INTRODUCTION TO PRIMUS' STG+™ TECHNOLOGY

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Synthetic Gasoline Process Overview

The production of gasoline, diesel fuel, kerosene and other light distillates from coal and other non-petroleum sources has been practiced on an industrial scale since World War II. The basic process involves gasifying coal or other carbon source (petroleum coke, biomass) to produce a so-called syngas consisting primarily of carbon monoxide (CO) and hydrogen (H_2). The syngas is first cleaned to remove impurities and then is converted to liquids using one of a number of catalytic processes. The most commercially successful of these processes is Fischer-Tropsch (FT), which was used extensively in Germany in the 1940s and continues to be used on a large scale by Sasol in South Africa for the production of liquid fuels from coal. While FT is commercially well proven, the process is not very selective and produces a wide variety of crude products ranging from light alkanes to waxes which must be extensively refined to produce marketable products. FT plants, therefore, tend to be very large and expensive as they must deal with a large number of products of varying quality.

Methanol was first commercially produced from syngas (typically produced from reforming of natural gas) starting in the 1920s under patents first granted to BASF. The basic catalytic processes described in the early patents are still in use today, but have been substantially improved upon. Modern methanol synthesis plants can achieve conversion efficiencies from syngas in the high 90 percent range and are available from a variety of vendors (Lurgi, Linde, Johnson Matthey [Davey], Casale and others). Methanol is a basic commodity chemical that is used in a wide variety of products and as an intermediate chemical. Global methanol demand today is approximately 50 million metric tons per year, most of which is produced from syngas made from natural gas reforming.

In the 1970s, Mobil Research (now part of Exxon Mobil) developed a process for converting methanol to gasoline (MTG). A 1,500 metric ton per day MTG plant was constructed in New Zealand using the Mobil MTG process in combination with a Davey methanol synthesis plant. The Mobil process proved to be highly selective for gasoline production with nearly complete conversion of the methanol and good overall energy efficiency. Unlike the FT process, the Mobil MTG process yielded high quality gasoline that required little additional processing.

Primus' proprietary STG+™ process in essence combines and improves upon prior commercially proven methanol synthesis and MTG processes. STG+™ technology is a single-loop process that converts natural gas feedstock directly to gasoline and is more efficient, less expensive to build and more scalable than other existing technologies for converting natural gas to gasoline. Instead of the gasoline product, the STG+™ process can also produce methanol, diluent and other high-value chemicals by simply changing catalysts, reactors and/or operating conditions.

Primus' STG+™ technology: How it works?

The Primus STG+™ technology converts natural gas feedstock to liquid fuels through a proprietary catalytic thermochemical process that minimizes complexity, improves product quality and increases yield. The Primus STG+™ technology converts ~70% of natural gas by mass to liquid fuels, which is the highest documented conversion efficiency in the industry. The "plus" in STG+™ stands for the alternate end products yielded by the process. The figure below is an example of a schematic diagram of the Primus Gas-to-Gasoline process.

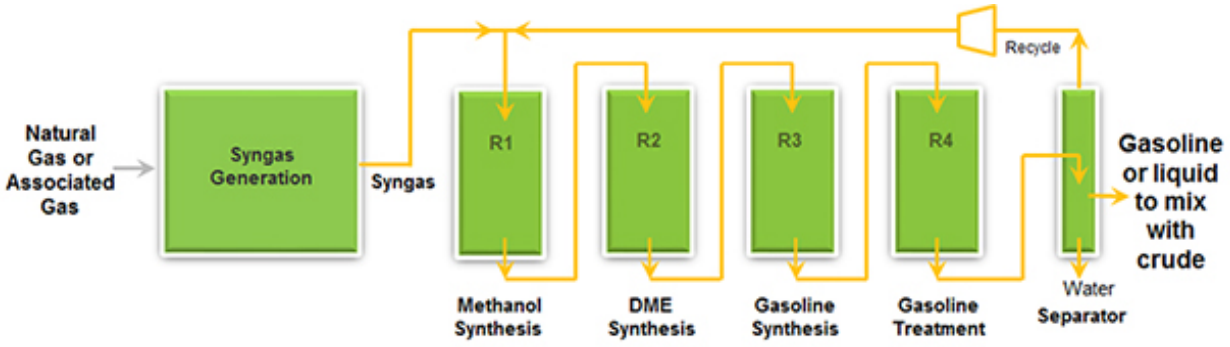

Figure 1: Schematic diagram of the Primus STG+™ Gas-to-Gasoline system.

The Primus STG+™ process includes the following principal steps in one continuous process loop. This process is comprised of steam methane reforming for syngas generation and four fixed bed reactors in series in which syngas is converted to a high quality synthetic gasoline.

Steam Methane Reforming – Natural gas or other hydrocarbon feed gas reacts with steam at a high temperature and pressure to produce syngas (CO and H_2).

Reactor 1 (*Methanol Synthesis*): Syngas is fed to Reactor 1, which converts most of the syngas (CO and H_2) to methanol (CH_3OH) when passing through the catalyst bed.

Reactor 2 (*Dimethyl Ether Synthesis*) - The methanol-rich gas from Reactor 1 is next fed to Reactor 2. The methanol is catalytically converted to dimethyl ether (DME), which involves methanol dehydration to form DME (CH_3OCH_3).

Reactor 3 (*Gasoline Synthesis*): The Reactor 2 product gas is next fed to Reactor 3, containing the catalyst for conversion of DME to hydrocarbons including paraffins (alkanes), aromatics, naphthenes (cycloalkanes) and small amounts of olefins (alkenes), mostly from C6 (number of carbon atoms in the hydrocarbon molecule) to C10.

Reactor 4 (*Gasoline Treatment*): Reactor 4 provides transalkylation and hydrogenation treatment to the products coming from Reactor 3. The treatment reduces durene (tetramethylbenzene)/isodurene and trimethylbenzene (TMB) components that have high freezing points and must be minimized in gasoline. As a result, the synthetic gasoline product has high octane and desirable viscometric properties.

Separator: Finally, the mixture from Reactor 4 is condensed to obtain gasoline. The non-condensed gas and gasoline are separated in a conventional condenser/separator, which is the far right element in Figure 1. Most of the non-condensed gas from the product separator becomes recycle gas and is sent back to the feed stream to Reactor 1, leaving the synthetic gasoline product comprised of paraffins, aromatics and naphthenes. The water is recycled back to the Steam Methane Reformer.

Syngas is produced by several commercially available technologies from a wide variety of feedstocks (e.g. natural gas, coal, biomass, and municipal solid waste [MSW]). Primus can also use syngas directly fed into the system and skip the reformer phase.

Primus' STG+™: Advantages

Primus' STG+™ technology has several advantages over other Gas-to-Liquids (GTL) technologies, including: higher yield, lower capital and operating costs, reduced process complexity, higher product quality and faster delivery times. In addition, Primus' STG+™ technology can use flexible feedstocks in any plant offered. Primus offers three different plants, one that produces gasoline, one that produces diluent, and one that produces methanol.

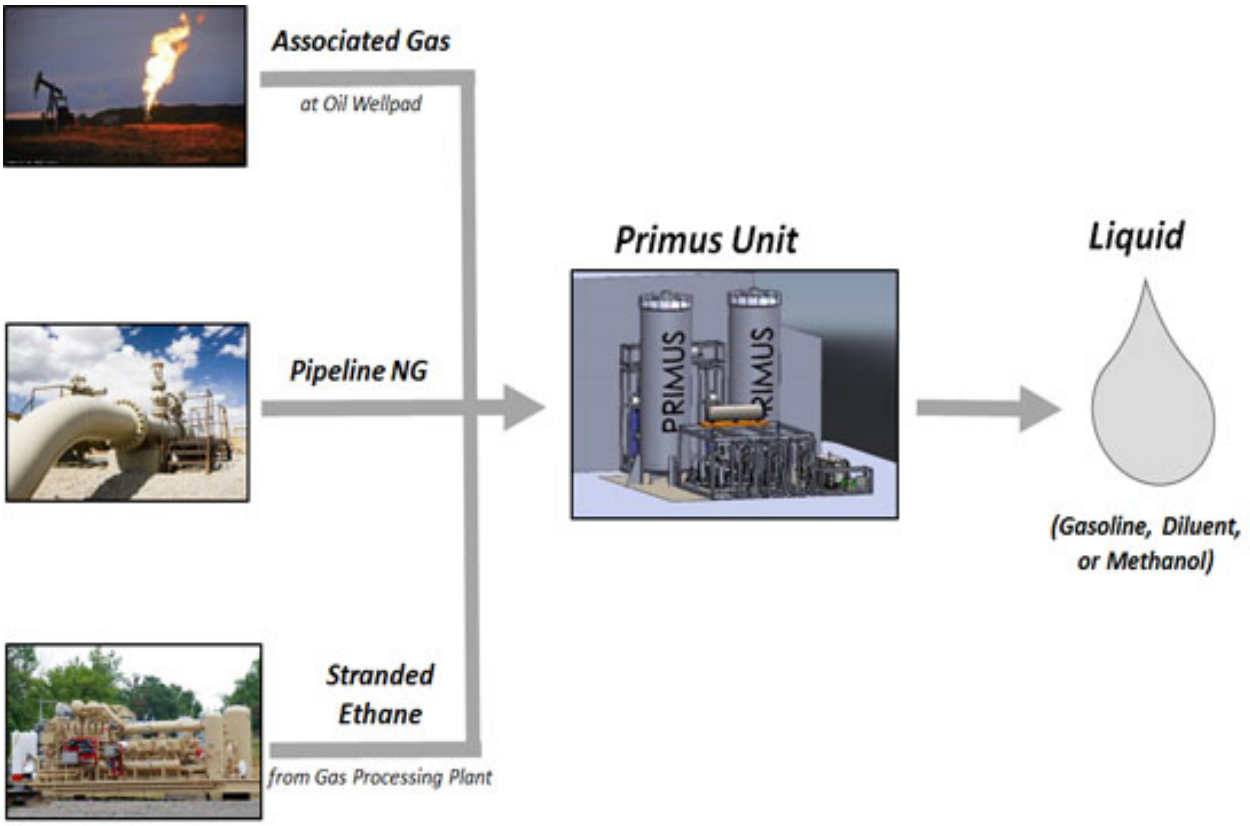

Figure 2: Primus STG+™ technology's flexibility with feedstocks and products.