

Carbon Trust/Future Blends [2008-2014]

I noted last week that this week I would focus on one specific project, due to the fact that 4 staff [full and part-time] were working on this one contract for over 4 years, in fact I was working with Future Blends for over 6 years.

Background

On 7th February 2008, the Carbon Trust issued an Expression of Interest, “Advanced Bio-Energy Accelerator Strand A – the Pyrolysis Challenge”. As stated in the EoI:

“As part of our mission to accelerate the move to a low carbon economy, Carbon Trust Innovations develops commercially viable low carbon technologies, through partnerships, funding, expert advice and outcome-driven research and demonstration. The Carbon Trust is seeking Expressions of Interest from groups including academic institutions, research organisations, technology-based SMEs and large industrial organisations interested in collaborating with us to develop breakthrough technology for the upgrading of biomass pyrolysis oils. The Pyrolysis Challenge is designed to capture an opportunity to produce low-cost, liquid fuels with low system GHG emissions, through integration of biomass supply chains into conventional refineries. Pyrolysis oil offers this potential, but the properties of oils produced from current fast pyrolysis processes are not suitable for direct integration. This first strand of our Advanced Bioenergy Accelerator has the objective of producing an improved oil through either a) modifying the pyrolysis process to produce a better quality oil directly or b) upgrading the oil before or at the refinery.

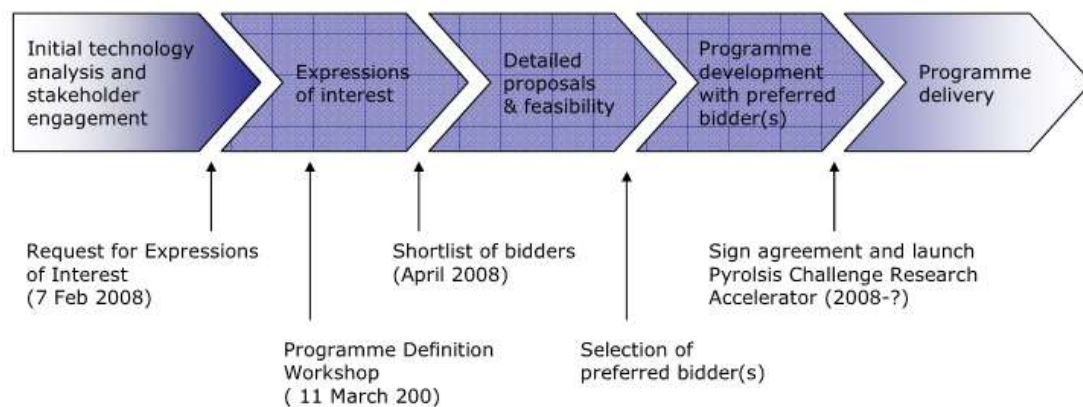


Figure 1: Outline process for public competition to select partners to deliver the Pyrolysis Challenge.

Following the success of the Advanced Photovoltaic Research Accelerator, the Carbon Trust is running a public competition (see Figure 1) to select partners to carry out a second Directed Research initiative in pyrolysis oil upgrading. Over the next 3-5 years, we intend to invest £5-6m in a project or projects to address this challenge.

We are planning to hold an event in London on 11 March 2008 to further explain The Pyrolysis Challenge and the other two strands of the Advanced Bioenergy Accelerator

(Strand B: Algae Biomass Systems and Strand C: Novel Biofuels) and give the diverse potential research and technology.”

CARE Ltd. attended the London Event and to cut a long story short, partnered with Axion Recycling, Oxford Catalysts, Greenergy, Sekab and Catal Ltd. to make a bid to the EoI – but not to the requirements of the EoI. There was also a partner for engine testing of liquids if required [Aquafuels Ltd.].

One of the key requirements in the EoI was that the biomass would be transported to a pyrolysis plant, converted to liquids, which would then be shipped to a refinery for processing to a hydrocarbon fuel, as indicated as part of Figure 2 below.

Bio-oil transforms logistics and final biofuel option

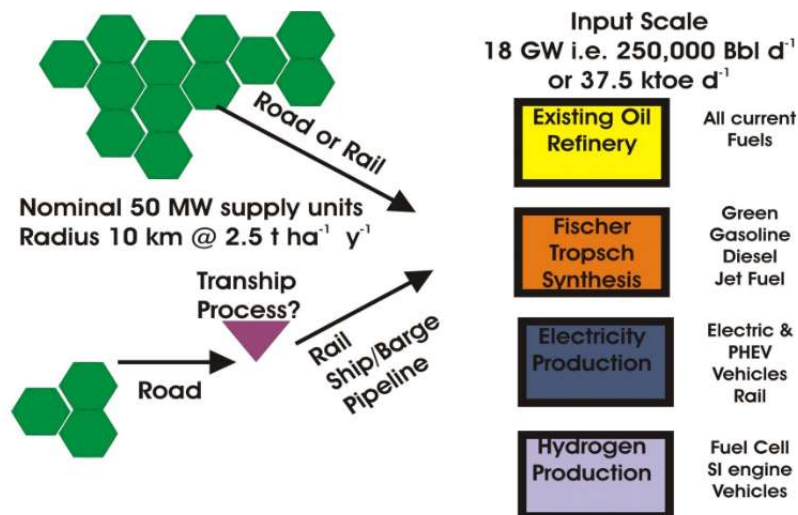


Figure 2. Biofuels to market routes

The Axion-led consortium challenged the Carbon Trust on the LCA of the proposed biofuel from pyrolysis: moving biomass to a fast pyrolysis plant, then moving the liquids to a dedicated refinery, of which there were only 6 of in the UK in 2008, then transporting those liquids again did not make sense.

The Carbon Trust carried out some work and came to the same conclusion, plus feedback from Nexant and others, and a refinery operator, made it very clear: no refinery would accept pyrolysis liquids as they are produced with high water, pH, O and low C/H ratio. The Axion consortium won the bid at the end of 2008 after 3 rounds of evaluations. We put forward the case that there were a range of upgrading options that would need to be done at the pyrolysis plant to make some sort of, “intermediate liquid” that would remove most of the difficulties with primary pyrolysis liquids and that would not be carried out at a refinery, but at the liquids production point. The additional advantage of our bid was to develop a new patentable hot vapour filtration process not based on ceramic filter or other formed porous media, but metal meshes.

The Project

Our outline route to market is shown in Figure 3 below.

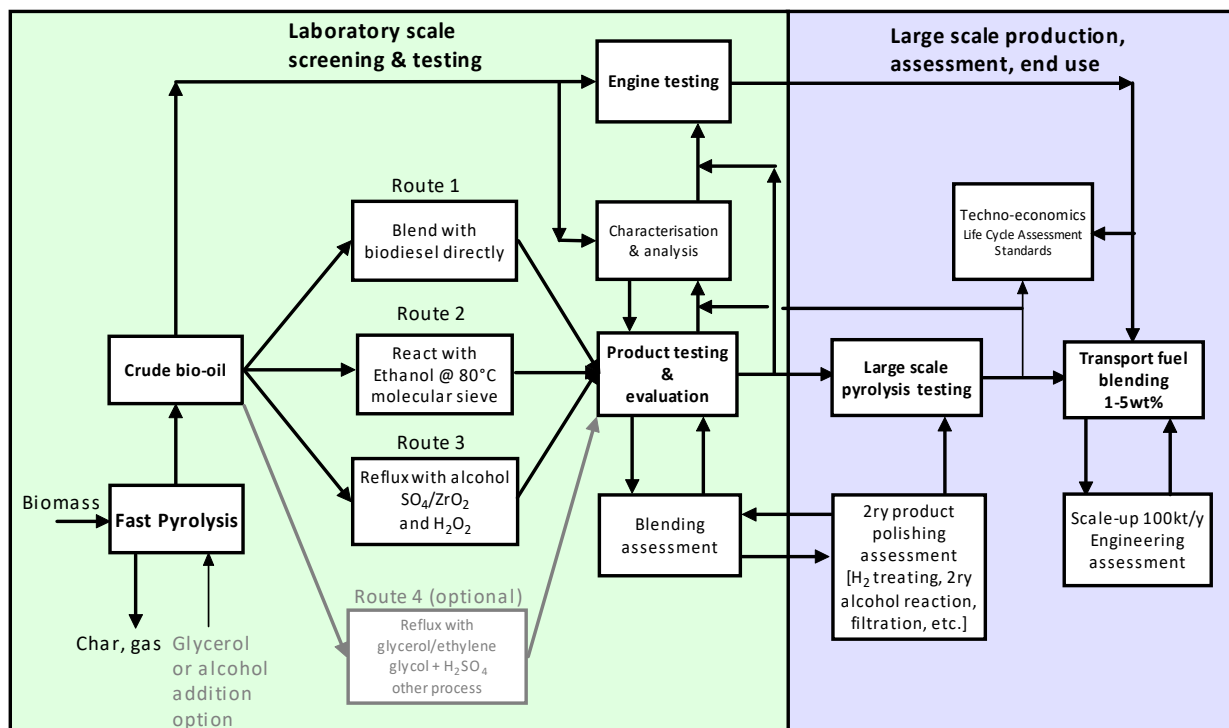


Figure 3. Overall processing methodology to an intermediate liquids product

I won't go into the structure of Future Blends, as we were only one of several contractors in the project, but to summarise the role of CARE Ltd. in the project over the next 4 years:

- Design of a 0.5 kg/h fluid bed fast pyrolysis rig for liquids recovery – built and hosted by Catal Ltd., Sheffield
- Design, build, install and commission a 5 kg/h fluid bed fast pyrolysis rig for liquids recovery – built by CARE Ltd. with a range of sub-contractors [CH Barnett, Genesis Control Ltd, others]
- Testing of 4 feedstocks [wood, straw, grass and bagasse] at Aston University under sub-contract initially to generate liquids for immediate upgrading testing.
- Arranging plan pot trials on the fast pyrolysis chars at the University of Limerick, Ireland.
- Mass and energy balances of the process and all secondary processing options.
- Complete processing and upgrading routes as advised by Catal to an end hydrocarbon product
- Full techno-economic assessment of various processing and upgrading strategies based on the empirical data from work at Future Blends.
- Development of the multi-metal mesh hot vapour filter design to produce stable low ash and low solids primary pyrolysis liquids.
- Assessment of esterification and identification of potential catalysts
- General technical contributions to Future Blends once rigs were built.

0.5 kg/h fluid bed fast pyrolysis for liquids production

CARE Ltd. carried out the process design for a 0.5 kg/h fluid bed reactor with integral liquids collection for the production of liquids for testing various feedstocks and also to make samples of liquids for catalyst testing by Catal Ltd. Catal had the rig built locally and CARE Ltd. commissioned it and trained Catal staff in its operation. Rig shown in Figure 4 below.

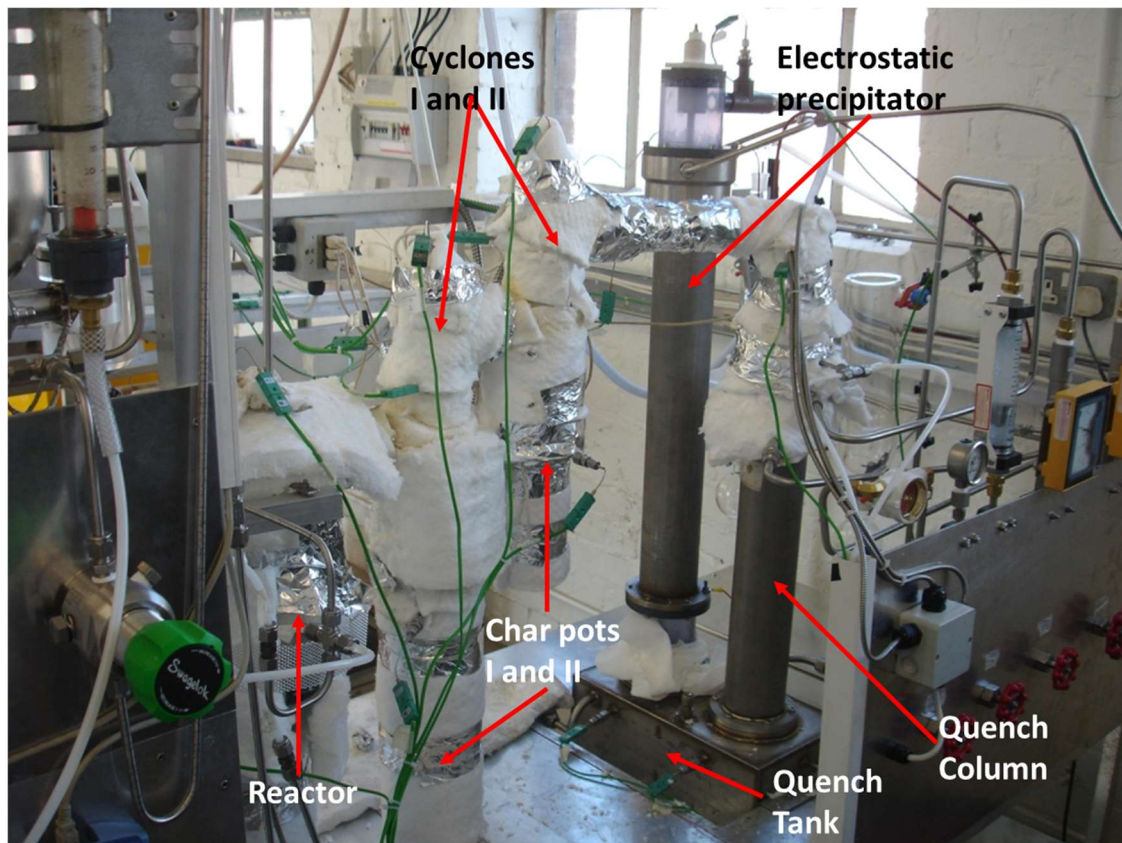


Figure 4. 500 g/h fluid bed fast pyrolysis rig and liquids collection system

This unit was flexible in terms of equipment addition and/or replacements and it was used to test the hot vapour filter [HVF] as discussed below. Use of the HVF meant the replacement of the 2 cyclones. The rig could be run for 4+ hours as required.

Vapour phase catalyst work was also carried out in conjunction with the HVF. This unit was then relocated from Sheffield to Future specific build facility in Abingdon in 2010.

5 kg/h fluid bed fast pyrolysis for liquids production

In order to make much larger bulk samples of pyrolysis liquids for upgrading, reaction and testing, a 5 kg/h fluid bed fast pyrolysis for liquids production was designed and built by CARE Ltd. with a range of sub-contractors in the UK. This was a full PLC controlled unit, with a sealed feed system, recycle of the cleaned pyrolysis gases to fluidise the reactor and excess gas flared. This unit could be operated remotely and the system would allow char and fines to be recovered in two separate char pots and the liquids quench would periodically drain the pyrolysis liquids into a storage tank after separation from the quench media, Isopar V.



Figure 5. 5 kg/h fluid bed fast pyrolysis rig and liquids collection system

This rig was one of the more complex fluid bed reactors that I've designed and built, given the very high degree of monitoring and control, the partial recycling of the cleaned syngas to fluidise the reactor, with pressure and flow control to ensure the bed fluidisation was accurately maintained. Everyone involved made this an excellent reactor system, which is still in use at another organisation now.

Testing of fast pyrolysis chars for biochar functionality

Various feedstocks were pyrolysed and samples of the fast pyrolysis chars tested at the University of Limerick in a local Adare soil with a control and the 1wt% added chars.

Table 1. Tested feedstocks

Run no.	Feedstock	Run no.	Feedstock
CT001	13 year old spruce	CT006	Miscanthus
CT002	Waste wood	CT007	Arundo Donax
CT003	13 year old spruce	CT009	Wheat Straw
CT004	MSW derived organic fraction		

All chars had a positive outcome, as shown in Figure 6.

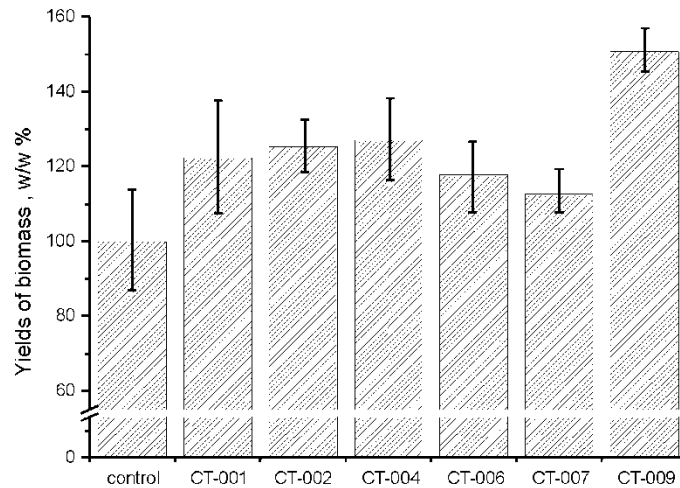


Figure 6. Grow results of maize based of green mass of the plants directly after cutting, for 1% of biochar applied.

This was 15 years ago before biochar took off and there were other positive outcomes for the use of the char in the soil on other plant types and paved the way for additional income for a pyrolysis process selling biochar.

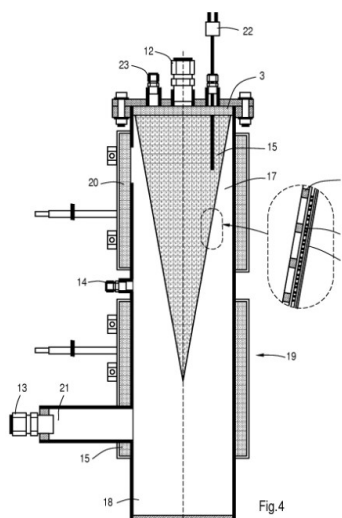
Hot vapour filtration of primary pyrolysis vapours

One of the successful outcomes of the project was a patent application for a hot vapour filter system. As noted earlier, as proposed in the original submission, there was an action to develop a hot vapour filter system. Prior approaches in the USA, Finland and elsewhere showed that the use of ceramic filter elements was highly problematical with the pores blocking due to vapour cracking and blockages with the secondary char particles.

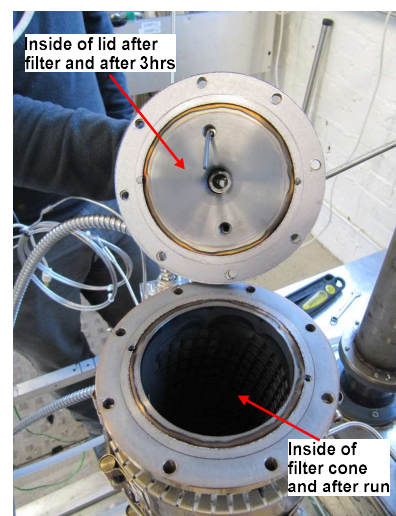
Use of layered metal mesh meant that there would not be a catalytic effect due to the use of stainless steel at low temperature, reduced costs, increased durability and use of higher backpulse pressures on the mesh filter.



Figure 7. Lagged, heated HVF



Schematic of HVF



HVF Filter lid, 3+ hours run time

As the concept was tested was on the 500 g/h reactor, there was no backpulsing of the candle as this would have been very difficult and caused issues with the reactor, so the candle was tapered so that char would slide off with time, but it also meant an accumulating layer, which would lead to increased cracking of the vapours.

Part of the concept development was to try different pore sizes and have 2 or 3 layers of mesh of different pore sizes. Pore sizes from 5 to 200 μ m were trialled and some initial results are given in Table 2 below. Further information and data can be found in the patent [<https://patents.google.com/patent/WO2014090992A2/en>]. The was later swapped out for a vertical candle which also worked incredibly well and gave the same results.

Table 2. HVF trials with different mesh pore sizes compared to cyclones.

Ex.	1	2	3	4	Comp.
Filter configuration	100/25 μ m	100/100 μ m	100/5 μ m	200/100 μ m	Cyclone, no filter
Feedstock moisture, wt%	11.75	11.9	11.9	11.9	10.58
Ash, wt% (db)	0.65	0.65	0.65	0.65	0.65
Mass Balance					
Char*	14.77	16.05	14.62	15.01	14.37
Organics*	49.12	47.26	49.10	44.32	52.15
Pyrol. Water*	12.66	13.87	11.23	11.97	10.47
Non condensable gases*	18.05	19.36	16.83	17.88	14.37
Closure	94.50	95.56	91.79	89.18	91.35

* [g/100g db]; db = dry biomass; pyrolysis water excluding feedstock water.

The product liquids were correspondingly low in metals: Ca, K, Mg, etc. and low solids of 0.04 wt% for the 100/5 μ m mesh combination compared to 0.17 wt% char in the liquids for the 2 cyclones in series. The filters tested did not block once with tars, the metals filters stayed clean and the vapours after filtration did not deposit downstream of the filter, shown in Figure 7. A cut through the char layer on the filter shows no deposits as shown in Figure 8 below.

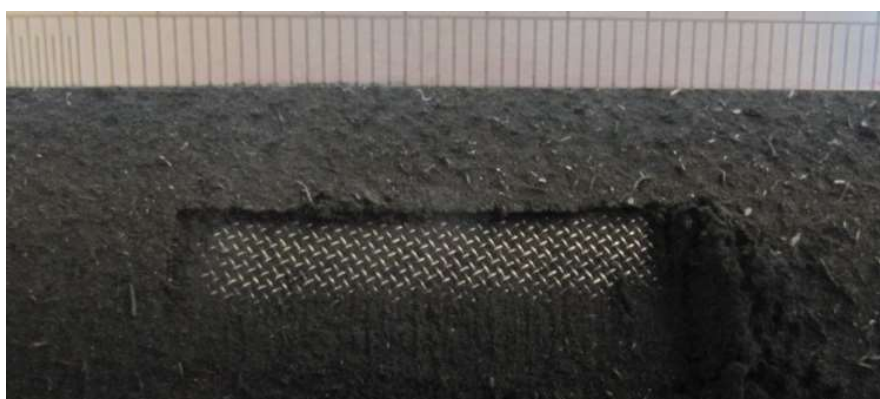


Figure 8. Slice through HVF filter candle char layer.

Techno-economic assessment of Future Blends upgrading routes

Other work on esterification, inline catalyst use and other concepts were worked on, but the other major contribution was on the overall techno-economic of various pyrolysis and post-processing options to intermediate liquids, catalytically upgraded liquids and optimising energy use and sale of “biochar. This was one of the last major contributions running into 2013 for Future Blends.

The task of CARE Ltd. was to compare the Future Blends process with competitive technologies such as Envergent, Metso/UPM/Fortum and KiOR, that offer a commercial or near commercial technology with the primary objective of manufacturing a transportation fuel in terms of cost [£/GJ, £/t] and overall upgraded liquids yield.

The work involved the development and expansion of an existing techno-economic model with new upgrading steps and the use of hot vapour filter (HVF) to remove solids and metals from the fast pyrolysis liquids.

The overall assessment basis was 100,000 dry tonnes per year plant, feedstock is clean softwood. Four scenarios have been considered:

1. Fast pyrolysis with cyclones and standard quench – Representative of competitive technologies using the Battelle PNNL upgrading route [S1]
2. Fast pyrolysis with HVF and standard quench – Future Blends [S2]
3. Fast pyrolysis with HVF and partial quench – Future Blends [S3]
4. Fast pyrolysis with HVF and standard quench followed by vacuum distillation – Future Blends [S4]

The first stage of the modelling considered the production cost of fast pyrolysis liquids (primary liquids) via cyclones, HVF, HVF and partial quench, HVF and vacuum distillation. The second stage of the modelling considered all the required upgrading steps to produce a fuel blend suitable for transport fuel (upgraded liquids).

Its not possible to review all of the work here and the full methodology used, but present a summary in comparison with other studies as shown in Table 3 overleaf.

Scale is critical to lower costs. Primary issues will come from biomass supply and ideally, sized and dried to plant requirements, as this again lowers the operational costs. It is therefore essential to look at a steady, guaranteed source for the biomass, ideally on a sawmill or other major biomass processing facility.

Table 3. Upgraded liquids cost comparison with other studies

Capacity	Biomass cost	H ₂ production	Selling price, £/l	Reference
100,000 t/y	£50/t	Yes	0.49	Cyclones
100,000 t/y	£50/t	Yes	0.49	HVF
100,000 t/y	£50/t	Yes	0.53	HVF partial quench
100,000 t/y	£50/t	Yes	0.54	HVF distillation
730,000 t/y	£31/dry t	Yes	0.34	PNNL 2009 [1]
730,000 t/y	£52/ dry t	Yes	0.50	Anex 2010 [2]
730,000 t/y	£52/ dry t	No	0.42	Brown 2013 [3]
730,000 t/y	£52/ dry t	Yes (from pyrolysis liquids)	0.51	Wright 2010 [4]

References

1. Jones, S.B., et al., Production of gasoline and diesel from biomass via fast pyrolysis, hydrotreating and hydrocracking: a design case. 2009, PNNL
2. Anex, R.P., et al., Techno-economic comparison of biomass-to-transportation fuels via pyrolysis, gasification, and biochemical pathways, Fuel 89 (2010) S29-S35.
3. Brown, T.R., et al, Techno-economic analysis of biomass to transportation fuels and electricity via fast pyrolysis and hydroprocessing, Fuel 106 (2013) 463-469.
4. Wright, M.M., et al., Techno-economic analysis of biomass fast pyrolysis to transportation fuels, Fuel 89 (2010), S2-S10.