CENTRE of POLICY STUDIES and the IMPACT PROJECT

Eleventh Floor, Menzies Building
Monash University, Wellington Road
CLAYTON Vic 3800 AUSTRALIA

Telephone: from overseas:
(03) 9905 2398, (03) 9905 5112 61 3 9905 2398 or
61 3 9905 5112

Fax:
(03) 9905 2426 61 3 9905 2426

e-mail: impact@buseco.monash.edu.au

Internet home page: http//www.monash.edu.au/policy/

Enhancing Agriculture and Energy Sector Analysis in CGE Modelling: An Overview of Modifications to the USAGE Model

by

R. ASHLEY P. WINSTON
Centre of Policy Studies
Monash University
and
US International Trade Commission

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Enhancing Agriculture and Energy Sector Analysis in CGE Modelling: An Overview of Modifications to the USAGE Model

R. Ashley P. Winston[1]

Abstract

This paper describes some key developments to USAGE, a dynamic computable general equilibrium (CGE) model of the US economy, aimed at enhancing its utility in agricultural and bio-fuels/bio-energy analysis.

The USAGE model is a large-scale dynamic CGE model of the US economy developed by the Centre of Policy Studies at Monash University in collaboration with the US International Trade Commission (USITC), and has been updated and modified for this study with assistance from the Economic Research service of the US Department of Agriculture (ERS-USDA). Additional sectoral detail and theory are developed and applied to USAGE, including a detailed modeling of land use in US agriculture involving 72 types of land, the explicit modeling of TRQ policies and by-product biomass supply (such as crop residues) using nested complementarity relationships, and careful accounting for subsidies in US ethanol production and their effects on public revenue streams.

JEL classifications: Q24, Q42, Q48, C68

[1] Senior Research Fellow, Centre of Policy Studies, Monash University, Melbourne, Australia, and US International Trade Commission, Washington DC.

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1 The USAGE model

USAGE is a dynamic computable general equilibrium (CGE) model developed by the Centre of Policy Studies (CoPS) at Monash University in collaboration with the US International Trade Commission (USITC). The version of the model described in this paper distinguishes 535 industries, 539 commodities, up to 700 occupational categories, 51 domestic regions (the 50 states plus the District of Columbia) and 27 foreign regions. The modifications to USAGE described in this paper were carried-out with assistance from the Economic Research Service (ERS) of the US Department of Agriculture (USDA).[2]

Theoretical modifications to USAGE include an enhancement of land use in production and the mobility of land between sectors in agriculture, adjustment to technologies in new sectors to better reflect bio-fuels production realities and the use of complementarity relationships to handle constraints on the supplies of two "second-generation" inputs into ethanol production. These changes are discussed in more detail below.

The database has been expanded to include the creation of 22 new industries and 36 new commodities, and a reformulation of the input-output accounting for 24 agricultural sectors, particularly in the accounting for value added (and most notably in land use).

In this section we outline the construction of some key additional sectors in USAGE.

2 New USAGE industries and commodities

Extensive work was carried out to modify and re-balance the USAGE database. The original USAGE model distinguished 503 commodities and 513 industries, based largely on the classifications embodied in the 1992 and 1998 US input-output tables generated by the Bureau of Economic Analysis (BEA) using the US Standard Industrial Classification (SIC) system. For the current project, an additional 36 commodities, 22 industries, 72 land-types and 26 foreign regions were developed for USAGE. The key sectors for this paper are summarized below in Figure 1 (a make matrix) and Figure 2 (a use matrix). A large part of the work required to modify USAGE involved finding or estimating data values to replace the "dots" in these matrices.

[2] We are particularly grateful to Mark Gehlhar and Agapi and Somwaru for expert advice and assistance and to Suchada Langley for her executive support of this work. Any opinions, analysis or assertions made regarding US energy policy in this paper should be attributed solely to the authors and not to the ERS-USDA.

Figure 1 Make matrix

Industry

Commodity	Feed grains	Switch grass	Crop residue	Cellul. material	Organic by-prods	Dry corn-milling	DDGS	Cellul. ethanol	Adv. ethanol	Petrol. Refining	Ethanol	Gaso/ ethanol
Corn	●											
Switch grass		●										
Crop residue	o		●									
Cellulose				●								
Organic by-products					●							
Corn ethanol						●						
DDGS						o	●					
Cellulosic ethanol								●				
Adv ethanol									●			
Gasoline										●		
Diesel										●		
Other fuels										●		
Ethanol											●	
Gaso/ ethanol												●
Other	●											

Figure 2 Use matrix

User

Input

	Feed grains	Switch grass	Crop residue	Organ. by-prods	***Cell Mater.***	Dry corn-milling	DDGS	Cell. ethan.	Adv. ethan.	Petrol. Refin.	*Ethan.*	*Gaso/ Ethan.*	Other Indus	Final Dem
Corn						●							●	●
Switch grass					●									
Crop resid.					●									
Cell. mater.								●						
Org. by-									●					
Corn ethan.											●			
DDGS														
Cell. ethan.											●			
Adv. ethan.											●			
Sugar ethanol											●			
Other Ethanol											●			
Crude										●				
Gas.										●		●		
Gas/ Ethano	●	●		●		●	●	●	●	●			●	●
Ethan.												●		
Fertil.	●		●											
Other com	●	●		●		●	●	●	●	●			●	●
Prod subsidy						●		●	●					
Labor	●	●	●	●		●	●	●	●	●				
Capital	●	●		●		●		●	●	●				
Land	●	●												

Some of the sectors in the two tables above did not exist in the US in 2005 in anything other than experimental form (for example, the cellulosic ethanol sector). Small starting values for output and a valid representation of the industries' cost structures were developed for each case to enable an analysis of the effects of their likely growth between 2005 and 2022. In Figure 1, circles refer to by-product commodities (in the row) produced by an industry (in the column).

Several of the new industries and commodities are created for purely technical reasons (such as cellulosic material, ethanol and motor fuels). These sectors have no factor inputs and use only a small selection of intermediate goods as inputs. For example, the cellulosic material industry's only inputs are switchgrass and crop residue, which are combined in a constant elasticity of substitution (CES) nest (see below, section 3).

Imports in USAGE are designated by source (by 27 foreign regional classifications built around definitions of trade agreements or some other similarity in the US treatment of their trade) and commodity. US ethanol imports are covered by a tariff-rate quota based policy that is modeled explicitly[3]. USAGE accounts for the importation of two types of ethanol: sugar ethanol and "other" ethanol. The commodity "other" ethanol is a catch-all category to capture, for example, US imports of ethanol from Europe made from excess wine stocks (typically industrial ethanol) and grains.

2.1 Constructing the ethanol industries

USAGE contains 5 different ethanol commodities:

1. Corn-starch ethanol.
2. Cellulosic ethanol.
3. "Advanced" ethanol made from biomass sources such as forestry residue and saw-mill waste.
4. Sugar ethanol.
5. "Other" ethanol (i.e. made from sources otherwise not specified above, such as grain ethanol from the EU).

USAGE has been designed so that corn-starch ethanol, cellulosic ethanol and advanced ethanol are domestically produced and imported, while sugar and "other" ethanol are only imported.

The three USAGE industries that produce ethanol domestically are dry corn milling (produces the commodity corn-starch ethanol); cellulosic ethanol (produces the commodity cellulosic ethanol), and;

[3] Imports of around 20 USAGE commodities are modeled explicitly with TRQs in place, including sugar (which involves a two-tier TRQ premium), various dairy products and tobacco.

advanced ethanol (produces the commodity advanced ethanol)[4]. Only the dry corn milling industry currently existed at a non-negligible level of output in the US in 2005.

2.1.1 Dry Corn Milling and DDGS

For 2005 we obtained the following information about corn-starch ethanol production:

1. The value of ethanol produced at basic prices, i.e. the value at the factory door. This value reflects the cost to the dry corn milling industry of all intermediate inputs, the returns to capital and land and the cost of labor. The basic value is the total of these costs less subsidies.
2. The value of subsidies on ethanol production. It is important to handle production subsidies convincingly. We understand that a subsidy of something like US51c per US gallon currently applies to the production of ethanol in the US.
3. The value of corn used to produce a unit of corn-starch ethanol. It is important to be accurate about corn use in this sector because we want the model to apply an appropriate level of pressure to the supply of corn when a simulation implies expansion in corn-starch ethanol production.

Output of ethanol from corn-starch ethanol in 2005 was 3.91 billion US gallons, with an average basic price of around $2.00 per US gallon. With the current subsidy of 51 cents per US gallon, this implies that the total value of subsidies is around $1.96 billion. Close to 14 percent of the 2005 US corn crop, or 1.55 billion bushels, was used in ethanol production in dry corn milling (implying an average conversion rate in 2005 of around 2.54 gallons per bushel) with price of corn averaging $2 per bushel. Of the 78.2 million acres used for corn production in the US in 2005, 15.6 million acres was effectively devoted to bio-fuels supply, meaning that US ethanol yields per acre amounted to 321 gallons per acre.

The main by-product of corn-starch ethanol production is dried distillers grains with solubles (DDGS). DDGS is used as a protein source for animals in feedlots, particularly in finishing cattle and poultry. The relevance of DDGS to an analysis of bio-fuels policy relates to (a) its importance as a source of revenue for corn milling plants and (b) its substitutability for corn in animal feed-stocks. Data for dry corn milling plants for 2005 suggests that one bushel of corn used for corn-starch ethanol production produces eighteen pounds of DDGS, and that the basic price of DDGS was $80 per ton. Implicitly (based on ethanol production data outlined above), around 12.7 million tons of DDGS was produced in 2005 with a value to the dry corn milling sector of $1.01 billion. The last figure is consistent with US Department of

[4] On the basis of advice from various expert sources in the US, we have used the dry corn milling sector as the focus of the RFS mandate as applied to corn-starch ethanol. USAGE also contains a *wet corn milling* sector that produces corn-starch ethanol, but the consensus of expert opinion seems to indicate that this sector is unlikely to expand. Increased US output of corn-starch ethanol is assumed to be driven by expansion in the dry corn milling sector.

Census financial data for the dry corn milling sector that suggests that around 10-20 percent of the income of corn-starch ethanol producers is derived from sales of DDGS.

Given this information, we build the dry corn milling column of the use matrix for 2005 as shown below in Table 1.

Table 1 Cost structure of the US dry corn milling sector in USAGE

Dry Corn Milling	$million
Corn	*3,111.36*
Other intermediate	
Capital	6,687.68
Labor	
Land	
Production tax	*-1,991.04*
Basic value of ethanol	*7,808.00*
Basic value of DDGS	1,010.00
Basic value of output	*8,818.00*
Reference item: Physical output	***3,904 million gallons***

The critical numbers are in italics. The value of other intermediate usage and value added (6687.68) is deduced as a residual and its composition is not crucial. In the USAGE database, other intermediate usage and the components of value added are attributed to dry-corn-milling in what we regard as a reasonable composition for a chemicals manufacturing industry based on data we have for other similar sectors. Corn input is critical because we want to attribute the correct demand adjustment to the corn industry as corn-starch ethanol expands. The value for physical output is critical because we want to ensure the correct shock is applied to output for the period 2005 to 2022 when we expand corn-starch ethanol production to the RFS mandate level. The production tax and basic value of output are critical because we need to accurately account for the rate of subsidy as this will be important in determining the welfare effect on the economy of expanding corn-starch ethanol production to meet the RFS mandate.

As DDGS is produced as a by-product (i.e. incidentally) in the dry corn milling industry, in order to model sales of DDGS accurately we develop a method using a complementarity relationship between the supply of DDGS to the market and its price, detailed below in section 4.2.

2.1.2 Cellulosic ethanol

Cellulosic ethanol was not produced in significant quantities in the US in 2005. As a means to deal with the "zero problem"[5], we assume that a cellulosic ethanol industry existed in 2005 that produced 10 million US gallons of ethanol with a basic value of $0.02 billion. This is an arbitrarily small number that otherwise carries no real significance.

Industry data describing 2005 suggests that, with the technologies available at that time, the cost of producing cellulosic ethanol was close to double (a critical relativity) that for corn-starch ethanol. As can be seen from Table 1 above, input costs per US gallon of corn-based ethanol are around $2.51[6]. On this basis, we assume that input costs per gallon of cellulosic ethanol are around $5.02 per US gallon. If we assume that the 10 million gallons notionally produced in 2005 was able to "compete" with corn-starch ethanol, the implied market price for cellulosic ethanol in 2005 was $2 per gallon, leaving approximately $3.02 per gallon to explain as subsidies or economic losses.

Under the RFS, a subsidy of $1.01 will be applied to cellulosic ethanol from 2009. We apply this subsidy to USAGE as a "genuine" production subsidy, and the remainder as what we call a "phantom" production subsidy (in both cases, a negative production tax). Genuine taxes in USAGE are revenue-raising taxes (or revenue-requiring subsidies), while "phantom" taxes drive wedges between variables at the margin but generate no revenue. Typically a phantom tax is interpreted as excess economic profit, and a phantom subsidy as an economic loss. In this case, the phantom subsidy of $2.01 per gallon is a non-revenue-requiring wedge that we impose as an economic loss to the cellulosic ethanol industry in 2005.

How much cellulosic material (switchgrass or crop residue) will this require? With 2005 technology, a US gallon of cellulosic ethanol required around 30 pounds of cellulosic material. Cellulosic material cost around $0.023 per pound in 2005. Therefore, the 2005 input of cellulosic material to our embryonic cellulosic ethanol industry is valued at $7 million[7].

With this information in place we build the cellulosic ethanol column of the 2005 use matrix as shown below in Table 3.

---

[5] The "zero problem" refers to technical difficulties associated with zeroes in databases of models with largely percentage-change equation systems.
[6] Calculated as ($7.808m + $1.991m)/3.904bg = $2.51.
[7] Calculated as 31 lbs/gallon*0.023$/lb*0.01 billion gallons.

Table 2 Cost structure of the US cellulosic ethanol sector in USAGE

Cellulosic Ethanol	$million
Cellulosic material	*7.00*
Other intermediate	
Capital	43.20
Labor	
Land	
Genuine production tax	*-10.10*
Phantom production tax	*-20.10*
Basic value of output	20.00
Reference item: Physical output	***10 million gallons***

Again, the critical numbers are in italics. The value of other costs (other intermediate, capital, labor, land) is deduced as a residual, and similar to our approach to create a dry corn milling sector, will be given what we consider to be a "reasonable" composition for a chemicals manufacturing industry. Cellulosic material input is a critical number because in determining the appropriate demand shift to the cellulosic material industry as cellulosic ethanol expands. The level of output, production tax and the basic value of output are critical for the same reasons stated earlier for dry corn milling.

The composition of the production subsidy is also critical. The effects on public revenue that flow from a large expansion in cellulosic ethanol production will be key to the welfare effects. By allocating $1.01 as genuine subsidy and the rest as economic losses we (appropriately) reduce the size of revenue effect. In the policy experiment, assuming that the industry is viable in the long run suggests moving the rate of the phantom subsidy to zero.

2.1.3 Advanced Ethanol

This industry is designed to serve as a catch-all for alternative biomass sources and technologies for US domestic ethanol production. Alternative sources of biomass include logging/forestry residue, urban wood residue, wood processing residue, fuel wood and manure. Advanced ethanol was not produced in significant quantities in 2005. As for the cellulosic ethanol industry, the advanced ethanol industry will be assumed to produce 10 million US gallons of ethanol in 2005 worth $20 million.

We assume for now that the technology for making advanced ethanol involves sourcing biomass from a commodity we'll call "organic by-products". The majority of the estimated stock of these alternative biomass sources is derived from forestry/logging residue, scrap wood and recycled paper products - that is, wood-based products. Wood provides a source of cellulosic biomass that, like in the use of switchgrass and crop residue, requires the application of enzymes to break down plant cell-wall tissue, which then provides the same basic material for conversion into ethanol. Based on some speculative data we have seen, it seems reasonable to guess that the cost of acquiring a ton of organic by-products will be about the same as for switchgrass and crop residue. As such, a first guess is to assume that the cost structure for advanced ethanol production is similar to those of cellulosic ethanol, and Table 3 below outlines the (identical) cost structure of this sector.

Table 3 Cost structure of the US advanced ethanol sector in USAGE

Advanced Ethanol	$million
Organic by-products	*7.00*
Other intermediate inputs	
Capital	45.00
Labor	
Land	
Genuine production tax	*-10.10*
Phantom production tax	*-20.10*
Basic value of output	20.00
Reference item: Physical output	***10 million gallons***

2.2 Constructing the biomass industries

This section outlines the creation of the key biomass supply industries.

2.2.1 Cellulosic material

In line with assumptions made in the construction of the ethanol sectors, the output of this industry in 2005 must have a basic value of $7 million. The output of the cellulosic material sector will comprise two inputs: switchgrass and crop residue. How should we weight each source of cellulosic material in the cellulosic material industry?

Assume for now that there is no shortage of crop residue (i.e. all of the cellulosic material requirements moving out to 2022 can be satisfied by crop residue). In this case we would expect very little development of the switchgrass industry in the absence of subsidies. To reflect this, we should make the input of switchgrass in 2005 arbitrarily small relative to the input of crop residue, e.g. $1 million for switchgrass and $6 million for crop residue. The cellulosic material industry treats switchgrass and crop residue as close substitutes (via the high substitution elasticities in the cellulosic material sectors input nest) and so, when the supply of crop residue reaches a bound (see section 4.1 below) or the price of switchgrass falls through technological advances in cropping, the substitution to switchgrass will be made without requiring a large increase in the relative price of cellulosic material.

Table 4 Cost structure of the US cellulosic material sector in USAGE

Cellulosic material	$million
Switchgrass	1.00
Crop residue	6.00
Other intermediates	0
Labor	0
Capital	0
Land	0
Production tax	0
Basic value of output	*7.00*
Reference item: Physical output	***0.14 million tons***

2.2.2 Crop residue

The output of crop residue has been tied down in the base year at 120 thousand tons. This is 6/7 of the cellulosic material requirements of the cellulosic material industry (which requires a total of 140 thousand tons[8]). In line with other assumptions made above, the output of this industry in 2005 must have a basic value of $6 million.

We model this by-product sector as using some labor to gather crop residue and by applying some replacement fertilizer to capture the loss of soil nutrients to corn farming associated with the removal of stover (see below). We assume that one ton of crop residue is equivalent to $5 of fertilizer, suggesting

[8] Calculated as 14 kg/gallon for the 10 million gallons produced by the cellulosic ethanol industry

that fertilizer replacement in corn farming in 2005 must be worth $0.6 million. With this information we set up the crop residue industry as shown below. As before, the distribution of costs between other intermediate, capital and labor are not critical.

Table 5 Cost structure of the US crop residue sector in USAGE

Crop residue	$million
Fertilizer	*0.60*
Other intermediate	0
Capital	0
Labor	5.40
Land	0
Production tax	0
Basic value of output	*6.00*
Reference item: Physical output	***0.12 million tons***

The supply of crop residue does have a potential upper bound. In 2005, total US acreage applied to corn farming was 75.1 million acres, producing 11,112 million bushels of corn weighing 282.85 million tons. On average, about one ton of corn stover is produced for every ton of corn, and USDA guidelines for soil protection require that some stover be left on the ground as anti-erosion coverage (a minimum of 30 percent cover). Depending on a number of local factors (such as soil type, tillage practice, crop rotation, slope of the field and length of the slope) this translates to between 1 and 3 tons of coverage stover per acre. Yields in corn in 2005 were around 148 bushels per acre, which translates to 3.76 tons per acre. Therefore, from a total stover yield of around 3.76 tons per acre and assuming an average requirement for anti-erosion cover of 2 tons per acre, there was approximately 132.65 million tons of removable stover available in 2005. If utilized entirely in ethanol production, this could have generated 9,727 million US gallons of cellulosic ethanol with 2005 technology.

Cellulosic ethanol production in 2022 is targeted to reach 16 billion gallons under the RFS mandate, implying a shortfall in cellulosic biomass supply from crop residue of over 50 million tons. Technological progress in converting cellulosic material into ethanol will overcome some of this shortfall in inputs, as will increases in corn (and therefore, stover) yields per acre. However, the rapid acceleration in cellulosic ethanol output indicated in the latter years of the RFS suggests some potential for the supply constraint on crop residue to reach a bound. The complementarity relationships used to model this are detailed below in section 4.

2.2.3 Switchgrass

Switchgrass is a versatile grass native to North American Great Plains that has been proposed as a low-cost biomass source suitable for the production of cellulosic ethanol. Although there is currently no large-scale commercial farming of switchgrass, it is commonly planted as pasture grass in the central and eastern United States and is currently grown on CRP (Conservation Reserve Program) land as a cover crop for conservation purposes. A switchgrass stand takes about three years to establish, and can be harvested with standard farm baling machinery.

The utility of switchgrass as a biomass source flow from several of its characteristics: it readily establishing itself in a wide variety of soil types, it adapts readily to temperature extremes and is more drought-resistant than other perennials such as alfalfa. Switchgrass is also well suited to cultivation on relatively marginal lands; an important implication of this is that it potentially generates comparatively reduced levels of competition with food and feed crops for land. Any natural rain-fed areas with adequate moisture for seeding establishment are considered as viable land for growing switchgrass, and we preclude only the Basin and Range (see sections 5.1 and 5.2 below) region of the US as a designated area for growing switchgrass (primarily because of known high capital costs associated with irrigation and soil improvement that would be needed for establishing grasses of this type in this region). In practice, although many locations in the United States are agronomically feasible for growing switchgrass, establishing the crop on very productive land may not be economically viable due to high land rents.

For our purposes, the basic value of switchgrass output must initially equal $1 million, and the total tonnage must equal 20 thousand tons. These numbers represent 1/6 of the total basic value and tonnage required to satisfy our assumptions for the use of cellulosic material in the cellulosic ethanol industry. An implication of satisfying this value and tonnage is that the basic price of switchgrass is $50 per ton - a number around 30 percent higher than projected future cost estimates presented at the 2006 Hearings of the US Senate Committee on Agriculture, Nutrition and Forestry, and thus a reasonable starting point for a fictional switchgrass industry in 2005.

Table 6 Cost structure of the US switchgrass sector in USAGE

Switchgrass	$million
Other intermediate	0. 620
Capital	0. 085
Labor	0. 195
Land	0. 028
Production tax	0. 072
Basic value of output	*1.000*
Reference item: Physical output	***0.02 million tons***

We believe that a reasonable starting point in constructing this sector is to take the cost shares from an existing USAGE industry called "general crops" as a guide to distributing the $1 million in costs. "General crops" is a USAGE sector that produces a variety of crops on a range of land types. Apart from the issue of structuring it's costs in a sensible way, the critical number in this case is the value of output.

2.2.4 Organic by-products

We assume that an organic by-products industry would look very similar to a crop residue industry. The commonality stems from the nature of by-product "production".

Various activities in USAGE implicitly generate waste materials that could be collected and used as biomass for cellulosic ethanol production. These by-products are incidental to production decisions, and so effectively are like endowments. On the input side, the organic by-products sector is similar to crop residue in that it's assumed production involves some labor, but different in that there is no requirement for fertilizer. The types of materials we envisage being produced by this industry are waste products that otherwise would have been burnt or buried in landfill and have no ulterior value[9].

[9] Use of these materials in producing ethanol does provide some external benefits. Used as inputs into ethanol production amounts to a net reduction in greenhouse gas emissions, as it changes the medium for the release of greenhouse gasses from a furnace or a dump site to an ethanol plant and a motor vehicle: when burnt or buried as waste, both organic by-products and gasoline are releasing greenhouse gasses; when organic by-products are used to replace gasoline, only organic by-products are releasing greenhouse gasses. The exact value of the gain on this substitution in motor fuels needs to be balanced against the possible use of these materials as an industrial fuel source when relevant. In the model reported here, these carbon-balance issues are not directly addressed.

Assume that this industry has an initial (arbitrarily small) size in 2005 equal to that of the crop residue industry. Also assume that it also can sell biomass for $50 per ton in 2005 to the advanced ethanol industry. The total basic value of organic by-product sales is tied down at $7 million, and the output-by-gallons assumed in advanced ethanol implies that a ton of organic by-products must make the same number of gallons as crop residue.

Table 7 Cost structure of the US organic by-products sector in USAGE

Organic by-products	$million
Other intermediate	0
Capital	0
Labor	7.00
Land	0
Production tax	0
Basic value of output	7.00
Reference item: Physical output	***0.14 million tons***

Some indicative estimates of the current annual availability of organic by-products *are*: 36.8 million dry tons of urban wood waste; 90.5 million dry tons of primary mill waste; and 45 million dry tons of forest residues. This 172.3 million tons of has the potential to produce 12.63 billion gallons of ethanol with current technology, although only 5 billion gallons is called for under the RFS.

3 Why use nesting industries?

Some of the new industries in USAGE are added to allow a more realistic representation of substitution possibilities between certain commodities in intermediate demand. These sectors are not "real" in the sense that they create no value-added. The candidates directly relevant to bio-fuels production are cellulosic material (which combines switchgrass and crop residue), ethanol (which combines ethanol types from different sources) and motor fuels (which combines gasoline and ethanol in to a final fuel mix) industries. Generally speaking, this method is used whenever it is critical to set the substitution possibilities for intermediate usage, use in capital creation, final consumption or export demand at values significantly different from other substitution elasticities at a given level of the production or consumption nest[10].

As an example, take the cellulosic material industry. This industry "produces" a product that is a combination of switchgrass and crop residue that we call cellulosic material and then sells it solely to the cellulosic ethanol industry. The reasoning behind this modeling approach stems from the desirability of a relatively large rate of technical substitution between certain intermediate commodities in (for example) ethanol production (such as between the biomass sources for the cellulosic ethanol industry) but not between these goods and other intermediate commodities in ethanol production. This makes it necessary to remove the substitution possibilities from the production function of the final industrial user (cellulosic ethanol).

USAGE uses multi-level nests of the CRESH (constant ratio of elasticities of substitution, homothetic) family of functions to represent a sector's production function. Using the CRESH format allows us the freedom to define individual substitution elasticities for each intermediate good against all other intermediate goods in the production nest, *but* not in a pair-wise fashion. Therefore, setting a high rate of technical substitution for inputs of switchgrass and crop residue in the production function for the cellulosic ethanol industry would allow these two biomass sources to substitute at high rates with all other inputs, not just each other. A notional "industry" is created that combines only the biomass sources across a relatively flat isoquant and the "output" of this sector (cellulosic material) enters the production function of the cellulosic ethanol industry with more constrained substitution possibilities against other inputs.

4 Complementarity relationships for crop residue and DDGS

Crop residue and DDGS attract special treatment in USAGE. Equations were added to the model to capture discontinuous relationships between their price and supply.

4.1 Complementarity relationship for crop residue

Several by-products of cropping are suitable as biomass sources for cellulosic ethanol production. These include those generated by corn, wheat, soybeans, cotton, sorghum, barley, oats, rice, rye, canola, beans, peas, peanuts, potatoes, safflower, sunflower, sugarcane and flaxseed. The availability of crop residues is a function of several factors, including total primary product output, the crop-to-residue ratio, moisture

[10] Other examples of the application of this approach are: combining refined cane and beet sugar into a refined sugar composite to be used in final household consumption and as an input into the generation of a sweetener composite, combining the final refined sugar composite with high fructose corn syrup, for intermediate usage in selected industries.

content and the use of crop residues for other agricultural purposes (such as for animal feed, bedding and silage, compost and for anti-erosion purposes). Milbrandt (2005) estimates that approximately 157.2 million dry tons of biomass suitable for producing cellulosic ethanol were available in the US in 2005 with existing technology.

For the current project, it is assumed that corn stover is the single source of crop residue biomass. We make use of a mixed complementarity approach to model the relationship between demand and supply in the crop residue market and the production decisions of the primary producer (the USAGE feed grains sector that produces corn).

The complementarity relationships are not complex. If the crop residue supply is not constrained, the price of it will move with shifts in demand in a relatively elastic fashion along a very elastic supply curve. The inputs to crop residue production are labor and fertilizers (i.e. no fixed or sticky factors), and the expansion in the output of crop residue is unlikely to put significant upward pressure on wages or fertilizer prices at an aggregate level. If the supply constraint on crop residue is binding, its price increases along a perfectly inelastic short-run supply curve and scarcity rents are generated. Rents generated on the boundary are an additional source of revenue to the feed grains industry, and are captured via a subsidy on the purchaser's price of corn. With these relationships in place, the feed grains industry faces a joint-profit maximizing decision in corn and the by-product crop residue.

Total stover output is approximately equal to total corn output (by weight). Generalizing, define a variable τ to denote the relationship between the output of the primary commodity and the byproduct, so that

(1) $$Q_{ts} = \tau Q_{corn} .$$

where Q_{ts} and Q_{corn} denote the total supply of stover and the production level of corn (both in quantity units) respectively. The value of τ will usually be set at 1 for corn and corn stover. Total stover supply is

(2) $$Q_{ts} = Q_{rs} + Q_{cs}$$

with Q_{rs} and Q_{cs} denoting "removable" and "coverage" stover respectively. Coverage stover per acre can vary with soil type and with technological change in agriculture over time, and therefore is specified as a (naturally exogenous) variable rather than as a parameter. Equations (1) and (2) imply that the constraint on the supply of crop residue Q_{cr} in USAGE is defined by

(3) $$Q_{rs} = \tau Q_{corn} - Q_{cs} .$$

Equation (3) defines the upper bound for a complementarity condition relating the supply of crop residue to corn output. In USAGE simulations, when sales of crop residue reach Q_{rs} a rent is generated that increases in the price of crop residue. Denoting the purchaser's price of crop residue by P_{cr} , the basic price of crop residue by $p_{cr,}$ the rent premium generated on the upper bound Q_{cr} by ϕ , and sales of crop residue by D_{cr}, the complementarity condition takes the form

(4) $$1 \le (1+\phi) \perp \left(\frac{D_{cr}}{Q_{cr}} - 1 \right)$$

where

either $1 = (1+\phi)$ *and* $1 > \frac{D_{cr}}{Q_{cr}}$ (state 1)

or $1 < (1+\phi)$ *and* $1 = \frac{D_{cr}}{Q_{cr}}$ (state 2),

and

(5) $$P_{cr} = p_{cr}(1+\phi) .$$

Before the upper bound is reached, the feed grains sector receives no incentive to alter corn production from crop residue sales. When the supply of crop residue to the cellulosic ethanol industry is constrained by the upper bound on supply, the rent premium generated at the margin on the price of crop residue is transferred to the purchaser's price of corn as a subsidy. Thus internalized in the profit-maximization problem facing the feed grains sector, the rent/subsidy increases the marginal revenue available to the feed grains industry from production of the corn/crop residue composite[11] and influences production decisions regarding corn. Figure 3 below summarizes this concept.

[11] This joint-profit maximizing decision is assumed to be implicit in the model's base data until the supply constraint on *removable stover* becomes binding

Figure 3 Crop residue and corn output, and the transfer of rents and subsidies

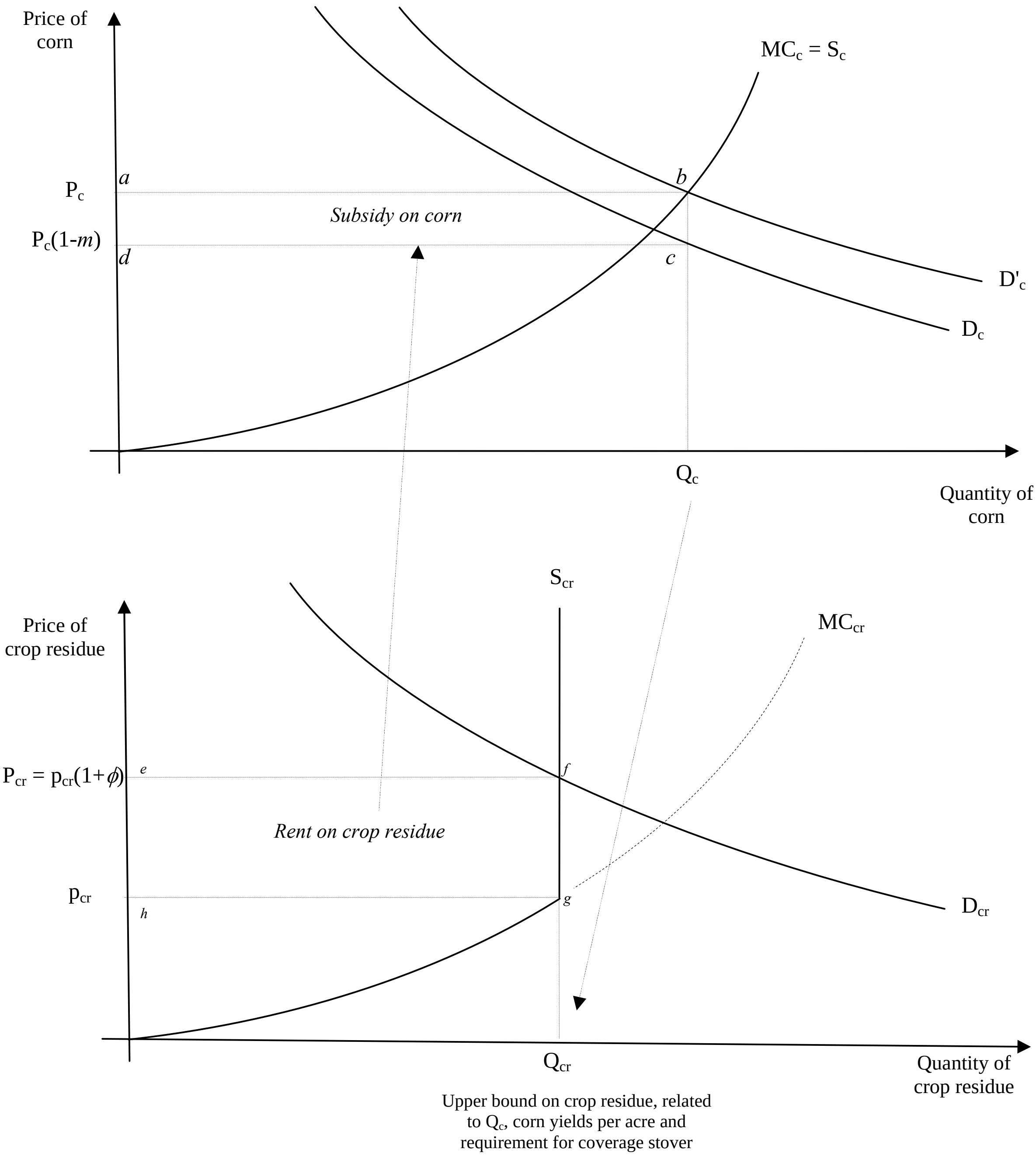


Figure 3 shows the relationship between the rent generated on corn-stover on the boundary and the subsidy it implies on corn demand. The value of the rent *efgh* generated by corn-stover scarcity with demand D_{cr} must be equal to the value of the subsidy on corn demand *abcd*, and as Q_c and Q_{cr} denote different quantities, the values of the rent (ϕ) and subsidy (m) rates must differ. Strictly speaking, the corn subsidy is applied to the demand curve as it operates via the purchasers' price of corn. The subsidy to corn is "self-funded" (and therefore there are no transfers to deal with) by the multi-product feed grains industry from rents generated on sales of crop residue produced by corn production. To avoid allowing this industry with transformation possibilities to supply more of its other output s (barley, sorghum and oats) because of the rent generated on crop residue from corn, the subsidy is targeted to induce an increase in corn production specifically by making the firm see the subsidy as an extra slice of revenue from sale of corn, rather than as a reduction corn production costs.

The relative size of the subsidy and rent will differ. This is because the total value of the subsidy and rent are equal but the level of output in the two goods by quantity units is likely to be different. The value of the rent generated from crop residue is

(6) $$RENT_{cr} = \phi p_{cr} Q_{cr} .$$

The total value of the subsidy on the purchaser's price of corn is equal to this total rent,

(7) $$SUBSIDY_{corn} = RENT_{cr} .$$

Denoting the rate of the subsidy on corn sales by m, equation (7) can be rewritten as

(8) $$mP_{corn} Q_{corn} = \phi p_{cr} Q_{cr} ,$$

and by solving for the rate of the subsidy on corn we obtain

(9) $$m = \phi \frac{p_{cr} Q_{cr}}{P_{corn} Q_{corn}} = \phi \frac{BAS_{cr}}{PUR_{corn}} ,$$

where BAS and PUR refer to basic and purchaser values respectively. In USAGE, tax, rent and subsidy rates are applied as "powers" (i.e. one plus the rate) to avoid numerical problems associated with zeroes when working with percentage-changes, and so it is the power of the rent on crop residue is calculated in the complementarity statements. In light of this, (9) becomes

(10) $$powm = 1 + \left(pow\phi - 1 \right) \frac{p_{cr} Q_{cr}}{P_c Q_c} .$$

where *powm* and $pow\phi$ are the powers of the subsidy and rent respectively. The variable *powm* is added to the USAGE equations determining the purchaser's price of corn to industries, households and exports demand. The subsidy is fully funded by the rents in the crop residue industry, and so m can be applied as genuine (negative) tax rate on sales of corn.

4.2 Complementarity relationship for DDGS and organic by-products

For these two by-products, the relationship is much simpler. Information on the production of DDGS by dry corn mills in 2005 (outlined above) suggests that around 7.16 pounds of DDGS is produced for each gallon of corn-starch ethanol. This figure results from the 27.94 billion pounds (12.7 million tons) of DDGS production that accompanied the 3904 million gallons of corn-starch ethanol output in 2005. The relationship between primary-product and by-product is linear in this case, and so the output of DDGS is defined by a simple application of (1) above,

$$Q_{DDGS} = \tau Q_{cse} \tag{11}$$

where Q_{DDGS} and Q_{cse} refer to the quantity of DDGS (in pounds) and corn-starch ethanol (in gallons) respectively, and τ set at 0.14. The complementarity conditions then operate identically to those described above for the case of crop residue.

For organic by-products, a version of (11) is also applicable with a different value for τ. Potential sources of biomass that could be captured in this sector are urban wood wastes, primary mill wastes, and forest residue. In the current modeling exercise, it is assumed that only forest residue is used as a source of alternative biomass for the organic by-products sector of USAGE.

Milbrandt (2005) estimated that approximately 56.612 million dry tons of usable forest residues was generated in 2005 and the USDA Forest Service reported that forestry production in 1999 was approximately 188.7 million dry tons (Howard, 2007). Based on these figures, approximately 0.314 tons of usable forestry waste is produced for every ton of output in the forestry industry, implying that an appropriate number for τ in the USAGE organic by-products industry is 0.314. As for DDGS, the complementarity relationships are then identical to those described above for crop residue.

5 Treatment of agricultural land

Simulating realistic interactions between food crops and energy crops hinges on accurate treatment of land.

Proper recognition of land heterogeneity plays a key role in governing allocation among competing uses. The United States has vast (950 million acres) and varied farmland, and diverse geography and climate within and across individual State boundaries has allowed the US to produce a large range of agricultural products.

Much of the expansion of the U.S. farm sector has been facilitated by gains in agricultural productivity. The total planted acreage of cropland has trended downward for decades as major U.S. crops were increasingly concentrated on fewer acres[12]. Advances in crop technology, the consolidation of small farms and improved management practices have contributed to a movement in favor of capital as an input share.[13] Similarly, pasture and rangeland utilization for animal grazing have steadily improved with advances in management practices and in the quality and weather resiliency of forages.

Despite technological improvements that help reduce total farmland use, competition for agricultural lands has remained high as the US economy has expanded. This competition, however, tends to be highly localized and segmented by geography. In some cases, crops are easily interchangeable between region and soil type, while in other areas alternative crop use becomes infeasible due to variation in physical and climatic conditions. Polices designed to support major field crops have exacerbated the effects of localized competition and lead to higher land rental values. The likely future expansion of acreages in dedicated energy crops creates the potential for the crowding-out of other land uses, but the degree to which this occurs will depend on the specific characteristics of demand and supply by locality of production. These reasons have lead us to the conclusion that consideration of the geography and characteristics U.S. farmland is key if we are to realistically capture the role of US farmland markets in bio-fuels expansion.

Detailed information on the agricultural uses and geographic characteristics of land in the United States are essential for establishing a mapping between U.S. land types and farming activities. Competition for farm resources is determined by a host of factors that influence why certain farm activities take place in different localities, with both physiographic and economic factors playing a role. We do not, however, consider competition between farming and forestry use - although forest products may eventually contribute directly to biomass sources for energy production, we do not offer special treatment for segmenting forest lands in this application[14] as the conversion of forests to farmland in the United States has not been an issue for more than a century.

[12] The major U.S. crops are now grown more heavily in fewer states than in the past. The top eight crops, corn, cotton, soybeans, sorghum, barley, oats, rice, and wheat, account for about 250 million acres of cropland. Corn, wheat, and soybeans alone account for about 90 percent the acreage of the major eight crops.

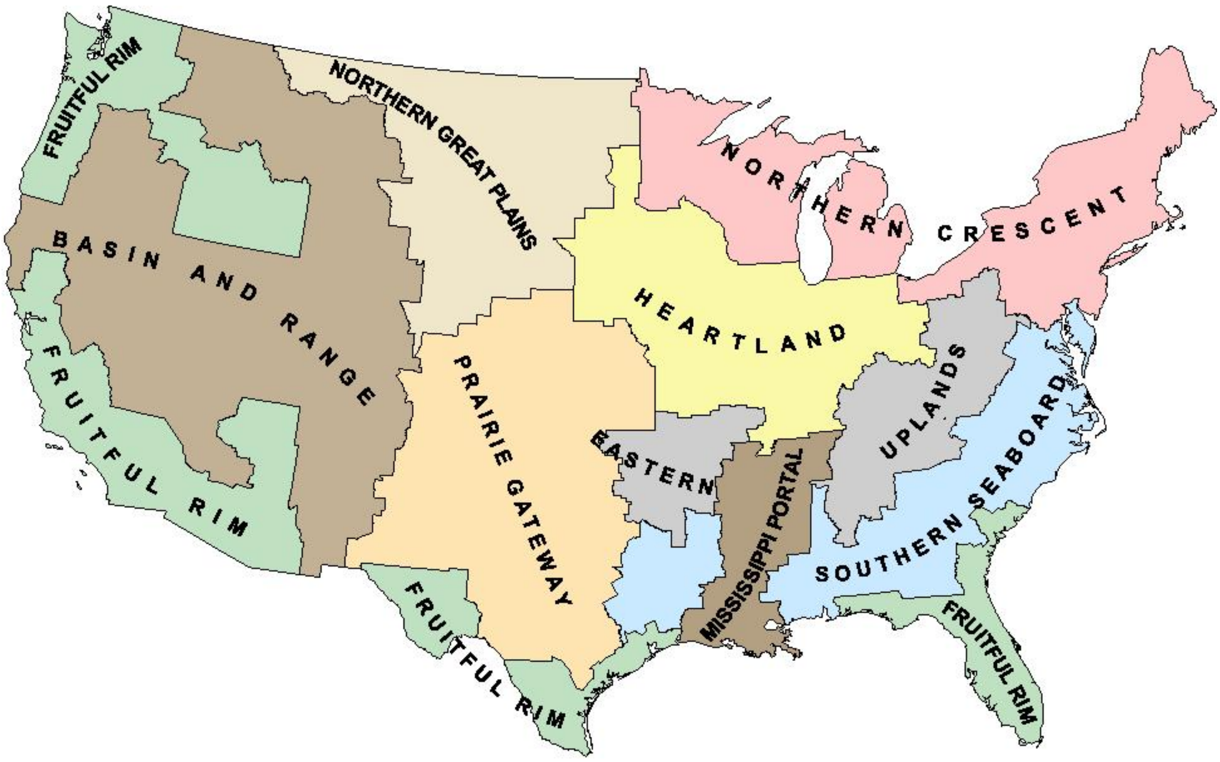
[13] Acreage devoted for growing crops reached as high as 383 million acres in 1949 but has dropped to as low as 331 million acres. Land set aside by programs such as the Conservation Reserve Program has retired 34 million acres of environmentally sensitive cropland.

[14] This application focuses on bio-fuels production primarily from agricultural feeds sources.

We analyze the agricultural uses of farmland across two dimensions: geographical regions and land physical capability/land quality attributes. Our goal is to have an informative but manageable amount data that can be incorporated into the USAGE framework.

5.1 Geographic areas by farm resource regions (FRR)

Our modeling of land utilizes a geographical categorization for all farming activity in the United States known as the Farm Resource Regions (FRR) system. The FRR designations consist of nine separate regions with boundaries defined using information on U.S. farm characteristics, county level production, and land resource information.[15]



Source: USDA/ERS Agricultural Resource Management Survey (ARMS) - Resource Regions

Regional boundaries are determined by a clustering of similar farm characteristics intersected with similar climatic traits and land features. The advantage of this type of regional grouping (as opposed, say, to a state-by-state classification) is that it more precisely delineates geographical farm specialization.

[15] The Farm Resource Regions were developed by the USDA's Economic Research Service for depicting geographic specialization in production of U.S. farm commodities. It is used for addressing economic and resource issues in agriculture.

As an example, the Heartland region comprises three entire US states and includes partial areas from five states based on differences in farm characteristics and the underlying crop growing patterns. The Heartland region specializes in corn and soybean production using relative large farms in comparison with the neighboring Northern Crescent region.

Regional boundaries can also arise from differences in growing season and rainfall which can fundamentally alter the mix of crops. The Prairie Gateway region, with its drier, semi-arid conditions, specializes in wheat and cattle grazing, while the Fruitful Rim region has geographic discontinuities comprising a set of disjoint coastal areas.

The Farm Resource Region system provides a basis for disaggregating national farmland based on use and underlying resource characteristics, enabling us to segment land markets based on competition for uses. As the boundaries are described above, intra-regional land competition is greater than competition between regions: By this geographical delineation, expansion in corn affects land rental rates more on land used for oilseeds in the Heartland than it would on rental rates for corn land in the Eastern Uplands region.

USAGE takes on these FRR classifications as follows:

Region 1	Heartland
Region 2	Northern Crescent
Region 3	Northern Great Plains
Region 4	Prairie Gateway
Region 5	Eastern Uplands
Region 6	Southern Seaboard
Region 7	Fruitful Rim
Region 8	Basin and Range
Region 9	Mississippi Portal

5.2 Land capability classes

Climatic conditions for each FRR are distinct and fairly uniform within each region, determining a primary reason for the regional specialization of crop production. Regardless of climatic conditions, however, land does not have uniform productive capabilities within each FRR, as there can be considerable physical variability of lands within each region due to differences in soils and topography. As such, each FRR engages in both crop and pasture/grazing farming activities.

The proportion of land used for crops varies considerably across regions, and the amount of a land in each region does not correspond well to the level of farm output. For example, the Basin and Range Region encompasses the largest arable land area but produce the smallest amount of crop output. It is the combination of acreages and the productivity of soil types that determine use characteristics and relative output levels, as evidenced (for example) in the Heartland region which has the highest value of farm output of any FRR because it has the highest proportion of prime cropland.[16] The Basin and Range and Heartland regions have in common some marginal lands for pasture and grazing, but there is no information in the geographic breakdown of a region to indicate variations in the quality of these lands, and crop and pasture uses may not always be in direct competition in the same region.[17]

One simple way to handle further distinctions of land by region is to break land into cropland and pastureland/grazing. However, there are many variations of land used for crop and pasture use, and certain croplands are sometimes used as pasture. Changes in market conditions can see some types of land switch between crop uses and pasture use while other lands in the same region may never be used for growing of crops because they have inherent features restricting their use. For example, some steeply sloping pasturelands can be used to grow specialty and ornamental crops when coupled with an ideal climate. For our purposes, incorporating greater specificity of lands warrants further designations of land beyond geographic regions as described by FRR system.

Land in the United States can be categorized by physical attributes that indicate crop-growing capability. One such classification is the nomenclature of the Land Capability Classes (LCC) system, comprising eight classes of land. This capability taxonomy is one of a number of interpretive groupings used for establishing U.S. agricultural land use of arable lands grouped according to their potentialities and limitations, as listed below.

LCC1. Soils with slight limitations that restrict their use.
LCC2. Soils with moderate limitations that reduce the choice of plants or require moderate conservation practices.
LCC3. Soils with severe limitations that reduce the choice of plants or require special conservation practices, or both.
LCC4. Soils with very severe limitations that restrict the choice of plants or require very careful management, or both.

[16] The Heartland has historically received a higher proportion of government farm payments which increases land values.
[17] The 2002 Census of Agriculture has determined that 434 million acres can be classified as cropland, while 395 acres is classified as pastureland or rangeland.

LCC5. Soils with little or no hazard of erosion but have other limitations, impractical to remove, that limit their use mainly to pasture, range, forestland, or wildlife food and cover.

LCC6. Soils with severe limitations that make them generally unsuited to cultivation and that limit their use mainly to pasture, range, forestland, or wildlife food and cover.

LCC7. Soils with very severe limitations that make them unsuited to cultivation and that restrict their use mainly to grazing, forestland, or wildlife.

LCC8. Soils with limitations that preclude their use for commercial plant production and limit their use to recreation, wildlife, or water supply or for aesthetic purposes.

Land types in the first four classes (LCC1 through LCC4) are generally suitable for the mechanical cultivation of crops. Lands grouped in the last four classes (LCC5 to LCC8) have severe limitations on use and are generally not suited for cultivation of crops. The higher the class number, the more restricted are the choices for cropping. Furthermore, management practices become more rigid and costly for circumventing these limitations as the LCC class number increases. As such, the scope for substitutability between alternative uses lessens with rank, and breaking down land by its "capability" in a modeling framework helps ensure that uses are constrained more severely on the lands with the most physical limitations. These varying substitution possibilities motivated the choice of CRESH and CRETH nests when modeling land in USAGE, as these functions allow each land type to be assigned a unique substitution or transformation possibilities parameter.

The capability classification is not a productivity or profitability ranking. Rather, it is an assignment of land types reflecting restrictiveness in substitutability in use due to the nature of soils and factors influencing sustainability. Physical limitations include such things as root-zone limitations, susceptibility to flooding and erosion, excessive steepness, leaching of salts and excessive clay or stone content.

Maintenance costs also increase as the ranking falls. For example, LCC1 lands are suited for intensive cropping with minimal requirement for management practices to maintain productivity when the use is changed. The LCC2 classification dictates some physical limitations (gentle slopes and moderate susceptibility to erosion) that reduce the choices in planting and cultivation, but LCC2 land can achieve the planting alternative choices characterized by LCC1 if more costly management practices are employed. LCC3 encompasses land with severe physical limitations such as steep slopes, shallow bedrock, or susceptibility to water or wind erosion. LCC4 is even more limited in crop choices and captures land requiring determined and sustained application of conservation practices if used for the growing crops. Although the land types classified above LCC4 are limited to uses of pasture and rangeland for animal grazing, some soils in classes LCC5 and LCC6 are capable of growing certain fruits and ornamentals under highly intensive management practices. LCC7 land has severe restrictions that limit use to grazing due to very steep slopes, susceptibility to erosion, or shallow or wet soil. LCC8 land, effectively the residual of LCC1 through LCC7, is a classification encapsulating barren and unproductive areas that are not expected to return any benefit in farming activity, but are suitable nonetheless for recreation purposes, wildlife refuges, water catchment or purely aesthetic purposes.

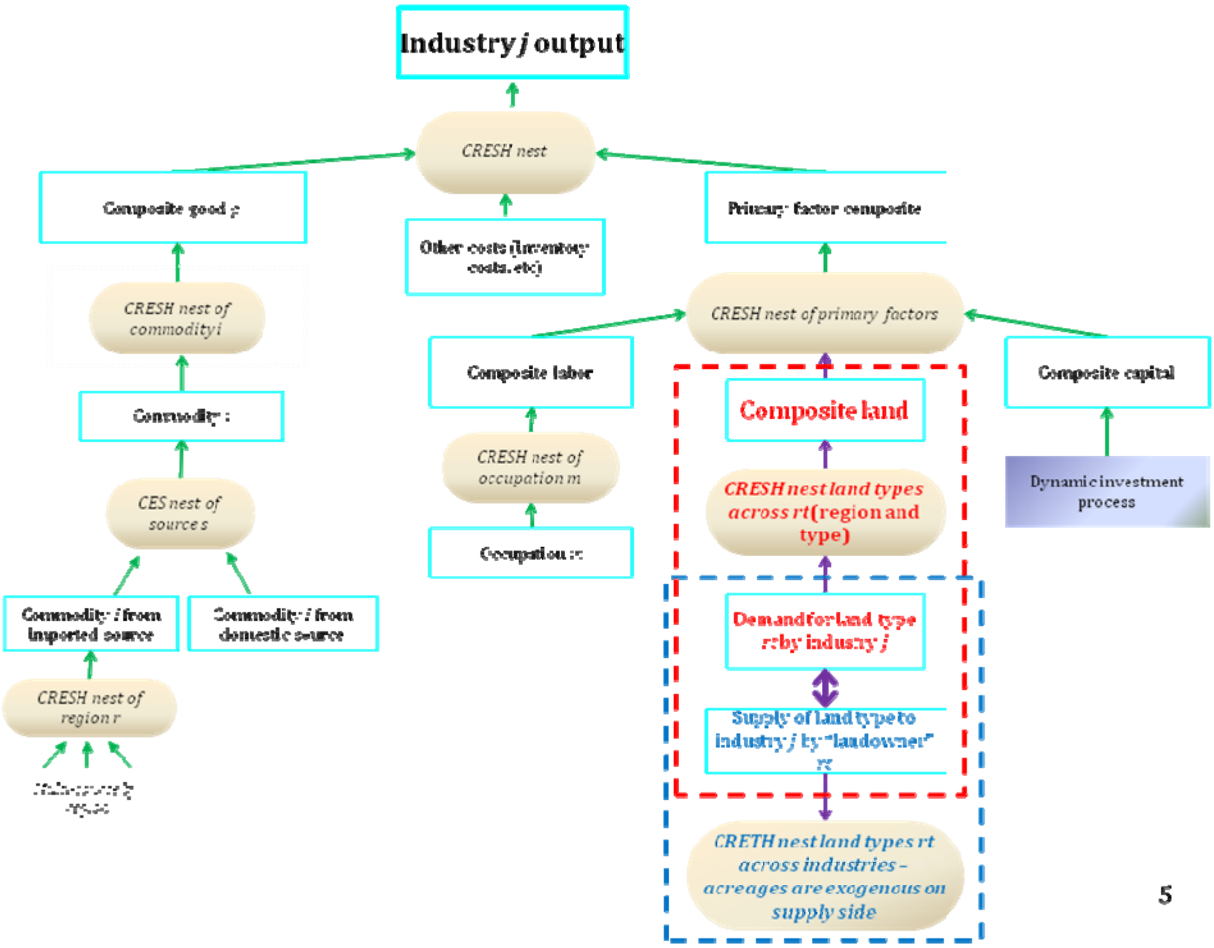
6 Modeling approach for land in USAGE

USAGE models 72 different types of agricultural land based on recognizing each LCC in each FRR.

The demand for land in USAGE is derived from a multi-level nested CRESH (constant ratio of elasticity of substitution, homothetic) demand system[18]. The supply side for land is also active in USAGE, utilizing a CRETH (constant ratio of elasticity of transformation, homothetic) transformation function[19].

[18] For technical background on CRESH functions, see Hanoch (1971)
[19] For technical background on CRETH functions, see Vincent *et al* (1980)

Figure 4 Stylized USAGE production function



Demands for land types result from a series of optimization problems starting with profit-maximization at the top level. The representative firm *j* chooses a profit-maximizing level of output for all potential types of output subject to relative output prices and transformation possibilities (i.e. technological constraints). For each good *Y* the profit-maximizing level of output in industry *j* is produced at least cost by choosing inputs of a primary factor bundle *PF*, an intermediate goods composite *Q*, and other costs *OC* (for example, the costs of holding inventories), such that

(12)
$$Y_j = CES\left\{PF_j, Q_j, OC_j\right\}$$

subject to technological constraints and the relative prices of these input bundles. For multi-product firms, input choices are not made with respect to each good, but rather the firm can be thought of as buying itself a production-possibilities frontier.

Intermediate goods Q are composites resulting from a second level of nesting. The producer seeks to minimize the cost (given technology and relative prices) of creating Q such that

$$(13) \qquad Q_j = CES\{Q_{i,j}\}$$

for each intermediate good i. The solution for each $Q_{i,j}$ then enters an Armington nest where the cost of creating the composite from foreign or domestically sourced goods is minimized

$$(14) \qquad Q_{i,j} = CES\{Q_{i,s,j}\} .$$

In determining the composition of the primary factor bundle, the firm seeks to minimize the cost of creating PF_j by choosing capital K, labor L and land N subject to technology and relative factor prices. Capital, K, is a lagged function of investment via a standard inter-temporal accumulation relationship and a dynamic investment process involving expectations. Labor and land at this level are composites resulting from further levels of nesting. Labor L is a CRESH function of m occupations,

$$(15) \qquad L_j = CRESH\{L_{m,j}\}$$

constrained by relative wage rates and labor-using technological constraints.

Focusing now on land usage, land N is a CRESH function of n land types (n = 72),

$$(16) \qquad N_j = CRESH\{N_{n,j}\}$$

where the firm minimizes the cost of N_j by choosing the $N_{n,j}$'s subject to land-using technologies and relative rental prices.

On the supply side for land, the 72 land types n are in fixed supply and typically remain exogenous in simulations. To help with intuition on the supply side, think of each land type N_n as being "owned" by a fictitious land baron who allocates a fixed acreage of land to the 23 agricultural industries in order to maximize revenue. The allocation decision - the "supply" decision - is a CRETH (constant ratio if elasticity of transformation, homothetic) function of industry bids, where the bids are land rentals, constrained by the transformation possibilities between uses (where "use" is determined by the USAGE sector j in question) and the exogenous total acreage of a given land type N_n

(17) $$\overline{N_n} = CRETH\left\{N_{n,j}\right\}.$$

Lastly it is necessary to ensure that the quantity units (say, acres) for land are constrained in the right way. N_n in equation (17) is strictly-speaking an *effective* land unit, and does not in practice impose an adding up constraint on *acres* - in a CRESH/CES system such as this, the "quantity" unit on the left-hand-side of the functions captures technological change and share effects. To constrain the acreages explicitly we redefine N_n in (17) as an *effective* land unit, denoted N^{eff}, endogenise this variable and add another equation that imposes an adding-up constraint on $N_{n,j}$ via

(18) $$N_n^{eff} = CRETH\left\{N_{n,j}\right\}$$

(19) $$\bar{N}_n = \sum_{j=1}^{J} N_{n,j}$$

for the 72 land types across the J agricultural industries. This ensures that the pre- and post-simulation values of the fixed acreages in the vector N_n are the same.

7 The technology for ethanol/gasoline substitution

The energy content of ethanol is only around 70% of that for gasoline. This relative energy balance is an important factor in modeling the substitution of one for the other. Complicating matters further, for ethanol/gasoline mixes in proportions up to 10/90 the ethanol is used to replace other additives with similar energy content to ethanol. As such, the energy balance deficit is not relevant until the motor fuel mix exceeds these proportions. Combining the RFS mandate with the EISA projection for motor fuel usage, we estimate that this 10/90 mix is achieved by around 2013 and increases to around 21/79 in 2022.

To ensure that different ethanol types and gasoline are substituted in the right quantity units, additional equations are added to USAGE. It is necessary to ensure that the levels relationships

(20) $$\sum_{z=1}^{5} A_{z,ethanol} = A_{ethanol}$$

and

(21) $$A_{gasoline} + \Omega A_{ethanol} = A_{motorfuel}$$

are preserved, where the index z accounts for the 5 ethanol types. Coefficient A is a technology-related concept that determines the top-level relationship between all inputs and the level of the output.

Relativities between the A's must be taken into account when substituting one good for another ;for example, if the value of A_1 is twice that of A_2 and the sum of the output of goods 1 and 2 is initially equal to Z, reducing good 1 by x units requires increasing good 2 by $2x$ units to maintain Z. Ω is a coefficient taking a value between zero and one that accounts for the energy balance issue discussed above, effectively modifying the $A's$ role as a parameter. The percentage-change versions of these functions are

(22) $$\sum_{z=1}^{5} A_{z,ethanol}\alpha_{z,ethanol} = d\_\alpha_{ethanol}$$

and

(23) $$A_{gasoline}\alpha_{gasoline} + \Omega A_{ethanol}\left(\theta + \alpha_{gasoline}\right) = d\_\alpha_{motorfuel},$$

where the variables α and d_α are the percentage change and ordinary change in the respective A coefficients and θ is the percentage change in Ω. The right-hand sides of these equations are exogenous and set on zero during forecast and policy simulations, ensuring that quantities (e.g. gallons) of different ethanol types substitute one-for-one with each other, and that 1/Ω units of ethanol substitutes for 1 gallon of gasoline in motor fuel mixes.

8 Conclusion

This paper provides an overview of the technical modifications made to USAGE to enhance its use in bio-fuels analysis. These modifications include the splitting of several new industries and commodities from the USAGE database, the addition of land matrices for acreages and land rentals in agriculture covering 72 types of land, and technical modifications to the USAGE theory for land use and by-product production. Further details can be sourced from the author.

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