its overall fuel demand evolves in a way that is different than the rest of the EU then it could be important to incorporate it. Supply and use, and policy data is generally available for the EU from either public or private sources. Some of the policies in place are not just mandates, and France and the UK include provisions for the mandate to not bind if biofuels prices get too high.

Specifying the trade policy for the EU is a big challenge. In recent years, when a country has found a way to export biofuels to Europe (say from the US in the form of ethanol, or from Argentina for biodiesel) the EU has found a way to keep markets closed. EU internal biofuel prices have usually traded above their world counterparts, with the difference not always the official tariff rate. An effective tariff can be calculated, however, through the comparison of the T1 and T2 ethanol prices, and an assumption made

for how to carry this to the future. In addition assumptions will probably need to be made regarding the impact of sustainability restrictions given the size of the EU market. This is a challenge as at present few fuels meet the ambitious requirements. However, if the requirements change the mix of biofuels that are used in the EU there would presumably be some substitution with other countries that do not differentiate between fuels import the "bad" ones. To a certain extent this has happened between the US and Brazil where the US imported sugar based ethanol as it filled the requirements for an "advanced fuel" while exporting corn based ethanol to Brazil where no distinction is made.

Brazil - model idiosyncrasies

It would be preferable to have a more complex specification for the consumption side for Brazil than that which is laid out in the discussion above. Consumers in Brazil use both anhydrous ethanol in gasoline at a mandated level and hydrous ethanol in pure form. The size of the flex fuel fleet means that consumption of ethanol in Brazil is much more responsive to prices in other regions.

In the model it would therefore to amend the use of ethanol equations so that there is an estimate of blended ethanol consumed as part of the mandate, and a component for the hydrous consumption. The former will be largely unresponsive to changes in biofuel prices, and indeed an increase in gasoline price would be expected to decrease ethanol used in that form. On the other hand, an increase in gasoline price relative to ethanol prices would increase use of hydrous ethanol, if the resulting ratio of fuel prices meant that hydrous ethanol was competitive.

In the FAPRI global biofuel model currently the use of ethanol is disaggregated into the two fuels. Total energy use for transport use is determined by fuel prices, income and population. The proportion of this fuel that comes from hydrous ethanol is then determined based on the relative price of hydrous ethanol to gasoline at the pump. The residual use is then determined to be gasoline, and using the mandated blending rate the volume of anhydrous ethanol consumed in Brazil can be determined. The hydrous use equation includes a trigger term in order to capture the fact that around energy equivalence the use of hydrous ethanol is very elastic.

2.4. Software considerations

The framework that is outlined here is flexible enough to be used on most software packages. FAPRI-MU uses Excel, SAS, or a combination of both to solve its models. The OECD/FAO operates a similar model on Troll, and the USDA uses spreadsheet models coupled with Fortran programming. Ideally the software used should be one that allows for transparency in that it is likely that for the biofuels component industry experts would need to be consulted.

2.5. Resource representation

A key consideration for BioGHySMo will be the level of product disaggregation that it undertakes. Biofuels can be separated into ethanol, biomass based diesel, and unrefined materials. But ethanol itself can be split into different fuels based on feedstocks, which although chemically identical are treated differently in the U.S. and the EU. For example, in the U.S. sugar based ethanol counts as an advanced biofuel and will usually be priced at least at the conventional fuel equivalent. In the EU, sugar based ethanol is treated as a first generation fuel along with corn based ethanol, although tighter sustainability requirements give sugar based ethanol added value there too.

The main problem with moving to a higher level of disaggregation of fuels is data availability. Given the changes in policy in the U.S. and the EU it could be that distinctions between feedstocks become less important. As biofuels become more widely traded as a competitor with fossil fuels the source of the ethanol might not matter. One important exception is California in the U.S. and it might be necessary to address their policy in the U.S. component of the ethanol model.

2.6. Production decisions

In section 2.2 above the proposed structure of production is laid out. Positive returns lead to the building of capacity several years later. Returns in any given year determine the level of utilization. This structure works well when the industry is expanding in response to market signals as was the case in the

U.S. over the last decade in general. However, another factor in this expansion was the security that the RFS2 gave producers, even when the mandates were not binding. Similarly in the EU, capacity was built (especially for biodiesel) on the anticipation of policy-based support for the industry. Capturing these sentiments is more difficult. As is the sometimes lumpy production response to market changes as important producers start up or shut down facilities in response to market signals.

In the EU for some countries capacity is actually falling as confidence wanes. In general modeler judgment must intervene and overrule the model if it is clear that expectations of policy are driving decisions. In the EU, for example, even several years of good returns are unlikely to mean that producers would invest in biomass based diesel capacity as there is already more than twice the levels of current consumption. As the modelling becomes more disaggregated then capturing industry dynamics with respect to capacity when profitability is falling becomes harder. If a particular facility contributes a significant amount of its output then production can be lumpy as facilities are either shut down when profits fall or dismantled altogether.
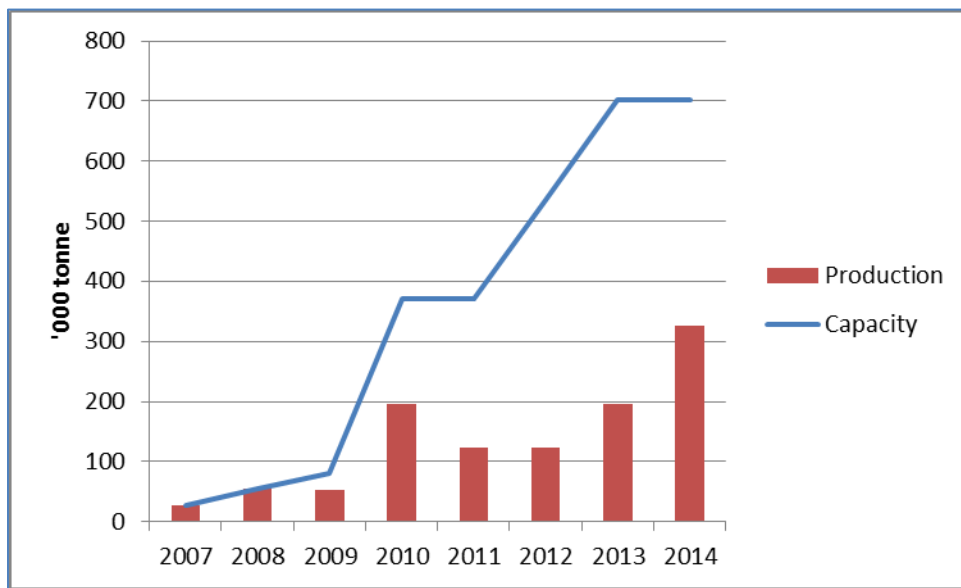

Figure 13: UK ethanol capacity and production.

Source: *Strategie Grains*

Figure 13, for example, shows the evolution of the ethanol sector in the UK. As additional capacity is added this can be seen by the "steps" in the line. During the years where grain prices were especially high a large plant was shuttered in 2011 and 2012, re-opening in 2013. A model such as that structured

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above will likely produce much smoother lines that that shown here and it is difficult to replicated the exact behavior for a country like the UK without a more complex model.

2.7. Geopolitical representation

Previous sections make the role of political considerations clear with regard to their importance in driving the evolution of the biofuels sector until this point. However, there are two issues that are important for representation of policies in the model; what are current policies, and given that policies are constantly being adapted, should they be endogenous in the model?

For an example of the first of these issues one could be that of the U.S. The legislation for the RFS2 is available and the policy has been in place for many years. However, there is some uncertainty on how it be implemented in the future. The full mandate levels are unlikely to be unwaived, so the modeler must use judgment to come to their own decision of how to predict EPA behavior in setting requirements. For Europe also, ambitious targets have been set, but there seems to be little interest in reaching them, so again the modeler must design his or her own rule. These decisions should be reviewed before the analyses are finalized.

For the second issue identified consider Brazil. Brazil is clearly a key region for the model. It has a large domestic market for ethanol and is responsive to price changes given the existence of a flex fuel fleet. Brazil has also typically exported large quantities of ethanol to both the U.S. and the EU, for example. Policy plays an important role in the sector, with the gasoline price administratively set, and a mandate for the level of ethanol to be blended. The government balances the needs of different constituents such as inflation considerations and the health of the sugar industry. These particular policy instruments are routinely adjusted, and not in entirely predictable ways, often in response to developments in the markets. Deciding on the degree to endogenise these policy levers is difficult.

Although administratively set, gasoline prices must have some relationship with oil prices given the limited resources of the government, but are unlikely to move as quickly in the short run as those in other regions. This is a matter for another module of GHySMo. However, the mandated level of ethanol also changes frequently, based on the perceived need to support the sugar/ethanol sector. In the EU, support for biofuels has fallen when prices are high.

Energy independence is another popular justification for supporting the biofuel industry – and measures of energy independence will presumable be available from other modules of GHySMo. Russia's current involvement in Ukraine, or troubles in the Middle East could also impact policies. Therefore decisions regarding policy implementation in the biofuel sectors should not be taken in isolation from the broader geopolitical assumptions made or the evolution of the psupply of hydrocarbons generally.

2.8. Passing prices and quantities between modules

It is clear from the discussion of linkages in section 1 and the structure of the model presented in section 2.2 that the main linkage will be between BioGHySMo and the liquid fuels component of the model. Prices are important, with retail level fossil fuel prices (with taxes included) required for the determination of the competitiveness of biofuels. It is important hat changes in energy prices feed back into the feedstock part of the model to, so that the costs (and therefore prices) of agricultural commodities are consistent with the assumptions in the rest of GHySMo.

3. Input/Output requirements

The scope of BioGHySMo is such that data requirements could prove to be a significant challenge, especially at finer levels of granularity. Regions and countries that dominate the global biofuel market have broad data coverage from several reliable sources. For example, detailed biofuel production data for the U.S. and Brazil can be obtained from agencies of their respective governments including EIA, USDA, and EPA in the U.S. and Secex in Brazil. Many of these data series are reported on a monthly basis. Industry trade groups, such as UNICA in Brazil and the RFA in the U.S., can also provide relevant biofuel production data.

That same level of detail is less likely to occur for emerging countries in the biofuel market. More aggregate data for OECD countries is available through the IEA and, perhaps, their own government reporting agencies. Commercial data providers such as F.O. Lichts also carry data for large, small, and emerging biofuel countries

Table 5: Potential data sources.

Region	Data sources
OECD America	
United States	EIA, EPA, F.O. Lichts, IEA, USDA, RFA
Canada	EIA, F.O. Lichts, IEA
Mexico/Chile	EIA, IEA
OECD Europe	F.O. Lichts, IEA
OECD Asia	
Japan	IEA
South Korea	IEA
Australia/New Zealand	IEA
Russia	F.O. Lichts, IEA
Other Non-OECD Europe and Eurasia	F.O. Lichts, IEA
China	F.O. Lichts, IEA
India	F.O. Lichts, IEA
Other Non-OECD Asia	F.O. Lichts, IEA
Middle East	F.O. Lichts, IEA
Brazil	EIA, F.O. Lichts, IEA, Secex, UNICA
Other Central and South America	F.O. Lichts, IEA

Analyst input and judgment is often quite important in biofuel modeling efforts. As the first section the BCDR noted, the global biofuel market has evolved significantly over the last decade. The limited timeframe of available data and rapid structural shifts in the market make estimating reliable price response parameters difficult. Synthetic parameters, based on the analysts' understanding of the market and through discussions with other market experts, must often be substituted for statistically-derived parameters. As with other parameters, those that are synthetic must be monitored closely and adjusted as new data and information become available. Furthermore, model calibration and impact multiplier analysis are also important steps to take to test the assumed parameters and ensure the model will behave appropriately when different shocks are applied in scenario analyses.

Broader BioGHySMo input requirements might include information regarding agricultural markets and inputs. Reduced-form models of those markets can be used to provide more detailed analysis within the BioGHySMo framework without much additional cost in terms of data requirements and model complexity. However, data problems could still exist for small countries even for reduced-form agricultural models.

As it was noted earlier, there could be an additional issue related to data reporting in terms of calendar years versus marketing years. Most current biofuels are produced from agricultural feedstocks, and the reporting agencies that track feedstock use often report those data on a marketing year basis. Unless the data are reported on at least a monthly level, converting data to a calendar year basis is never exact. However, it may still be preferable, especially in the GHySMo exercise, since most if not all the other modules that interact with BioGHySMo will be constructed using a calendar year basis.

3.1. Knowledge Management System (KMS) Design

3.1.1. KMS structure

The nature of the biofuels sector requires that along with the traditional elements of an economic model – hard data and a parameterization methodology – additional forms of input are needed. It is clear from the discussion above that the parameterization for the model will involve some modeller intuition based on expert input, as will the decision making regarding policy assumptions.

Ideally, the KMS should be structured for efficiency in importing, updating, and reporting the data to be used in BioGHySMo. Modern spreadsheets can typically handle datasets large enough to serve large-scale models like BioGHySMo, and they have features that will allow automatic updates of external data. The FAPRI-MU biofuel datasets, while large, are Excel spreadsheets that are updated manually as necessary. While automatic updates are possible within Excel, there is a potential issue with discontinued data series and broken links. This is particularly true for biofuel data and certain related agricultural data, even for countries like the U.S. The potential for these occurrences requires diligence from the analyst to make sure the automatic updates are pulling the most relevant data and can shift seamlessly to different data series or sources.

Dataset "vintages" are also easy to establish with spreadsheets. However, an automatic "rollback" to a setting with only previously available information may be difficult to implement. Data series are often revised *ex post*, so automatic data updates may prevent a straightforward rollback. One option would be to maintain copies of previous versions of the KMS as well as previous versions of BioGHySMo. The length of the archive would be up to the analyst and would depend on potential research questions. In the case of biofuels, the global market is evolving such that model versions and assumptions can

become outdated very quickly (e.g. within a year or two). Thus, the archive would not have to be very lengthy, and the files could be maintained fairly easily.

The dataset can be split into two parts, data on physical quantities and market prices, and policy data. The former will presumably be a standard set-up and biofuel data probably does not need special treatment with regard to the other sectors of the model. Policy data will require careful management however, given the considerations outlined in Section 1 and Section 2 of the BCDR.

Policy assumption management in the KMS

There are three types of information required for BioGHySMo:

i)   The official policy in each of the given regions. This would include posted tariff rates and policies that are recorded in the legislation of the country or region concerned. This would refer to EISA for the U.S., to the Renewable Fuel Directive in the EU.

ii)   An assumption regarding the actual aim of the policy. This might be for the EU "The EU seeks to maximize reduction in GHG emmissions without increasing food prices beyond a certain level" or " the EPA acts to control overall costs of the RFS2 as manifested in RIN prices".

iii)   The actual policy assumptions as they are included in the model.

For example, in the EU there are posted tariff rates for ethanol, but in practice the average rate that ethanol entering the EU pays is less than that. So (i) would refer to the posted rates, and (iii) would detail the assumption of the actual tariff rate used in the model say the average of the last 5 years difference between T! and T2 rates, expressed in euro/liter.

The FAPRI approach, in common with other modelling systems of this type usually make the assumption that in the baseline projections "current agreed policy remains in place". This means that tariffs or blenders credits are reduced or eliminated on the basis of the schedule in the relevant legislation, and that no attempt is made to pre-empt future agreements such as trade agreements that are under negotiation. This approach can work well for some sectors, including agriculture. However, biofuels is different, as outlined by the discussions above.

The first challenge is in deciding what the "currently agreed policy" in place is. In October 2014 the EPA has still not released its final decision regarding the implementation of policy for 2014. The proposal appears to indicate an intention of policy that is open to interpretation. Just putting in the levels of the RFS2 is likely to give answers that would be considered unlikely by experts and therefore undermine the projections. This is an issue for the EU where assumptions for use of first generation biofuels are difficult since the political environment and technologies do not support meeting the 10 percent target for alternative fuels in transport. The policy environment is also vague after 2020, so a model that goes beyond that will have to make some assumptions regarding the continuation of policy, rather than just remove mandates.

For Brazil determining the major parts of current biofuel policy is more straightforward. However, those policies change in reaction to developments in both oil markets and agricultural markets. In fact, it could be argued that both the U.S. and EU policies should in fact be endogenous to a system that includes agricultural prices and energy prices (and also environmental indicators if those are included as part of GHySMo). In some cases endogenisation of policy into the model will be hard and just making simple assumptions is preferable. For the EU for example, where a simple "fuels with food crops as feedstocks should not make up more than 5 percent of total biofuel use for transport" would work. However, where this is used then the results need to be checked to make sure that the results are in the spirit of the legislation.

So the KMS for BioGHySMo includes a standard dataset including prices, production, consumption etc as well as policy variables as appropriate, for the entire period if exogenous, or just as historical values for those to be endogenous. A separate record of the basis for these policies should be maintained and preferable made available as part of reporting on the project. An example of how this might be laid out is shown in Table 6. In practice this documentation could be substantial. It could include links to source material including legislation, and supporting evidence of the assumptions made.

Offiicial policy	Assumed aim of policy	Inclusion in BioGHySMo
EU		
Renewable Energy Directive. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC	Source up to 10 percent of transport fuels from 2020 dependent on food prices and GHG savings	Assume only 5 percent will come from first generation fuels, model as a fixed mandate Assume this level continues past 2020
Various tariff rates: €0.19/liter undenatured, €0.10/liter undenatured, other ad hoc tariffs	Commission manipulates protection to keep effective tariffs at a certain rate	Set effective tariff on ethanol as three year average of difference between T1 and T2 prices

The maintenance of this system is challenging as policy data changes frequently and needs to be collected from different sources. A suggestion is that those responsible work with others who may have interest in such a dataset such as FAPRI, OECD/FAO or some other group. Those groups would probably be receptive to working together on these issues given they are already attempting to maintain similar datasets.

3.1.2. KMS role in model calibration

There are essentially two steps regarding model calibration in the BioGHySMo example.

i)   In the parameterization of the model itself. Given the lack of data, the transformation of the industry and the potential new fuels and regions the model will not be able to generate all of the parameters required itself, say through the estimation of a system of equations. The parameters are likely to be drawn from a number of sources and these should be documented. It is unlikely that this documentation can be carried out in the model itself,

and so an ancillary record of sources and the decision making behind them is preferable. This would normally be part of model documentation, but is also a resource that would be useful if responsibility for the model is passed on through giving an idea of the vintage of the parameters imposed.

ii) The generation of the baseline outlook can also be viewed as a kind of calibration. In some cases it is appropriate to adjust the raw output of the model to take consideration of the input of expert judgment with regard to forces outside of the model's scope. These adjustments are recorded in the workings of the model are not generally reported, or the logic for their incorporation. Again this is something that can be potentially incorporated into the model but could be managed outside..

4. Uncertainty and limitations

Policy uncertainty is an important factor to consider in relation to biofuel production. There have been, and still are, many government policies enacted to support biofuel industries around the world. As we have seen, however, those supports are rarely permanent and may be altered on a regular basis. In the U.S., for example, the tax credit given to biomass based diesel blenders has expired multiple times in recent years, but it has traditionally been renewed and retroactively reinstated. At present, there is no clear indication that such renewal will occur, so models that account for current policies are likely to show no tax credit in place for the projection period.

At the same time, use requirements such as the RFS in the U.S. and the RED in the EU have undergone interpretative changes over time. The proposed implementation rules for the 2014 RFS requirement represented a shift in the determination of applicable renewable fuel volumes that came as somewhat of a surprise to the industry and obligated parties. In the EU, environmental and food security concerns regarding land-use change have prompted an increased emphasis on biofuels produced from sustainable, non-food feedstocks. Moreover, the landscape of EU biofuel trade policy has also shifted dramatically as several global biofuel producers, including the U.S., have had countervailing duties applied to their product in recent years.

In addition to policy uncertainty, there is also considerable technology uncertainty in a long-term outlook. While production incentives for fuel ethanol have been around since at least the 1980s, first-

generation biofuels, as an industry, did not mature rapidly until the last decade. Looking ahead, it is impossible to know which, if any, of the next-generation biofuels will reach significant commercial scale and a similar level of maturation. The first commercial-scale cellulosic biofuel refineries began production in 2013, although the initial quantities were quite small. One year later, two more cellulosic refineries went online even as production from the two earlier companies had ceased almost entirely due to technological and financial difficulties. Several more cellulosic biorefineries are scheduled to begin production in the coming years. Nevertheless, the outlook for cellulosic biofuels remains highly uncertain.

Assuming next-generation biofuel production matures in the course of the outlook period, there is still uncertainty related to the feedstocks supplied for biofuel production. Currently, cellulosic biofuels are produced primarily from residual material occurring as part of other human activities. Those residues include municipal solid waste, forest material, agricultural residues, and even ethanol production residues (e.g. corn kernel fiber). Next-generation biofuel production from devoted energy crops and algae have yet to reach commercial scale. One question is where those crops will be grown and can they be grown both economically and sustainably. Land-use change is an important factor that must be accounted for in the model. In addition to energy security goals, current policies in the U.S., including the RFS and LCFS, try to meet environmental and sustainability goals through the use of disincentives related to land-use change. In other words, fuels that result in land-use change will be treated less favorably. The EU has similar goals and disincentives to reduce the likelihood of biofuels resulting in land-use change.

In addition to uncertainty surrounding next-generation biofuel feedstocks and the potential for land-use change, there is uncertainty related to the form of future biofuels. Until now, most biofuels have been subject to some sort of upper limit on blending rates. Only flex-fuel vehicles can use high-level ethanol blends (e.g. E85) while older vehicles (pre-2001) have only been approved for 10% ethanol blends or less. Newer vehicles have been approved for ethanol blends up to 15%. Most biomass based diesel blends sold at the retail level remain in the 2%-5% range, although some diesel vehicles are approved for blends that are 20% or greater. To get around this "blendwall" issue, much research has been devoted to developing drop-in fuels that have properties nearly identical to those of traditional petroleum-based fuels. Such fuels could be used in existing vehicles without separate approvals or changes in vehicle technology.

However, changes in vehicle technology could occur, regardless, that affect which type of fuels reach the market. In other words, the fuel market will need to adapt to the changing vehicle technologies as CAFE standards become more stringent in the medium- to long-term. For example, one possibility might be to sell vehicles employing higher compression ratios and optimized for high-octane, mid-level ethanol blends (e.g. E30), which could serve a dual purpose of meeting more stringent CAFE standards as well as boost demand for current biofuels. While it would not completely preclude the adoption of drop-in fuels in the liquid fuel market, it could pose somewhat of a barrier to entry.

Biofuel supply could also be affected by the role of aviation biofuels in the future. The aviation industry represents a very large and underserved market for biofuels. There have been successful test-flights using biofuel blends in recent years, but widespread adoption has not yet become a reality. If biofuels, conventional or drop-in, were to gain significant market share in the aviation industry in the long-term, then very strong growth in global biofuel production could be a potential outcome.

5. Conclusions and recommendations

The model that is outlined above is a simple framework for the determination of the supply and demand of biofuels. A simple, flexible framework is recommended given the peculiar challenges of the biofuels sector. The shortcomings of this approach have also been discussed above – but any further complication in the model comes at the expense of an expansion of data, and expertise in order to monitor that data.

General recommendations from the BCDR are:

- Develop a simple, reduced form feedstock model parameterized with co-operation with one of the large, partial equilibrium models operated by FAPRI-MU, OECD/FAO or the USDA or through the selection of parameters from the literature that has examined the relationship between feedstocks and biofuels. It is unlikely that there is anything "off the shelf" that would exactly meet the needs of BioGHySMo, so this part of the model would require some work and ingenuity on the part of the modeler.

- Linkages with the upstream module are likely to be minimal. Natural gas plays a key role in agriculture through it being the main cost component of nitrogen fertilizer, and also is a significant part of some ethanol processing costs and so if scenarios where the price of natural gas is envisioned, it's inclusion in the cost parts of the agricultural sector and ethanol returns should be considered.

- Stronger links with the liquid fuels model and logistic models will be required. It is likely that fuel demand should be considered and in that case biofuels will probably be represented in the liquid fuels model or similar. Although under current policy this can often be treated as a fixed blending rate given the prevalence of that policy, effort should be made to consider uses outside of the mandate, particularly in low level blends where the experience of the U.S. has shown that once infrastructure is in place, usage can exceed mandated blending levels on the basis of economic competitiveness.

- Structure the model such that in the long run key price relationships are maintained such as those between oil prices and agricultural prices, and feedstocks and the biofuels that they are made out of. But use a flexible system that allows prices such as those for corn and oil, or corn and ethanol to diverge in the short run as those divergences can be important.

- Have a simple underlying structure that can be specified at a regional level reflective of the GHySMo given the availability of data. Introduce into the structure detail for the most important countries or regions to capture important policy differences there. At a minimum it is likely that a different structure for the U.S., EU and Brazil be considered.

- In addition to the raw data, a significant amount of other knowledge would be required for BioGHySMo regarding the parameterization and calibration of model and determination of policy assumptions. This will require expert input and a way of processing, implementing and recording these interventions. Work with existing users of global biofuels models in order to minimize the workload in maintaining the model – a large part of which will be keeping current on different country's policy updated and the viability of new fuels or technology.

- In determining the scope of the model careful consideration of the type of analyses to be examined is required. There is huge scope for granularity in the model with different countries, regions, fuels, feedstocks, blend levels etc so a good idea of the types of analyses foreseen should be determined before choosing which of these paths to choose.

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Appendix I. Variable names

Variable name	Description	Units	Source
COPRW	U.S. fob gulf corn price	$/tonne	FAPRI/USDA/OECD
SOPRW	Hamburg soybean oil price	$/tonne	FAPRI/USDA/OECD
XOPRW	Tallow, US, cif Rott	$/tonne	Oilworld
SUPRW	Sugar, #11 price	$/tonne	FAPRI/USDA/OECD
OMPRW	Other material price index	Index	Calculated
COCST	Corn production cost index	Index	Calculated
SOCST	Soybean oil production cost index	Index	Calculated
SUCST	Sugar production cost index	Index	Calculated
GRFSK	Total grain feedstock demand	Thousand tonne	F.O. Lichts, USDA, county resources
VGFSK	Veg. oil feedstock demand	Thousand tonne	F.O. Lichts, USDA, county resources
XOFSK	Other oil and fats feedstock dem.	Thousand tonne	F.O. Lichts, USDA, county resources
SUFSK	Sugar feedstock demand	Thousand tonne	F.O. Lichts, USDA, county resources
OTFSK	Other material feedstock demand	Thousand hectares	Calculated
ETCST	Ethanol cost of production	National currency/liter	Calculated, based on industry input
ETPRW	Wholesale ethanol price	National currency/liter	Country resources
ETPRR	Retail ethanol price	National currency/liter	F.O. Lichts, county resources
GSPRR	Retail gasoline price	National currency/liter	Other GHySMo modules
BDPRR	Retail biodiesel price	National currency/liter	Other GHySMo modules
AVPRW	Wholesale avaiation fuel price	National currency/liter	Other GHySMo modules
DIPRW	Wholesale diesel price	National currency/liter	Other GHySMo modules
ETPRR	Ethanol returns	National currency/liter	Calculated
ETCAP	Ethanol production capacity	Million liters	F.O. Lichts, county resources
ETCSB	Ethanol capacity subsidy	National currency/liter	Country resources
ETPSB	Ethanol production subsidy	National currency/liter	Country resources
ETUTZ	Ethanol capacity utilisation	Per cent	Calculated
ETPRD	Ethanol production	Million liters	F.O. Lichts, county resources
ETMAN	Ethanol use madate	Percent or volume	Country resources
GSUSE	Gasoline use	Million liters	Other GHySMo modules
ETUSM	Ethanol mandated use	Million liters	F.O. Lichts, county resources
ETUSK	Ethanol market use	Million liters	F.O. Lichts, county resources
ETSTK	Ethanol ending stocks	Million liters	F.O. Lichts, county resources
ETNIM	Ethanol net imports	Million liters	F.O. Lichts, county resources
DSUSE	Diesel use	Million liters	Other GHySMo modules
BDUSM	Ethanol mandated use	Million liters	F.O. Lichts, county resources
ETUSB	Ethanol use subsidy	National currency/liter	Country resources
BDUSB	Biodiesel use subsidy	National currency/liter	Country resources

	Description	Units	Source
Sub script identifiers			
Countries			
i	Denotes for each country		
BR	Brazil		
US	U.S.A		
WD	World		
Products			
j	Denotes for each product		
ALL	All products		
GR	From grain		
SU	From sugar		
ET	Ethanol		
BD	Biodiesel		
OT	Other fuel		
AV	Aviation fuel		
MT	For military use		
EG	Electricity generation		
Conversion factors			
etgr	Grain used for ethanol	tonnes/liter	
etsu	Sugar used for ethanol	tonnes/liter	
etot	Area used for ethanol	hectares/liter	