Intelligent Energy Europe

Use of BioTrans in REFUEL
Functional and technical description

refuel

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Report of REFUEL WP4

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Executive summary

This report consists of a functional and technical description of the BioTrans model, as developed at ECN. A functional and technical description of a model helps a reader to interpret the results. A model is a simplified representation of reality, mostly designed for a specific task. A description of the model provides transparency on the strengths and weaknesses of the model. Should one wish to understand why a certain effect, phenomenon or policy option cannot, or can hardly be covered with the BioTrans model, one is advised to consult this functional and technical description. This description also aims to prevent misunderstandings. For example, to prevent highly detailed interpretations of a model that itself is not intended to be so detailed.

This description can also be used to assess the possibilities of using BioTrans in future projects.

Data inputs for BioTrans have been summarised in a separate appendix report.

1 Introduction

The use of biofuels for transport has been known for a long time, but only recently development has increased in Europe. This is due to European and national policies aiming at security of supply and the reduction of CO_2 emissions. Biofuels are an important technology for reducing the emissions in transport, although the biofuel production chain is not fully CO_2 neutral due to emissions during production and transport of biomass and biofuels.

The project REFUEL, supported by the European Commission, attempts to provide clear and structured data on the availability and viability for using biofuels in the transport sector in Europe. As a part of work package 4 of this REFUEL research program, ECN applied the BioTrans model for optimizing full supply chain allocation. This model can support policy makers in the development of a cost efficient biofuel strategy for Europe in terms of biofuel production, cost and trade, and in an assessment of its larger impact on bioenergy markets and trade up to 2030. BioTrans includes biofuel raw material production, processing, transport and distribution. The model essentially aims at finding the minimal cost allocations along the supply chain, given projections of demand (e.g. based on biofuel policy targets), potentials and technological progress. Between the different steps in the supply chain, trade is possible between the different member states.

The model uses as input a wide range of (mainly techno-economic) parameters regarding the current European biofuel situation, as well as macro-economic and technological projections. These projections result in both a variant for the target year and a set of constraints for the development towards this target year, by restricting year-to-year variations. The output of the BioTrans model includes detailed allocations of production, processing, transport and distribution of energy crops and biofuels. Output also indicates the extent to which member states trade between different steps in the production chain.

This document contains a functional and technical description of the BioTrans model, accompanied by a description of the system[1]. Section 2 contains a conceptual and functional description of the biofuel model. Section 3 describes the optimisation method in technical terms, discussing aspects like the target function and constraints used. Finally, section 4 discusses the input and output requirements for the BioTrans system.

[1] The ***model*** is a mathematical structural description of the production chain, whereas the ***system*** is the concrete software implementation of the model.

2 Functional model

2.1 Introduction

In order to describe the model transparently, it is useful to first describe what the purpose of the model is. What is the question the model is designed to help answer, and in what context. For BioTrans, we can state the purpose of the model as:

> *Find the optimal (least cost) configuration of resources and trade, for meeting specified biofuel demand in a group of countries, given and constrained by a number of assumptions on economic and technological parameters in a specific target year.*

In addition to this, the model is able to help analyse the influence of the factors comprising the optimal configuration, e.g. what is the effect of limiting allowed trade flows to biofuels in stead of energy crops. These additional questions are typically answered by looking at scenarios (external changes), policy variants (internal changes) and sensitivity analysis.

BioTrans is cost-oriented, meaning that it can minimize costs given some demand target, e.g. based on the EU biofuel directive. In order to find a feasible demand target given a limited promotional budget, BioTrans can only be used indirectly.

2.2 Conceptual design

BioTrans is – simply put – a model that determines the least-cost configuration of the entire production chain, given constraints on supply, conversion (processing) and demand. To get from the input biomass to the output end-use biofuels, a number of product conversions are needed. The entire chain from raw input material to end-use biofuel is called *conversion route* and consists of one or more conversion steps.

A simplified model as shown in figure 2.1 could be used to determine the product volumes and conversion routes that minimize the overall costs while meeting an end use target demand. Not all nodes in this conceptual model represent physical locations. Furthermore, it is assumed that every country has one production plant for each raw material and one processing plant for each conversion (sub) process.

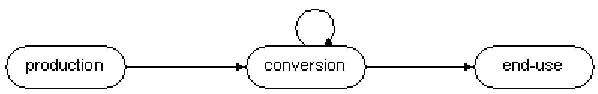


Figure 2.1 simplified BioTrans model 1

Consider this simplified BioTrans model 1. The end-use node sets the amount of final biofuel product that the model should provide by imposing a constraint on the inflow product (in GJ). The production node sets the amount of raw material available for conversion, by imposing a constraint on the outflow (biomass potential). The production node also sets the cost per unit. Every conversion step balances the in- and outflow and adds conversion costs to the total cost amount. Costs and revenues of auxiliaries and by-products are also accounted for in the conversion steps.

A logical extension to the basic model in figure 2.1 is to include country-specific product demand (constraints) and specify distribution related costs per technique. Including demand and distribution results to a more complicated model, as shown in figure 2.2.

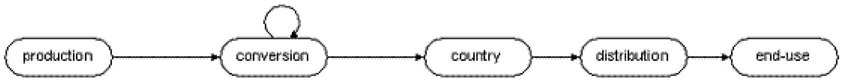


Figure 2.2 simplified BioTrans model 2

In this simplified BioTrans model 2, a country node can be used to set country-specific targets on different types of biofuel and the distribution[2] node can be used to incorporate costs that are specific for different types of distribution (e.g. DME or ethanol fuelling stations).

The final step towards the BioTrans model is allowing for trade between countries in input products and (partly) processed products. The resulting model is shown in figure 2.3. The import- and export nodes do not impose constraints. Rather, they are used to make cost-efficient solutions for the entire set of countries possible, and calculate international transport costs.

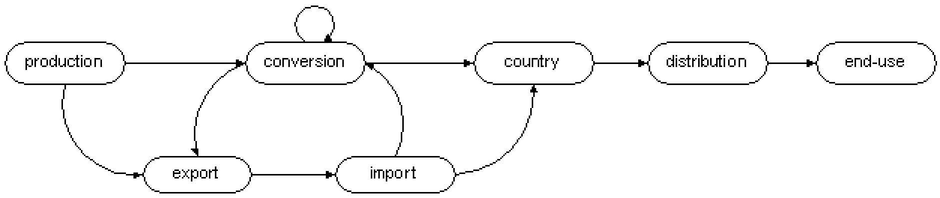


Figure 2.3 BioTrans model

This is only a conceptual representation of the model. Each of the nodes can have several instances and the country specific production chains are loosely coupled by the import and export nodes. The current REFUEL model configuration uses:
10 crop/non-crop raw materials;
12 conversion steps with 2 intermediate products, 1 auxiliary and 6 byproducts;
7 biofuels and associated distribution technologies;
30 countries and a 'rest of world' category: EU27, Switzerland, Norway, Ukraine; Brazil and Malaysia represent 'rest of world' for ethanol and palm oil imports, respectively.
In the following sections of this chapter, each of the nodes in the conceptual model is discussed in some more detail. A final section discusses the costs in some more detail.

Table 1 Crop and non-crop products in BioTrans

Conventional biofuels technologies of today:	*Advanced biofuels technologies of tomorrow:*
Biodiesel	Cellulosic bioethanol (enz. hydr.)
• from vegetable oils	Fischer-Tropsch Diesel
• from used fats	Biodimethylether (DME, gasific.)
Conventional bioethanol	Substitute Natural Gas (SNG) by
• from sugar crops	• gasification, methanation
• from starch crops	• anaerobic digestion

[2] In this model, the term ***transport*** is used for moving products between locations (truck, sea) and ***distribution*** is used for costs related to presenting the biofuel to the end-user (different fuel stations).

2.3 Production

Every country in the model has a production location for each of the raw material (input) products with associated capacity/potential, but without minimum production constraints. These data are specified on NUTS2 level. Whether the production facility is actually used, is determined on economic grounds by the model. Land is specified as most-suitable for a particular crop, i.e. it has the highest yield for the latter crop. Whether that crop is actually grown, or a substitute, is again determined by the model on economic grounds. Production costs and potentials are provided as input for the model. Future development for costs and potentials can be specified using growth rates. Cost levels and development are specified relative to a reference country, providing a transparent approach to differences between countries through time.

Table 2 Crop and non-crop products in BioTrans

Energy crop categories:	Crops considered:
Herbaceous lignocellulosic crops	Canary reed, miscanthus, switchgrass
Lignocellulosic crops	Eucalyptus, poplar, willow
Oil crops	Rape seed, sunflower
Starch crops	Barley, maize, wheat
Sugar crops	Sugar beet
Other products:	**Imports from outside Europe:**
Agricultural residues	Ethanol (Brazil)
Forestry residues	Palm oil (Malaysia)
Used fats and oils	
Wet manure	
Wood processing residues	

2.4 Conversion

In order to create biofuel from the raw material products, one or more conversion[3] steps are needed. Each country has a complete chain of conversion facilities, with country- and process specific costs for each conversion step. For each processing step, different indicators are used for determining costs and output: raw material costs, full load hours, lifetime, O&M costs, investment costs, state of the technology and yield of the product. Each step uses a well-defined combination of input products and auxiliaries produces output products and by products. Costs and revenues of auxiliaries and byproducts are taken into account.

Table 3 Key conversion processes in BioTrans

(vegetable) Oil extraction
Transesterification of vegetable oil
Transesterification of used fats
Ethanol production from sugar crops
Ethanol production from starch crops
Ethanol production from lignocellulosic crops
Biogas production
Pretreatment of lignocellulosic biomass for gasification (by torrefaction and pelletisation)
Fischer-Tropsch diesel production (incl. gasification)
DME production (incl. gasification)
SNG production (incl. gasification)

The investment costs reduce in time depending on the past cumulative output volumes of the technology. As such, the model includes indigenous learning.

[3] ***Conversion*** and ***processing*** are used interchangeably throughout.

2.5 Countries and regions

The BioTrans model operates on a country aggregation level. Input and projections can be set at national level and costs and production quantities can be determined at this national level. As mentioned, each country has a complete production and supply chain with one production or processing facility of each type. As to regions: countries are categorized into WEC, CEEC and OTHER, with sub categories among the EU countries: EU15/EU27/EU30. Demand (target) is fixed on a country specific level or on EU aggregate level (burden sharing).

Table 4 Countries included in BioTrans

Country group	Countries
Western European Countries (WEC):	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom
Central and Eastern European Countries (CEEC):	Bulgaria, Cyprus, Czech Rep, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia
Other Countries:	Brazil, Malaysia, Ukraine

2.6 Trade: import and export

One of the most important features of the BioTrans model is the ability to link the national production chains allowing for international trade. By allowing trade, the future cost of biofuels can be approached in a much more realistic way then when each country is evaluated separately. The only costs associated with international trade are transport costs (including handling). For trade between two locations, generalized distances between countries are used. BioTrans uses three transport modalities: trucks, trains and short sea shipment (SSS).

All domestic transport is assumed to take place using trucks. Domestic transport costs are calculated using standardized distances (see figure 2.4) and country- and modality specific costs per km. Note that in the model, country, distribution and market nodes are 'virtual ' to facilitate constraints and costs attribution, situated on the same physical location. There is no transport between country nodes and market segment nodes. International transport can take place using trucks, trains or SSS and is based on actual distances. Costs are determined using costs per km, per modality, from the exporting country.

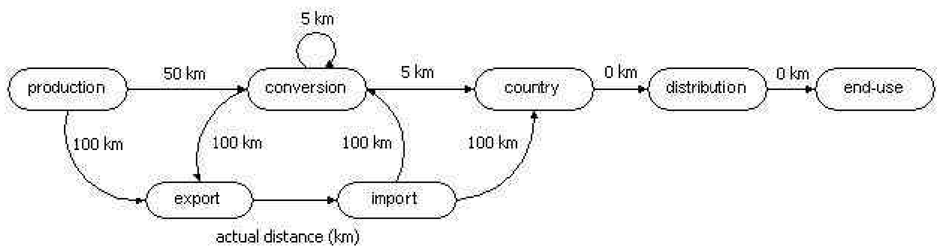


Figure 2.4 BioTrans model standardized transport distances

2.7 Distribution

Some biofuels require some technical or structural adjustments in the distribution stations. Per end use technology, BioTrans considers the costs associated with the distribution, e.g. the extra cost for safety measures in case of hydrogen distribution stations.

Note that distribution nodes are 'virtual' and therefore not associated with any physical location.

2.8 End-use

Not all biofuel technologies can be used directly in conventional motor systems; some require some adjustment. BioTrans considers costs associated with the use of different technologies in the market segment, e.g. the adjustment of vehicle motors for use with E85 bioethanol.

Table 5 End-use types in BioTrans

public road transport
private cars and motorcycles
trucks

2.9 Costs

In the BioTrans model, the overall costs for biofuels consider production, processing, transport, distribution and vehicle adaptation. All costs are on a per unit bases: there are no fixed costs. BioTrans determines energy flows (amounts) as part of the solution and unit costs serve as input. BioTrans distinguishes between the following cost categories:

Production costs for crop input are based on unit costs per region and suitability of a production location. Costs for non-crop (waste and residual) input are based on unit production costs for each region. Relative costs between countries and products vary considerably. For non-crop production, yearly cost growth rates are based on rough estimates of costs in 2030.

Processing costs are strictly variable, i.e. there are no fixed costs. Costs per unit depend on the sub-process used and the country where the processing takes place. Processing costs consist of four aspects:
Specific investment costs per unit are calculated by using a technology dependent (2005) reference amount. For first generation biofuels, the costs growth factor is dependent the output volume in the past and on the progress ratio. Progress ratios (PRs) typically are 0.8 to 1. A PR of 0.8 means that with a doubling of cumulative produced volume, the investment costs drop to 80%. For second generation biofuels, the costs growth factor is the result of scale dependent cost reduction and cost reduction based on cumulative historic conversion capacity. These PRs are typically 0.98 to 1.
Operation and Management (O & M) costs are calculated by using a technology dependent (2005) reference amount. O&M costs have a seperate wage component, which is set to 0, which follows the country specific wage pattern. The remaining O&M costs are linear dependent on the specific investment costs of each year.
Costs for auxiliary products needed at some processing steps (like additional electricity or enzymes) are based on cost estimates for a product where available and on prices otherwise.
Byproduct revenues at some processing step can reduce costs. The country specific price of the byproducts is determined using relative labour costs for this country. By-products range from electricity to glycerine and pulp.

Transport costs consist of domestic transport for which fixed distances are used and international transport using real distances. In the international transport, handling costs are also considered. All domestic transport is assumed to take place using trucks. Domestic transport costs are based on standardized distances between different types of nodes within a country (figure 2.4) and on country specific costs per km[4]. Growth rates for transport costs are assumed to be constant, though varying for each country.

International transport is based on actual distance estimates and costs are determined using costs per km, per modality from the exporting country[5]. Handling costs for international transport are modelled explicitly and costs both exporting and importing country are used. Growth rates for transport costs are assumed to be constant, though varying for each country and modality.

Each country has one (sub) processing location of each type. International transport takes place using three types of modality, whereas domestic transport is done by truck. Costs are in €/GJ.

Distribution costs represent costs necessary to adjust distribution points for use with biofuels. Distribution costs for biofuels are based on known distribution costs for fossil fuels and vary per biofuel (or more specific, per biofuel generating end use technology). Note that distribution costs represent the costs for adjusting a distribution point for use with a specific biofuel alternative. Costs do not include transportation costs, which are calculated separately.

End use costs, or vehicle adaptation costs are based on the investment needed to prepare existing transport for use with biofuel. Investments use simple 6% annuity loans. End use costs are based on known costs for fossil fuel alternatives in the market segment and end use technology. End use costs represent costs for adjusting a vehicle for use with a specific biofuel alternative.

CO_2 costs are costs due to emissions of greenhouse gases throughout the production chain. These costs are allocated to the fuel consuming country. The costs are optionally included in the model, depending on the choice for greenhouse gas emissions policy if any.

[4] Distances are based on the report "International bioenergy transport costs and energy balance" Hamelinck, C., Suurs, R. and Faaij, A. http://www.chem.uu.nl/nws/www/publica/Carlo%20e2003-26.pdf
[5] The same distance is used for both trains and trucks.

3 Technical model

3.1 Nodes and arcs

BioTrans is a generalized network flow model with nodes and arches. Flows represent quantities of (half)products expressed in Gigajoules (GJ) and nodes represent aspects in the process from production (source) to consumption (sink). Table 3.1 shows an overview of different node types.
A network flow model aims at finding the load of flows that minimizes some objective function of the flows, given a set of constraints. The objective function in BioTrans is minimization of total biofuel cost and the constraints are various (Section 3.3 describes the constraints in detail). The optimal solution to the BioTrans model, is a load for each of the flows; i.e. a quantity of (half) products between two nodes.

In a generalized network flow model, the restriction that inflows must match outflows for each of the nodes, does not hold. BioTrans minimizes cost and does not keep track of energy balances (i.e. inflows and outflows in processing nodes do not have to match). For example, if a sub process requires electricity input, this is reflected in the processing price but there is no actual flow; as a consequence a processing node can have more GJ outflows than it has inflows. For each arc however, energy contents on both sides should be equal.

BioTrans is a multicommodity network flow model, a special type of generalized flow model, which means that different flows of 'commodities' are optimised and constrained simultaneously. This has no implications for the model description, but it has for the AIMMS solver: optimised network flow routines don't apply and performance is much less than with 'standard' network problems.

Table 3.1 Node descriptions

Nodes	Description
Non-crop production nodes	Production nodes for waste and residues. No input flows, source in the network model; capacity is constrained. Output to processing nodes and export nodes.
Crop production nodes	Production nodes for energy crop. No input flows, source in the network model; capacity is constrained. Output to processing nodes and export nodes.
Processing nodes	Nodes for some part of the transformation process between input product and biofuel. Input from import nodes, production nodes and other processing nodes. Output to export nodes, country nodes and other processing nodes.
Export nodes	Nodes for export of (sub)products across borders. Input from either production or processing nodes. Output only to import nodes.
Import nodes	Nodes for import of (sub) products across borders. Input only from export nodes.
Country nodes	Nodes for aggregate demand of a country. Aggregate country demand constraints apply here. Input from processing nodes and import nodes, output to distribution nodes.
Distribution nodes	Nodes for attaching end-use technology to a product. Nodes are within country and used for technology-specific capacity and transition constraints. Input from country nodes, output to market segment nodes.
Market segment nodes	Nodes to simulate demand per market segment. No output flows, sink in the network flow model. Input from distribution nodes.

3.2 Target function

The target of the optimisation is minimising total costs for biofuels along the entire supply chain, from production to consumption. Total costs consist of:
Production – crop
Production – non-crop
Processing – Specific investment costs
Processing – Operation and Management
Processing – Auxiliary input
Processing – Byproduct output (with negative costs)
Transport – Domestic
Transport – International
Distribution costs
End use costs
CO_2 costs (optional)

3.3 Constraints

BioTrans uses two types of constraints. 'Node balancing constraints' to make sure there is no 'leakage' of products from the model and 'capacity constraints' to enforce capacity of nodes and flows. Some capacity constraints are optional.

3.3.1 Conservation of flow (node balancing)

(1) ***Processing***: For each processing node, the inflows must equal the outflows, corrected for the conversion yield of the (sub)process. Processes with a correction factor lower than 1.0 have an energy loss (e.g. in the form of lost heat), and as a consequence, inflows don't match outflows in terms of GJ.
(2) ***Export***: For each export node, the sum of inflows from production and processing must equal the sum of flows to import nodes.
(3) ***Import***: For each import node, the sum of inflows from export nodes must equal the sum of outflows to country nodes and processing nodes.
(4) ***Country***: For each country node, the sum of inflows from import and processing must equal the sum of outflows to distribution nodes.
(5) ***Distribution***: For each distribution node, the sum of inflows from country nodes must equal the sum of outflows to market segment nodes.

3.3.2 Lower and upper bounds on flow (capacity)

(6) ***Crop production capacity***: actual production cannot exceed the capacity for crop production of a production node.
(7) ***Crop production rotation***: Some crops need to grow for a number of years without changing, whereas for other crops periodic rotation is essential.
(8) ***Crop production perennial***: limits the production of a certain crop at a production node, as a fraction of the product in the previous period.
(9) ***Crop production land use***: limits the absolute increase of production in terms of land use.
(10) ***Non crop production capacity***: actual production cannot exceed the capacity for waste and residue production of a production node.

(11) ***Process introduction***: Some conversion (sub) processes are not available yet and use is limited to the period after a given introduction year.
(12) ***Process technology shifts***: limits the change in (sub) processes used, as a fraction of the processes used in the previous period.
(13) ***End-use technology introduction***: Some end-use technologies are not available yet and use is limited to the period after a given introduction year.
(14) ***End-use technology shifts***: limits the change in end-use technology used, as a fraction of the end-use technology used in the previous period.
(15) ***Segment demand***: limits the biofuel consumption to the total fuel demand for each market segment.
(16) ***Segment fossil replacement***: limits the use of biofuel as a replacement for each market segment.
(17) ***Target requirement country***: Biofuel target constraints on country level, for some biofuels the content is adjusted for blend fractions.
(18) ***Target requirement EU***: Biofuel target constraints on EU total level, for some biofuels the content is adjusted for blend fractions.
(19) ***Subtarget requirement***: Biofuel target constraints for gasoline replacements (first and second generation bioethanol) and diesel replacements (bio-DME, bio-FT-diesel).
(20) ***Next generation requirement***: Biofuel subtarget constraint for 2nd generation biofuels (2nd generation bioethanol, bio-SNG, bio-FT-diesel and bio-DME).
(21) ***Greenhouse gas emission target.*** Emission constraint that imposes obligatory total emission reductions due to biofuel production.

3.3.3 Miscellaneous

Production capacity is modelled using capacity constraints on the production nodes. Demand is given and segment nodes are constrained to exactly match demand in any segment. This exact constraint has the same function as an inequality constraint would, since we are dealing with continuous variables. There are six special constraints for including or excluding certain policy options:

Burden sharing – (constraints 17 and 18) In the normal case, targets for biofuel shares are set on country level. When burden sharing is activated, targets are aggregated for all EU countries. Burden sharing in the model results in the least-cost country specific targets, whereas no burden sharing in the model implies that all countries have the same generic European target.
Crop rotation – (constraints 7, 8 and 9) activating crop rotation constraints limits crop rotation, perennial production and shifts in land use.
Limit technology shifts – (constraints 12 and 14) activating these constraints limits technology shifts for sub processes and end use technologies within years.
Subtargets for diesel and gasoline replacements – (constraint 19) activating sets specific shares for diesel replacement biofuels and for gasoline replacing biofuels.
Subtarget for 2nd generation biofuel – (constraint 20) activating sets specific shares for second generation biofuels.
Include CO_2 price – (target function) activating includes the costs of greenhouse gas emissions (CO_2-eq) in the total costs that are to minimize.

3.4 Endogenous learning

The model optimises for each year consecutively and there is no linkage between periods (i.e. no storage of products or balances of targets). Demand is considered exogenous and is modelled as constraints on end nodes. Different amounts have a time component, using a growth path, with an interdependence between specific investment costs and historic output volume.

On these previously destribed characteristics, one major distinction is made. The costs of conversion technologies, i.e. investment costs and O&M costs in fixed ratio, change in time, depending on past production.

A general distinction has been made between the well-developed technologies, like the first generation technologies producing biodiesel from oil crops or bioethanol from sugar and starch, and emerging technologies, like technologies of Fischer-Tropsch diesel production and bioethanol production from lignocellulosic materials.

The learning effects of the well-developed technologies are described by an initial historic volume, that is the European production up to 2005, and a progress ratio, consistent with the theory of 'technological learning'[6]. The progress ratio defines the relative cost reduction of the production process for each doubling of historic production volume. The progress ratios for first generation technologies range typically between 0.8 and 1.

In absence of sufficiently long historic data, it is difficult to estimate the progress ratio for emerging technologies. Furthermore, as historic production volume of emerging technologies is still rather small, the doublings of historic production succeed rapidly and so does the cost decline. Therefore, for emerging technologies a distinction has been made between cost reductions that are a result of scale effects and the residual cost reductions that follow a learning curve. The corresponding progress ratios of these residual effects are typically estimated between 0.98 and 1.

The scale dependent cost reductions are bounded by several constraints. Each technology has a maximum scale size, the size beyond which scale increase does not result in lower production costs. It also has a maximum doubling time, thus the scale of a production facility can only double every three to five years typically. Finally, it has a maximum market share, thus each facility can only serve a fixed fraction of the total market, typically 5-10%. Specific assumptions on these parameters per technology have been included in the data report.

[6] IEA, Experience Curves for Energy Technology Policy, Paris, 2000.

4 Input and output

Whereas the BioTrans model is built in the AIMMS modelling environment, all data are managed using a relational database. The data structure is designed to provide a practical compromise between usability and promotion of data integrity. The AIMMS model uses a set of 'interfacing' routines to read and write data to the database.

4.1 A note on data and structure

BioTrans is to a large extent data-driven, meaning that the input data largely determine the size of the model. Where possible, the number of object instances is determined by the data: there is (for example) no fixed or minimum set of products, countries or processing steps[7]. The structure of the model is largely defined by the constraints, discussed in some detail in the previous chapter. The actual number of constraints is based on the number of object entities in the model. Data on these entities are called '*structural data'* whereas data on costs, distances or projections are called '*parametric data*'.

4.2 Input data

This section sums up the data BioTrans uses as input, without providing the complete and detailed data model. Note that for the parametric values, the level of detail is not prescribed and there is always a subjective trade off between detail and confidence. In the same line of reasoning, the level of aggregation is open to the data modeller.

Structural data (objects)

Biofuels (see table 2.1)
Products with units and categories (see table 2.2)
Technologies (see table 2.3)
Sub processes (see table 2. 3)
Countries (see table 2.4)
Sub process/Product relations (see Annex 1)
Sub process by-products and auxiliaries (not specified in this report)
Demand segments (modalities, see table 2. 5)

Parametric data (values)

Technology related data: start year, costs per category
Transport distances and costs
Sub process data on yields and investment costs (progress ratios, growth factors)
Sub process technology parameters
Wage level and growth per country
Product costs and energy contents
Non-crop potentials and relative unit costs per country and production/processing combination, projected growth
Crop potentials: productivity, projected growth
Emission data per biofuel
Demand per segment (modality), per country, including growth projections per decade

[7] **Object type** refers to the sort of item, such as a country or a product. **Object instance** refers to the actual occurrence of a type, such as 'Italy' or 'biodiesel'.

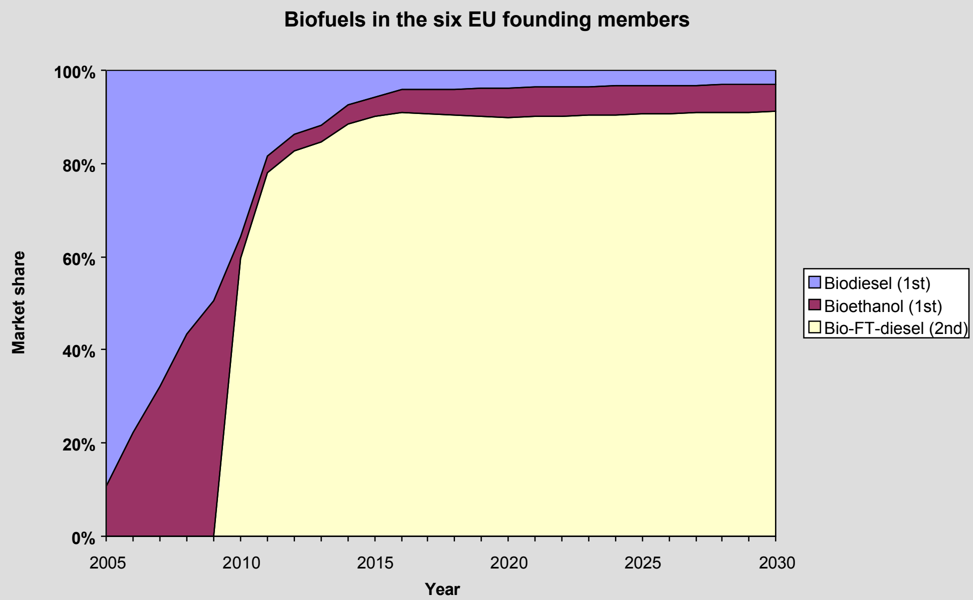
4.3 Output data

The model produces a least cost energy flow from production to demand, complete with associated costs. The output therefore consists of:
Composition of the biofuel mixes in each year (GJ, %)
Detailed costs for each biofuel and each demand segment (€/GJ)
Total raw material production at each of the locations (GJ)
Production chain configuration and throughput at each of the processing plants(GJ)
Import and export between countries for each of the (half) products (GJ and €)
Use of by-products and auxiliaries during the processing steps (tones, GJ)
Emission data (tCO_2)

Results example 1: Composition of the biofuel mix in each year

The development of the least-cost fuel mix over time in BioTrans is summarized in the figure below in a simplified run in which only the countries Belgium, France, Germany, Italy, Luxembourg and the Netherlands are considered. Biodiesel starts as least-cost conventional biofuel option. First generation bioethanol has a rising market share in the current decade, even considered the necessary cost of vehicle adaptation. Key message of this analysis is, however, that second generation biodiesel has good prospects. Necessary condition is that several successful pilot plants can be constructed.

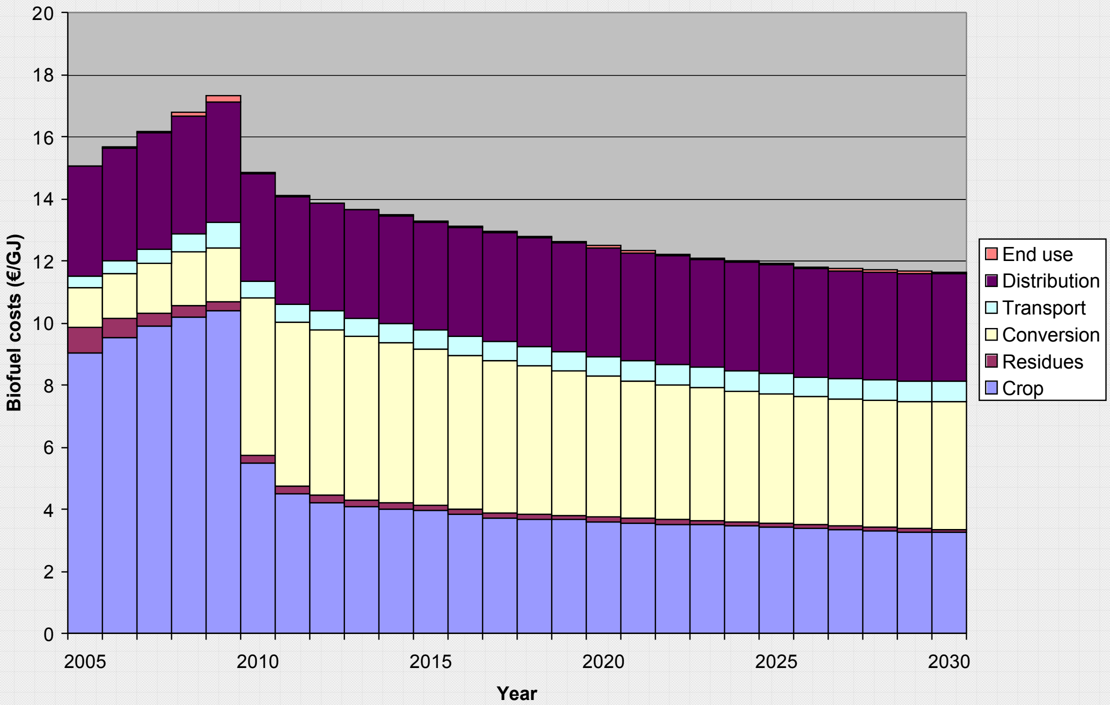
In BioTrans, the fraction of first generation biofuels decreases after 2010 in favour of advanced biofuels. Not only the declining costs of bio-FT-diesel are responsible for this trend. The less attractive potentials (less suitable land for crop production) of oil crops will also lead to higher marginal costs for these fuels. The use of advanced biofuels, with related crops with higher energy potential per ha, then becomes economically attractive, if the conversion technology is also available. In 2010 and beyond, this development results in the increasing market penetration of second generation biofuels, in the current example bio-FT-diesel. Note that the cost reduction assumptions for the different fuel conversion technologies have uncertainties as they are in the R&D, or at best in the pilot phase. The extrapolation regarding cost reductions, up scaling and economies of scale still creates relatively large uncertainties. Therefore, the data are not sufficiently reliable to indicate the 'winner' biofuels with solid certainty.



Results example 2: The average costs of the biofuel mix

The average costs of the biofuel mix are depicted the figure below. The slight decrease in fuel mix cost is a net effect of several developments. On one hand, crop prices decrease due to the replacement of oil crops by cheaper and more energy efficient woody biomass. On the other hand, conversion costs increase due to the growth of advanced biofuel technologies. Although fuel costs of advanced biofuels are higher than those of first generation biodiesel and bioethanol, these technologies will enter the market, since the conventional biofuels will become more expensive due to the use of less attractive land in order to meet increasing biofuel targets beyond 2010. Eastern Europe has sufficiently cheap biomass potential to fulfil the needs. European wide biofuel costs may turn out to be lower, than the costs depicted in this box, calculated only for the Benelux countries, France, Germany and Italy.

In the far future, 12 €/GJ projected costs of advanced biofuels can be reached, provided that the development and up scaling of advanced biofuel technologies, based on e.g. gasification, is successful, meaning available on time, with sufficient production volume, product quality, and economies of scale, and the advanced biofuels meet their fuel specifications.



4.4 Minimal data requirements

Since the model is largely data driven, it is relatively easy to transpose the model to other countries or groups of countries, and to other biofuel chains. The minimal requirement is the specification of at least one complete production chain and a demand to be met, as indicated in figure 2.1.

Name	*Required*	*Optional*	*Growth rate*	*Country dependent*
Products				
Name	•			
Category		•		
Value (price or cost)	•			
Energy content	•			
Unit	•			
Biofuel efficiency		•		
Non-crop production				
Location	•			•
Product	•		•	•
Unit costs	•		•	•
Potential (availability)		•	•	•
Crop production				
Location, suitability	•			
Product	•			
Unit costs	•		•	
Labour input		•		
Potential (availability)	•		D	
Productivity	•		•	•
(Sub)Processes				
By-product amount		•		
Auxiliary amount		•		
O&M costs	•		D	
Investment costs	•		P	
Raw material costs	•		S	
Yield	•		S	
Full load hours		•		
Demand				
Segment demand	•		D	•
End use technology				

Start year		•		
Blend/ vol%		•		
Distribution costs	•			
End use costs	•			
Miscellaneous				
Countries	•			
International transport distances		•		
Transport modalities		•		
Transport costs per modality		•	•	•
Wage level		•	•	•
Emission data		•	D	

D: different values per **D**ecade
S: growth uses **S**tartyear
P: growth uses **P**rogress Ratios

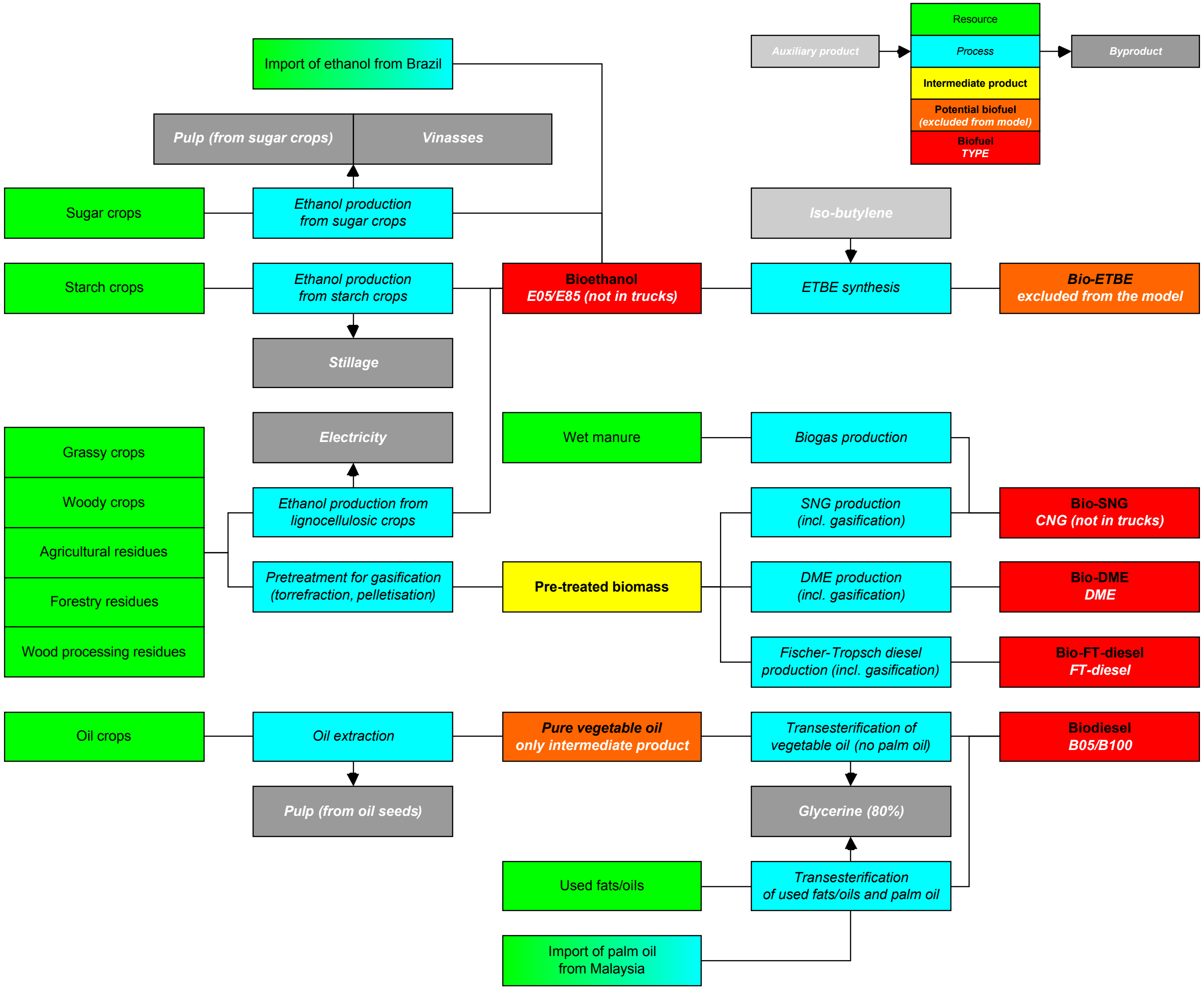
5 Literature

Xander van Tilburg, Ruud Egging, Marc Londo, BioTrans functional and technical description, Report of VIEWLS WP5, modelling studies, Energy Research Centre of the Netherlands, Unit Policy Studies, Petten, the Netherlands, 2005.

Ewout Deurwaarder, WP4 BioTrans data background report, REFUEL, Energy Research Centre of the Netherlands, Unit Policy Studies, Petten, the Netherlands, 2007.

IEA, Experience Curves for Energy Technology Policy, Paris, France, 2000.

Annex A: Biofuel conversion scheme used in BioTrans



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