BayFAME®

Continuous Free Fatty Acid Esterification

INNOVATION ENGINEERING OPTIMIZATION

Bayer Technology Services

Powering Your Performance

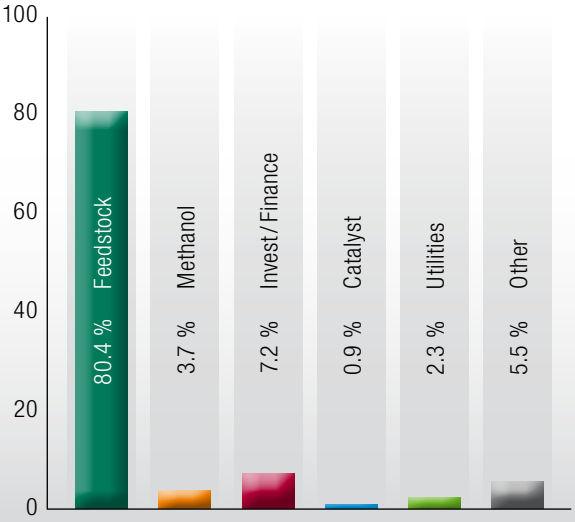
THE CHALLENGE

Biodiesel Feedstocks

The manufacturing costs of Biodiesel are dominated by the feedstock costs. While the feedstock presents 80 % of the cost of goods, other factors like investment cost, utilities and labor only play a minor role. Furthermore, feedstock prices and availability are a moving target in today's environment since typical feedstocks like soybean oil and rapeseed oil, which are easily turned into Biodiesel (FAME), have reached price records of 1,200 €/t and 1,100 €/t in 2008. Less expensive potential feedstocks are available but they contain a significant amount of Free Fatty Acids (FFA) which cannot be processed in conventional Biodiesel plants. In the past, these free fatty acids had to be treated as waste or as a by-product of low value. Some acid esterification techniques for these FFA were available in the market but presented significant issues in terms of acid removal and waste water treatment.

Why Continuous Esterification?

Biodiesel manufacturing costs



Prices December 2008

FEEDSTOCK	PRICE	FFA wt%
Rapeseed Oil	640 €/t	< 2 %
Soybean Oil	610 €/t	< 2 %
Crude Palm Oil	470 €/t	~ 8 %
Yellow Grease	240 €/t	15 – 20 %
Edible Tallow	350 €/t	15 – 20 %
PFAD	250 €/t	~ 100 %
Jatropha	–	10 %

The Solution

With BayFAME®, the new clean FFA-Esterification Technology developed by Bayer Technology Services based on the Dow AMBERLYST™ BD20 catalyst, our customers will now be able to turn any FFA-containing feedstock into FAME without worrying about yield loss, acids and waste. Whether customers want to use a specific feedstock like different types of animal fat, used cooking oil, trap grease, jatropha or even 100 wt% FFA (PFAD), or want to achieve a maximum flexibility in feedstock, we have the solution to get the competitive advantage and flexibility to succeed in a world of volatile oil and raw material prices.

OUR TECHNOLOGY

At Bayer, Innovation has deep roots

Bayer Technology Services is the technology backbone of the Bayer Group, one of the world's largest chemical and pharmaceutical companies established in 1863. As experienced partners, we develop the processes and production plants that assure efficient operations. Years of constant pressure to innovate have paid off with a wealth of expertise – in engineering as well as in process technology. The large number of patents we hold on marketable innovations in the area of chemical engineering are proof of our outstanding expertise.

The Chemical Reaction

Free fatty acids in biodiesel feedstocks can be converted into fatty acid methyl ester (FAME) by esterification with methanol. This reaction is typically catalyzed by an acid catalyst, such as sulfuric acid. However, the application of strong acidic homogeneous catalysts like H_2SO_4 requires a significant extra effort in terms of materials of construction and safety compared to a conventional biodiesel plant. These restrictions are resolved by the Bayer Technology Services continuous free fatty acid esterification process, which includes an optimized process design for the application of the heterogeneous esterification with AMBERLYST™ BD20 catalyst from Dow. As the esterification of free fatty acids is equilibrium limited at relatively low FFA conversions, the driving force to achieve complete FFA removal needs to be increased by using methanol in excess to the stoichiometric requirement. This is combined with a multi-stage reactor configuration with an inter-stage removal of the by-product water, which offers a further shift of the thermodynamic equilibrium towards complete conversion of even high FFA concentrations in the feedstock.

The Process

The multi-stage concept offers a flexible process design, which ensures that feedstocks with any FFA content up to 100 wt% can be processed with an optimum yield and minimum manufacturing costs. While for low FFA concentrations a single reaction stage is sufficient to reduce the FFA concentration to a level as low as 0.1 wt%, a 3-stage process will cover the complete spectrum up to 100 wt% FFA.

The process has been designed with the target to preferentially employ robust and simple process equipment, which minimizes investment costs and operating complexity. The core part of each reaction stage will be a continuous flow reactor containing a fixed bed of the heterogeneous esterification with AMBERLYST™ BD20 catalyst. After each reaction stage water is removed by evaporation together with most of the methanol excess. The resulting wet methanol stream is dried by distillation before being recycled and reused for further esterification of fresh FFA. In case multiple reaction stages are employed, the methanol will not be removed after the last stage. The final esterification product including excess methanol can be directly sent into a downstream transesterification unit. This will reduce the methanol requirement in the transesterification and also reduce the heat requirement for methanol drying. In multi-stage process configurations the energy demand will be further optimized by heat integration between the evaporator stages and the methanol drying column.

The Configuration

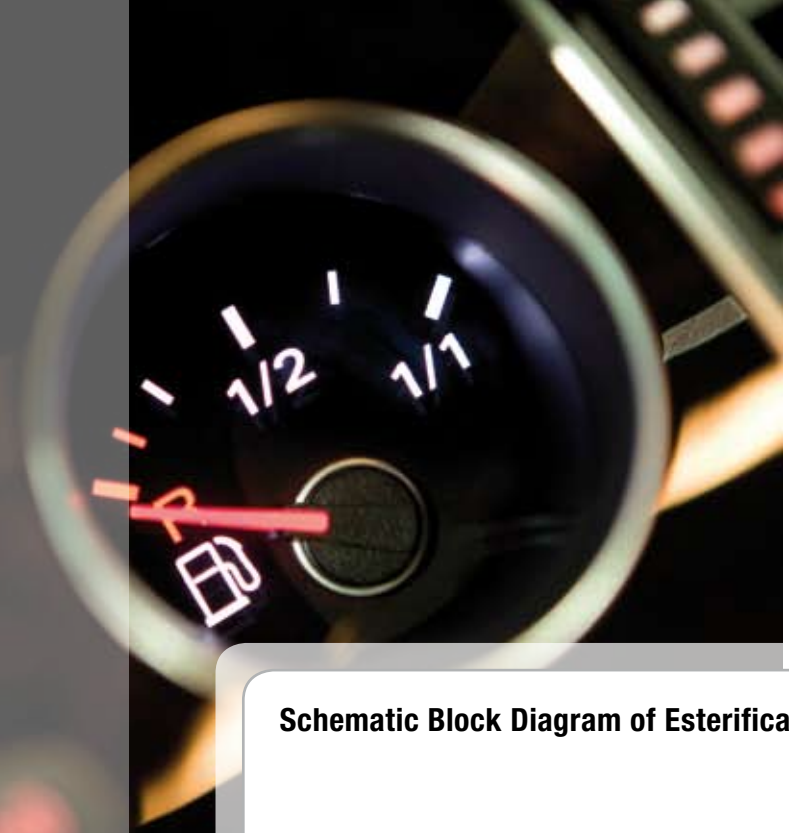
The appropriate number of reaction and evaporation stages that should be selected depends mainly on the range of FFA content of the prospective feedstock as well as on the desired target residual FFA concentration, i. e. the inlet FFA specification of the downstream transesterification reaction. The figure on page 5 illustrates the dependence between FFA concentration in the feed and outlet of the esterification and the required number of reaction steps. For feedstocks containing only a few percent FFA such as e. g. crude vegetable oil a single reaction stage will be mostly sufficient to reduce the FFA concentration to a residual level that can be tolerated in the transesterification. A 2-stage

Esterification Principle

$$RCOOH + R'OH \underset{k_-}{\overset{k_+}{\rightleftharpoons}} RCOOR' + H_2O$$

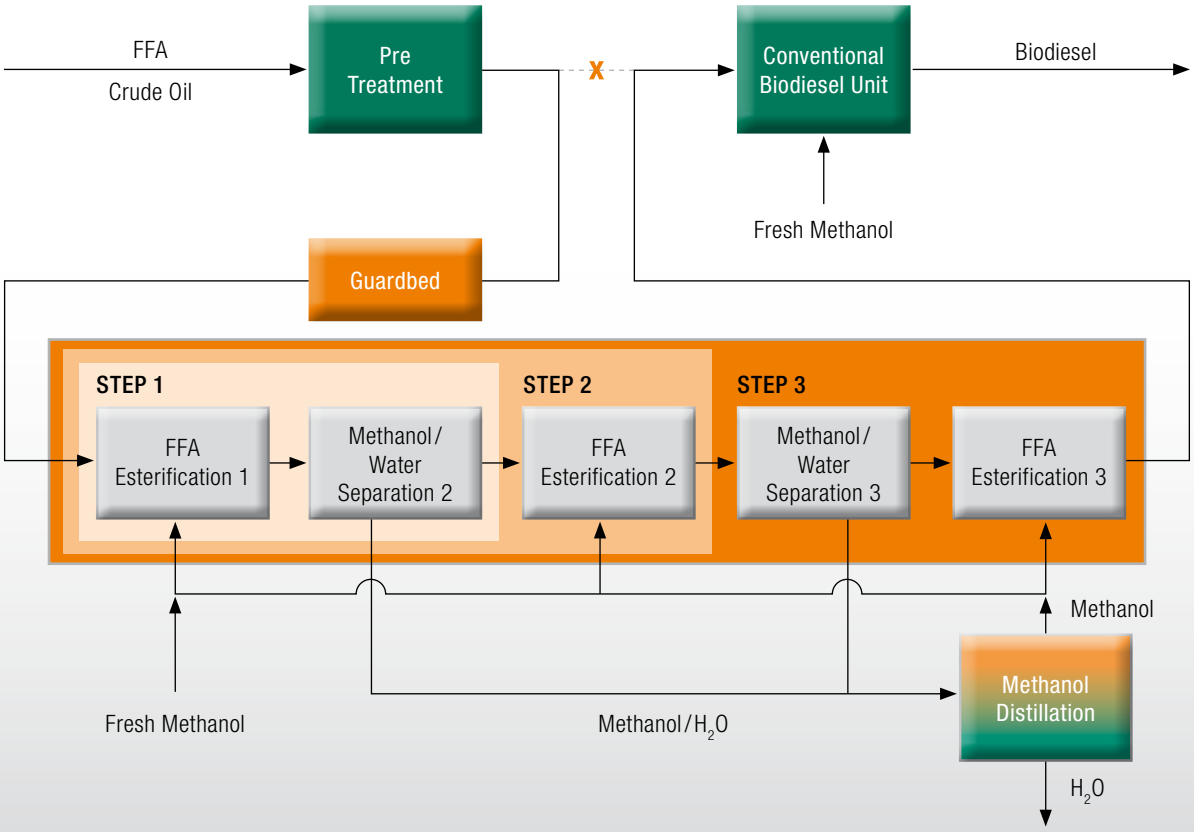
Dow AMBERLYST™ BD20 catalyst

FAME matches DIN EU standard but not AGQM specification



configuration will be suitable for feedstocks with moderate FFA content ranging between 10 – 20 wt% FFA or equivalent mixtures of high FFA feed with vegetable oils and fats. If a third reaction stage is employed, feedstocks with FFA concentrations up to 100 wt% can be directly esterified. In case of feedstocks with varying FFA content the process design will be determined by the maximum expected FFA content, which will be also suitable for lower FFA concentrations.

Schematic Block Diagram of Esterification Process BayFAME®



The Integration

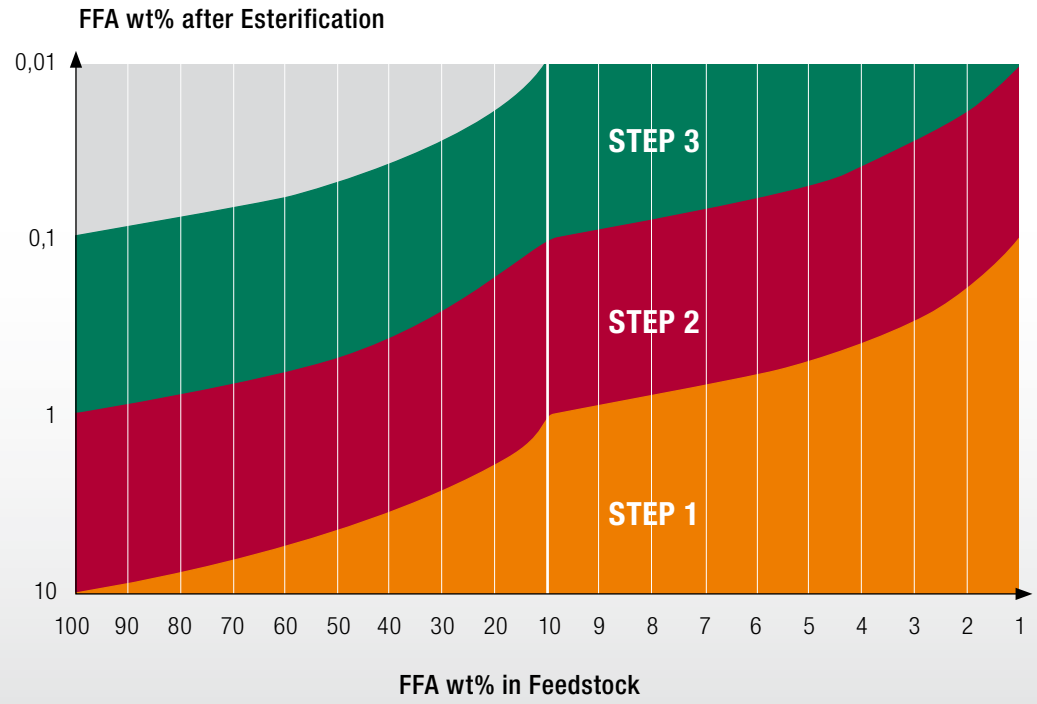
The FFA esterification process can be easily tied-in between the oil pretreatment and the transesterification units of a conventional biodiesel process. The pretreated oil will be directly fed together with dry methanol into the first esterification reactor stage. After the last reaction stage the FFA initially contained in the feedstock will be converted to FAME and the resulting product stream can be further processed in a conventional transesterification unit to convert the triglycerides into FAME as well. The esterification

product stream will additionally contain the excess methanol from the last reaction stage, which will not be removed in order to minimize energy consumption and will therefore reduce the methanol requirement of the transesterification unit.

With an installation of the FFA esterification process the severity of the oil pretreatment can be reduced in cases where currently low FFA concentrations are removed as soap stock. The yield loss that is so far caused by the soap stock purge will be converted into the final biodiesel product with the help of the esterification process and thus result in a considerable increase of the overall product yield. In case the existing conventional biodiesel process already comprises a methanol distillation column with spare capacity this offers a potential to reduce the investment for the esterification process by implementing an integrated methanol recycle for the entire biodiesel unit. The esterification process will need similar feedstock purities like a conventional transesterification processes, which are usually achieved by a state-of-the-art biodiesel pretreatment unit (degumming and/or bleaching). However, to sustain a high lifetime of the esterification catalyst the reactors should be protected from impurities such as ionic species and components that are potential sources of fouling. This will be ensured by an ion exchanger (AMBERSEP™ BD19 resin) guard bed that captures these impurities and therefore protects the active catalyst. For biodiesel plants that do not yet include a feedstock pretreatment unit, Bayer Technology Services can offer support in selecting the most cost effective pretreatment strategy and integrating this into the esterification unit.

Which Configuration is required?

How many steps are required to reduce FFA in feed to reach a certain FFA content in transesterification, or in case of 100 wt% FFA, in final FAME quality?



Figures valid for 90 % conversion rate. Has to be validated individually for each single application.

OUR SOLUTIONS AND YOUR BENEFITS

Our Product Portfolio

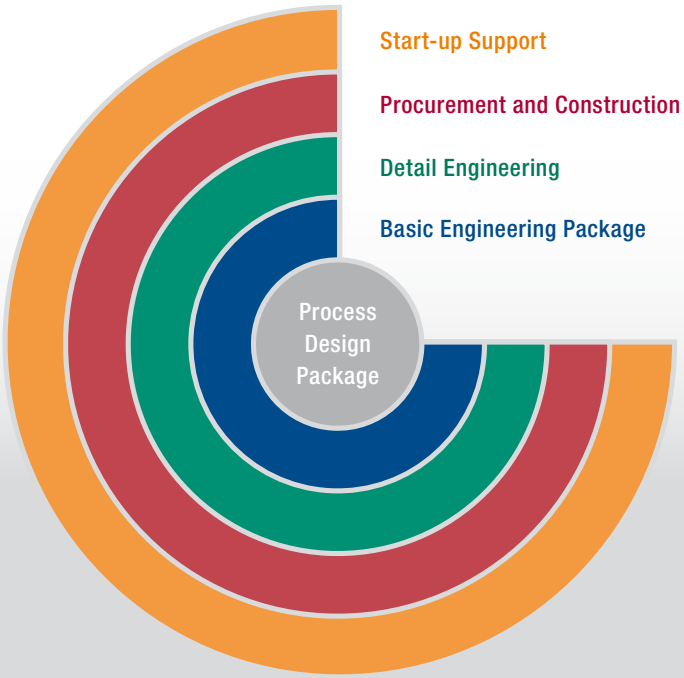
Our FFA-esterification process BayFAME® was developed in close cooperation with Dow. While each customer of AMBERLYST™ BD20 catalyst will already receive our Process Design Package BayFAME® with the purchase of the catalyst, Bayer Technology Services can offer even more valuable services on the way to a modern FFA-esterification plant.

We can provide our customers with

- a Basic Engineering package tailored to a specific Biodiesel process and infrastructure,
- a complete detailed design package for an individual plant, and also with
- a complete installation including procurement, construction and start-up.

In either case we can also help to integrate the esterification unit into an existing plant concept, in particular with regard to the methanol processing and process control systems.

Our Product Portfolio

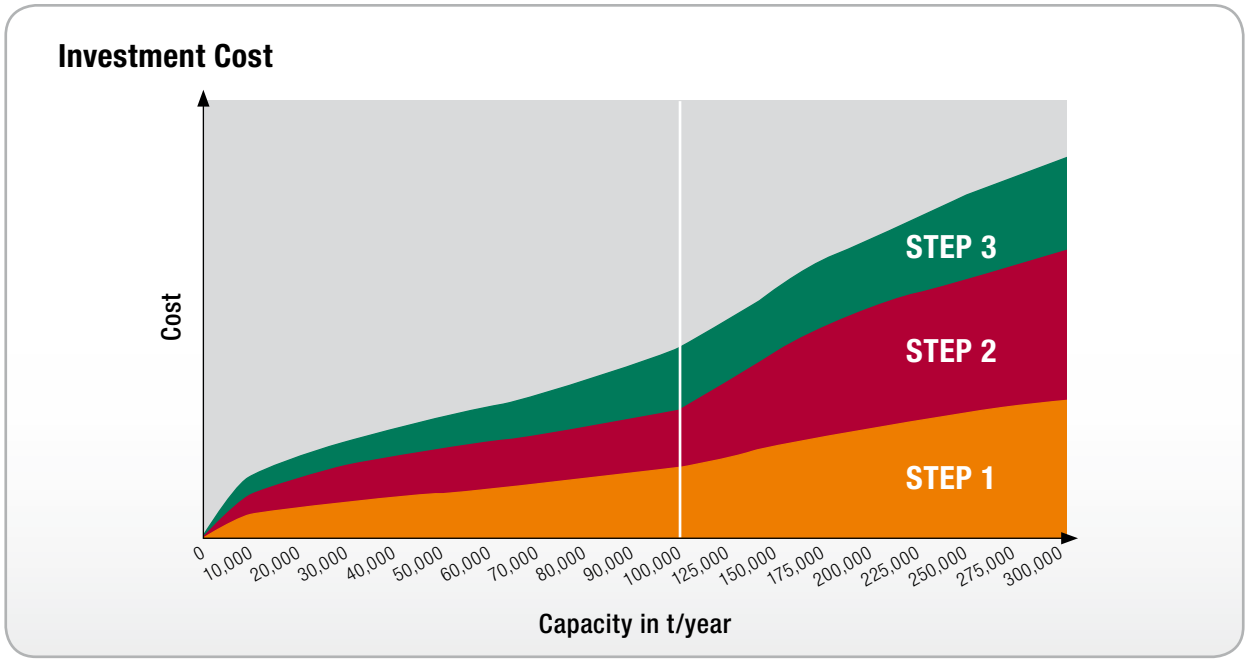


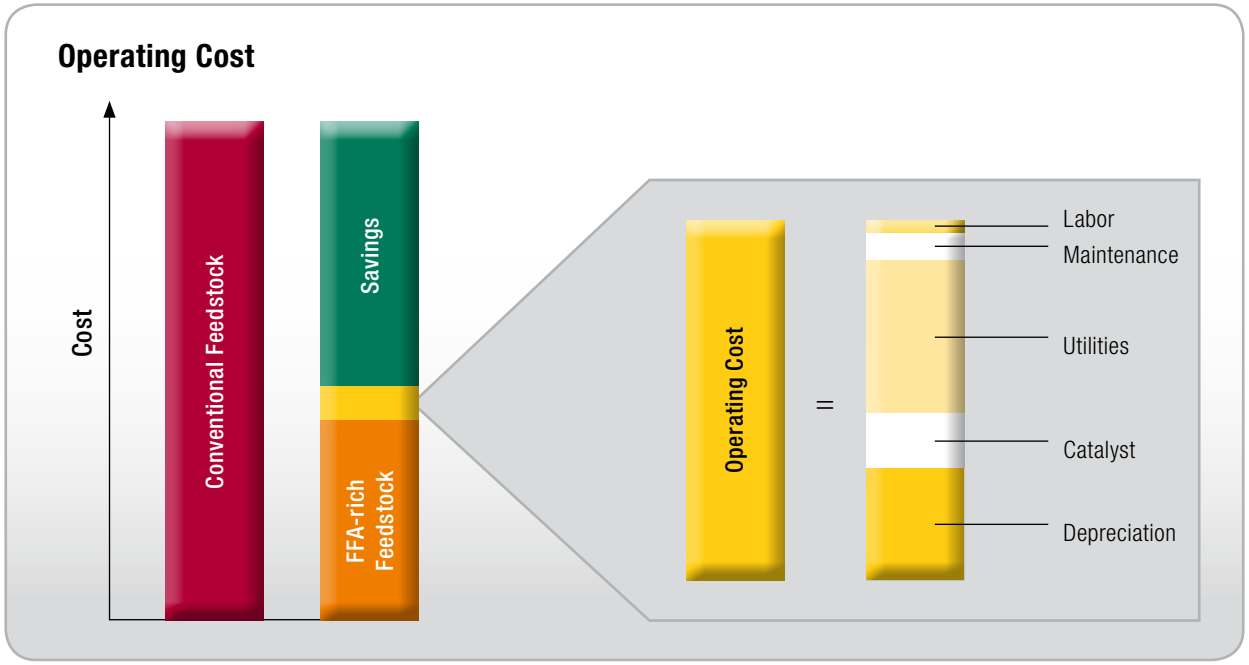
Costs and Savings

The capital investment costs for the esterification process vary depending on your requirements with regard to feedstock, overall capacity, biodiesel process and flexibility. Costs for a typical installation of a 2-step configuration with methanol processing will range from € 3.5 mln to € 4.5 mln for 100,000 t/year or € 1.5 mln to € 2.0 mln for 20,000 t/year, but will be depending on local conditions as available infrastructure and buildings, local standards and codes, labor market etc.

Typical components of the operating costs are depreciation, catalyst, utilities (steam, electricity and cooling water), maintenance and labor, though most likely the additional esterification unit can be easily run by the personnel already working on site.

Overall the savings using an FFA rich feedstock with the Bayer Technology Services esterification technology BayFAME® are significant compared to conventional feedstocks like rapeseed or soybean oil. Typically, a price difference of about 40 €/t pays off for the costs of depreciation and operation.





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