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# Risk advantages of platform technologies for biorenewable chemical production

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ABSTRACT

Recent investments in bio-based chemical development are financing the construction of commercial production facilities, often designed to produce a single biorenewable chemical. Investments in technologies targeting a single biorenewable chemical are subject to significant technological and market risks. Platform technologies that can convert biomass into a range of related biorenewable chemicals can reduce these risks significantly. Researchers are now developing platform technologies that combine bio-and chemical-catalysis, such as a process of converting glucose into fatty alcohols of specific carbon chain length. The financial risk and profitability of investments in platform technology producing fatty alcohol of different chain length were analyzed. A techno-economic model to evaluate single- and platform technologies was developed. A platform technology that can produce two products: 1-decanol and a blend of dodecanol and 1-tetradecanol reduces financial risk of investment by 23% and increases profitability by 55% compared to production via single-product technologies. This financial advantage of two-product technology is eliminated as the cost of switching between products rises above $4 MM for a 14 MT/yr plant. Investments in technologies that can produce a larger number of products provide higher returns lower risk. Other less quantifiable risk advantages of platform technologies that nonetheless important are also discussed.


## 1. Introduction

Most industrial chemicals used as materials, plastics, surfactants and solvents are currently derived from petroleum feedstock. Depletion of non-renewable petroleum feedstocks and environmental considerations have been drastically changing the prospects for renewable biomass as a raw material for industrial chemicals (Brehmer et al., 2009). In order to transform the petroleum-based chemical industry to a bio-based chemical industry, a substantial amount of research is ongoing throughout the world targeting one biorenewable chemical at a time. For example, Burk et al. (2011) describe a biological process for converting sugars into 1,4-butanediol; bio-isoprene can be synthesized by genetically modifying microbial cells to overexpress levels of an isoprene synthase polypeptide and a mevalonate kinase polypeptide (Beck et al., 2010); and biobased chemical company Rennovia, Inc. is commercializing a catalytic process for the production of adipic acid from carbohydrates (Boussie et al., 2014).

Unfortunately, this approach of developing single-product technologies is slow and costly, as it requires all the investment in time and money for one chemical product. Moreover, investing capital for producing biorenewable chemicals via technologies that yield a single-product magnifies a variety of the technological and market risks that characterize the highly competitive chemicals industry. Volatility in prices of feedstock, energy, and the market demand for chemicals are just a few of the sources of market and financial risk of

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investment in the biorenewable chemical business (Curtis, 2010). Since biorenewable chemicals can either structurally or functionally replace existing petrochemicals, renewable chemicals compete for market share with existing petrochemical products. Thus, there is a risk of reduction in market price as supply is increased by new market entry and a risk of aggressive price reduction by incumbent petrochemical companies, whose capital investments are already partially or fully depreciated. During the scale-up of pioneer renewable chemical technologies, there is risk of process failure due to technical barriers, characterized as technology risks (Edwards and Eng, 2015). Furthermore, lack of economies-of-scale may create a barrier to market entry for low profit margin biorenewable chemicals synthesized via single-product technologies.

The various risks to the investments in the biorenewable chemical business may be reduced by producing biorenewable chemicals via platform technologies. We define a technology as a platform technology when it meets following criteria: (1) it enables the synthesis of multiple chemicals; (2) the technological investments made in the synthesis of each chemical are at least partially used in the research and development of one or more other chemicals; (3) the production of each chemical in the platform uses at least 60% of the same plant equipment as the other products in the platform—in other words, it should enable the plant to make multiple chemicals by slightly modifying existing production equipment; and, (4) the products made using the chemicals platform can be sold in different market segments. The platform concept fits into one class of biorefinery identified by Sadhukhan et al. (2014) in which a portfolio of products are derived from a single biomass feedstock using flexible conversion processes. Thus, the development of platform technologies can expedite the development of a biorefinery that operates similarly to an oil refinery.

The recent development of a reverse β-oxidation pathway in *Escherichia coli* as reported by Cintolesi et al. (2014), for example, facilitates the synthesis of a range of di-carboxylic acids with varying carbon chain length from glucose. This technology is considered a platform technology for the following reasons: Of these di-carboxylic acids, medium chain di-acids such as adipic acid can address the needs of the nylon industry (Taylor et al., 2015), and the long chain di-acids such as octadecanedioic acid have applications in polyamide, polyurethanes, lubricants and adhesive industries (Greenwood, 2013). Since the mechanism with which the reverse β-oxidation pathway in *E. coli* that makes medium and long chain di-acids is similar, the technological advancements made in the development of bio-catalytic technology to synthesize medium chain di-acids are applicable to the synthesis of long chain di-acids. Although separation and purification processes are somewhat different for medium and long-chain di-acids, the production of these di-acids will utilize a substantial portion of the same equipment including the seed and product fermentors.

Platform technologies for biorenewable chemical production can be developed using purely biological, purely chemical, integration of biological and chemical processes, or thermochemical processes. The above mentioned reverse β-oxidation pathway in *E. coli* to synthesize various di-acids is considered as an example of a purely biological method. Similarly, synthesis gas from the thermochemical conversion of biomass can be used to synthesize a range of products, including paraffins and olefins using the Fisher–Tropsch process (Ng and Sadhukhan, 2011) and methanol using Cu/Zn/Al catalyst (Hamelinck and Faaij, 2002).

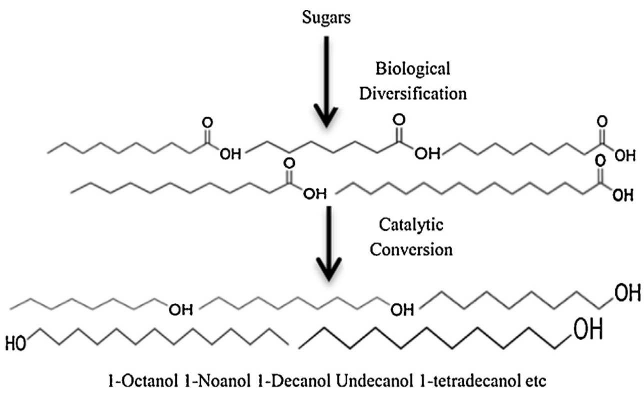


**Fig. 1 – The carboxylic acid platform technology: synthesis of wide array of fatty alcohols by coupling of biological and chemical catalysis (single column).**

One example of a purely chemical approach is the oxidation of glucose over a platinum catalyst which yields glucaric acid (Boussie et al., 2010). This glucaric acid subsequently undergoes selective dehydration to lactones or selective esterification to polyglucaric esters (Werpy et al., 2004). Another example is the catalytic dehydration of fructose to 5-hydroxymethylfurfural (Pagán-Torres et al., 2012), which can be further transformed catalytically into various bio-fuels and bulk chemicals (Boisen et al., 2009). As an example of an integrated approach, triacetic acid lactone is produced biologically from sugars through overexpression of 2-pyrone synthase in Saccharomyces cerevisiae (Cardenas and Da Silva, 2014) and this biological intermediate is catalytically upgraded to sorbic acid, hexenoic acid, and γ-caprolactone (Chia et al., 2012).

The concept of a platform technology is somewhat related to, but different from platform chemicals, as described by Werpy et al. (2004), who identified the most promising building block chemicals that can be derived from biomass. Among the building block chemicals identified by Werpy et al. (2004), most of chemicals can be produced via microbial technology, and subsequently upgraded to yield a diverse portfolio of biorenewable chemicals using a chemical catalyst (Shanks, 2007).

The NSF engineering research Center for Biorenewable Chemicals (CBiRC) is currently developing three platform technologies by integrating bio- and chemical-catalysis (The Center for Bio Renewable Chemicals, 2008). One of these three technologies is the carboxylic acid platform technology (Liu and Jarboe, 2012). In this platform, microbial strains such as *E. coli* are engineered to synthesize various carbon chain lengths of fatty acids from glucose via the fatty acid biosynthesis pathway (Zhang et al., 2011), and these fatty acids are subsequently upgraded to yield fatty alcohols of different carbon chain length using a chemical catalyst (Gervajio, 2012) (Fig. 1). The medium- and long-chain fatty alcohols are used in perfume, fragrances, cosmetics, pharmaceutical, and surfactant and lubricant industries (Noweck and Grafahrend, 2006).

In this paper we analyze and compare the risks of investment in technologies for producing fatty alcohols of different chain length via both single-product and platform technologies. We quantitatively analyze financial risk and the profitability of investment, and qualitatively evaluate other risks of investments in developing single and platform technologies. Financial risk is quantified by assuming all the risk due to variation in prices is captured in the standard deviation