# CENTRALIZED VS. DISTRIBUTED BIOFUEL SUPPLY CHAINS BASED ON LIQUE-FACTION TECHNOLOGY – THE CASE OF SWEDEN

*Sierk de Jong, University of Utrecht, the Netherlands*
*Elisabeth Wetterlund, Luleå University of Technology (Bio4Energy)*
*Karin Pettersson, SP Technical Research Institute of Sweden / Chalmers University of Technology*
*Ric Hoefnagels, University of Utrecht, the Netherlands*

## *Background*

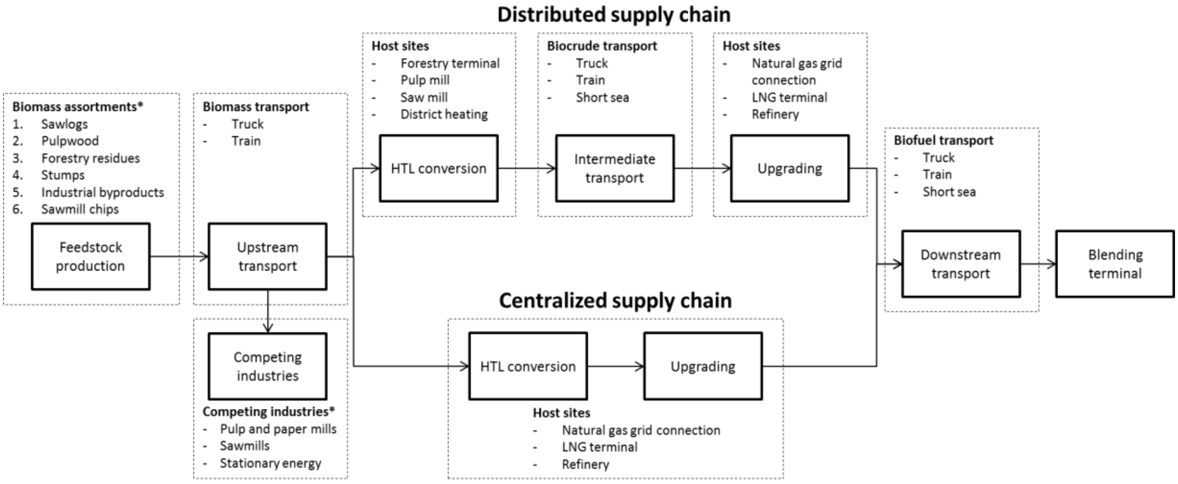
Unlike fossil fuels, biomass is a dispersed resource. Although higher production scales allow for benefits of economies of scale, it also requires a larger collection area, thus increasing the upstream transport cost. Whereas fossil energy carriers typically have high energy density, biomass generally has low energy and bulk density. Consequently, biomass transportation can be a significant contributor to the overall cost of the product. Distributed supply chain configurations including pre-treatment methods based on drying or densification (e.g. chipping, pelletization, torrefaction, liquefaction) are often proposed to decrease the transportation cost, especially when transport distances are high. Although an intermediate conversion step adds capital expenditures (CAPEX) and operational expenditures (OPEX) to the overall costs, it may reduce transportation costs as the intermediate product has a higher energy and bulk density than raw biomass.

As the merits of a distributed supply chain configuration are proposedly more profound in areas with high transportation costs or low biomass supply density, it seems cardinal to take into account the geospatial character of biomass supply, intermodality in transport networks, competing demand for biomass, and integration benefits with existing industries. Whereas the first factor is generally included in optimization models, the influence of the latter three aspects on supply chain configuration is still poorly understood.

In this analysis we explore the preconditions under which distributed supply chain configurations are preferred over centralized supply chains, for the case of Sweden. The overall aim of the study is to identify cost efficient supply chain configurations for the production of drop-in biofuels from forest biomass using liquefaction technologies. We apply a spatially explicit modeling approach attempting to reflect local circumstances by including aforementioned factors, supplemented with detailed CAPEX scaling curves for biomass pre-treatment and upgrading to biofuels.

### *Investigated supply chains*

The case study is based on the introduction of additional forest-based biofuel production in Sweden. The scope includes the entire supply biofuel chain from feedstock to blending terminal (Figure 1). On the supply side virgin feedstocks (stem wood and harvesting residues) as well as by-products from the forestry industry are considered. Both centralized and distributed supply chain configurations are considered for production of biofuels based on Hydrothermal Liquefaction (HTL) of woody biomass. The biocrude is consequently upgraded to gasoline, diesel, heavy oil and light ends by hydrotreating and hydrocracking. Sawmills, pulp and paper mills, district heating systems, together with forestry terminals, constitute possible host sites for the HTL plants in the distributed supply chains. Possible host sites for the biocrude upgrading include the natural gas grid, liquefied natural gas (LNG) terminals and refineries. In case of centralized supply chains, HTL conversion also takes place at these sites. Existing competing biomass demands from sawmills, pulp and paper mills and the stationary energy sector (heat and power) are taken into account. Various modes are included for the transportation of biomass, biocrude and biofuel.




* Assortment 2-6 are considered for biofuel production, paper mill heat demand and stationary energy sector. Assortment 1,2 and 6 can be used by the pulp mills. Assortment 1 is used in sawmills. Industrial byproducts from sawmills are used on-site to cover sawmill heat demand.

**Figure 1. Scope of the analysis.**

The model is evaluated for a range of total biofuel production scenarios, from 1-150 PJ/year, in order to evaluate the resulting supply chain configurations at various scales. The base case solution for each biofuel scenario is compared to additional cases to identify key determinants regarding supply chain design decisions (no intermodal biomass transportation, no integration benefits, restricted biomass supply, higher competing biomass demand, centralized supply chain configurations only, and reduced maximum capacity per site).

### *Results*

The results show that even though distributed supply chain configurations may decrease upstream transport cost and unlock areas of cheaper feedstock supplies, the benefits are generally outweighed by additional costs for intermediate transportation and conversion, especially at lower biofuel production levels (<75 $PJ_{biofuel}$, roughly equivalent to the size of a large scale plant). Below this level centralized supply chain configurations, preferably integrated with a refinery, yield lower biofuel production costs. At higher biofuel production levels, distributed supply chains that help access more widely dispersed biomass supply locations are introduced. The number of production units increases gradually with biofuel demand; from one centralized facility (integrated with a refinery) at lower production scales, to nine production units at maximum biofuel production (one centralized facility, two upgrading facilities, and six HTL units of varying size). HTL conversion plants are generally built integrated with sawmills or pulp mills as they provide the greatest integration benefits.

Contrary to what could be expected a decreased biomass availability, distributed supply chains are introduced at the same biofuel demand as in the Base case. Furthermore, neither the feedstock procurement costs nor the amount and type of units built vary significantly between these cases and the Base case. The only difference is related to feedstock and upstream costs which increase in these cases because more expensive feedstocks are used (particularly stumps) and feedstock is transported over larger distances. As biomass supply is particularly under additional stress near clusters of competing demand in these cases, host sites for distributed supply chain configurations are also associated with increased transport costs and/or feedstock costs. Hence, decreasing the biomass supply or increasing the competing demand was not found to give rise to a stronger preference for distributed supply chain configurations.

Conversely, limiting the maximum allowed capacities for individual production units promotes distributed supply chain configurations. Distributed supply chain configurations are also shown to be favored by integration possibilities. When removing the integration related benefits (steam sales, hydrogen exchange, OPEX/CAPEX reductions due to share equipment and workforce) the supply chain design shifts to centralized production also for higher biofuel scenarios, due to that integration benefits are particularly applicable for locations utilized by distributed supply chain locations (HTL conversion plants integrated with forest industry). Without integration benefits the preferred centralized production location shifts from refineries to areas which may be better situated in terms of biomass supply, like locations with a natural gas grid connection or LNG terminals.

Figure 2 gives an overview of the resulting average biofuel production costs and supply chain designs for the considered cases. All cases show a sharp downward cost trend when moving from lower to higher total biofuel production scale which is counteracted by a slight upward tail at higher biofuel production. The initial cost decrease is mainly due to a decline in CAPEX, while the upward trend in the tail is mainly caused by increased feedstock costs due to more expensive assortments having to be used, and by increasing upstream transportation costs.

Relative to centralized supply chain configurations, distributed supply chains are associated with lower upstream transport costs, but higher conversion costs and additional costs due to intermediate transport. As the cost of feedstock and upstream transport grows only gradually with rising biofuel demand, the benefits of distributed production are generally offset by its higher conversion costs, especially at lower biofuel demands. In general the results show that transport costs have little impact on the resulting total biofuel production costs.

The performance of distributed supply chains may improve for areas with low biomass surplus, host sites at which additional benefits may be achieved through site-specific integration (bolt-on units), and geographies without an intermodal transport infrastructure. Nonetheless, the results show that centralized supply chain configurations always prevail at lower biofuel demands for all studied cases (with some exceptions due to site-specific circumstances). As the development of biofuel capacity generally sprouts from bottom-up action of single actors, it is unlikely that distributed supply chain configurations will be preferred by early movers, especially because the biofuel production capacities at which distributed supply chains are introduced (>75 $PJ_{biofuel}$/year) are currently unprecedented for single production facilities. However, solutions at higher biofuel demand scenarios (which may represent more mature biofuel systems) do include distributed supply chain configurations. Hence, the introduction of distributed supply chains may provide benefits as the biomass resource base becomes fully utilized.

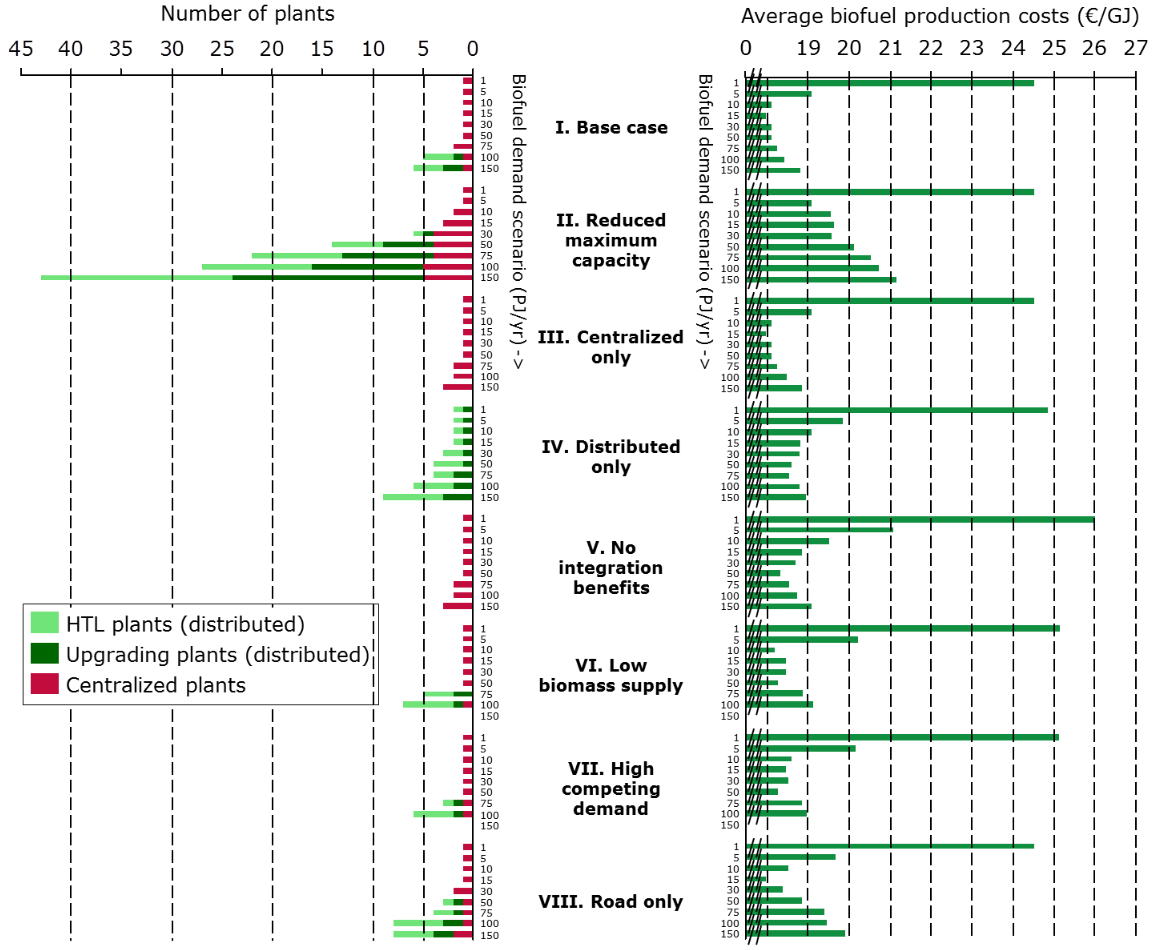



**Figure 2. An overview of number of units and average biofuel production costs for different biofuel demand scenarios. The biofuel production costs can be compared to current (2015) fossil fuel pump prices in Sweden of 14-15 €/GJ (taxes excluded).**

Project developers should not discard distributed supply chains altogether as they provide distinct benefits in some cases. A more profound preference for a distributed configuration may emerge for supply chains whose cost profile shows a lower share of conversion cost (and hence less benefits of economies of scale), lower additional conversion costs for distributed relative to centralized configurations, a steeper feedstock cost-supply curve or a greater differential between the cost of transportation of biomass and the intermediate product. In addition, 'soft' benefits at host sites, such as experience with biomass handling, safety aspects, strategic interest to produce bioenergy or existing feedstock contracts, may justify the cost premium for a distributed supply chain design. For instance, for demonstration units an incubator environment is more important than optimal cost performance. Additionally, some host sites, e.g. refineries, may not be willing to take in untreated biomass directly from the forest to co-produce biofuels, due to lack of experience in handling biomass or to safety issues. Then distributed supply chains, where the biomass is pre-treated at host sites with experience and infrastructure for biomass handling (pulp mills or sawmills) to a feedstock more similar to crude oil (biocrude), or another actor taking responsibility for the pre-treatment of biomass but located adjacent to the refinery, could be preferred.

In the literature, the merits of distributed supply chains have mainly been identified for supply chains in which the location of biomass supply and end use are fixed and far apart. When cost-supply curves are too shallow (like in this case study, especially with intermodal transport included), distributed configurations start to become interesting only when the most suitable production locations are taken, when the additional conversion costs in distributed relative to centralized supply chains are marginal, or when very high total biofuel scales are targeted.

### *Conclusions*

In summary, the results from this study show that supply chains designs involving distributed biofuel production generally only perform better than centralized supply chains at high total biofuel production volumes. However, the preference for centralized supply chains relies heavily on economies of scale; when the maximum capacity is constrained a trend towards distributed production becomes visible. Distributed supply chains may also show better performance in specific circumstances in which demand and supply are far apart, additional conversion costs can be mitigated (by e.g. bolt-on solutions), feedstock cost-supply curves are steep or high production scales are targeted.  In addition, distributed supply chains provide a cost-effective solution when approaching the maximum utilization of the biomass resource base.

*This summary is based on a scientific paper:*

*de Jong S, Hoefnagels R, Wetterlund E, Pettersson K, Faaij A, Junginger M. Cost optimization of biofuel production - The impact of scale, integration, transport and supply chain configurations. Applied Energy 2017;195:1055-70.*
*doi:10.1016/j.apenergy.2017.03.109*