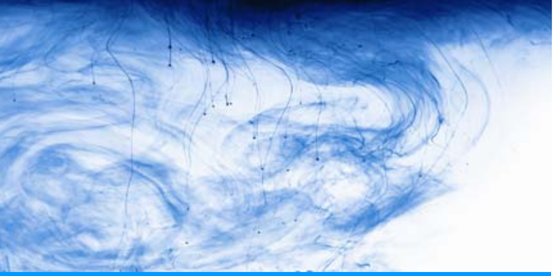

CHEMSYSTEMS
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Report Abstract

Benefits of Refinery/Petrochemical Integration
PERP06/07S7

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INTRODUCTION

In today's environment a fully integrated refining and petrochemicals complex (i.e., having access to downstream chemicals "value chain") provides feedstock synergy and flexibility to optimize products to capture the highest market value, thus, helping to maximize overall profitability. However, integration between plants is not an "off-the-shelf" design and this report is not intended to provide a general, optimized integration scheme, but to provide insights into what integration can save/do for a petrochemical plant or refinery.

Standalone petrochemical economics capture the benefits of pricing feedstocks and by-products at refinery values, but do not reflect all of the potentially significant savings that can be gained from refinery/petrochemical plant integration. Additional cost savings from integration can be attributed to lower outside battery limits (OSBL) costs, in some special cases savings in inside battery limits (ISBL) investment, savings in working capital requirements, and staff reductions in non-operating departments.

Integration Discussion and Analysis (Section 2) - presents a general discussion of refinery and petrochemical plant integration synergies followed by several examples.

Economic Analysis (Section 3) - of the examples discussed in Section 2. Specific examples include:

- An ethylene facility integrated with an upstream refinery including a case employing cat cracker offgas (CCOG).
- An aromatics facility (as represented by the product *para*-xylene, PX) integrated with an upstream refinery.
- An ethylene facility integrated with a downstream ethylene glycol (MEG) unit.
- Both an ethylene facility and a refinery integrated with a downstream styrene monomer (SM) unit.
- A terephthalic acid (PTA) unit integrated with an upstream aromatics facility.
- A polyethylene terephthalate (PET) unit integrated with an upstream PTA facility and/or MEG facilities.

Commercial Analysis (Section 4) - presents examples of companies that have employed a high degree of integration between their refining and petrochemical facilities (one each in the United States (ExxonMobil), Europe (Total), and Asia (Reliance).

INTEGRATION DISCUSSION AND ANALYSIS

Savings that can be made on capital investment, operating costs (working capital inventory carrying charges, energy conservation, maintenance planning and execution costs, administrative costs) and in other areas (e.g., joint fire fighting, medical services) are briefly outlined.

Eliminating Steps and/or Close-Coupling Units

It is possible through integration to eliminate processing steps and reduce the ISBL investment significantly. A few examples of such close-coupling are presented in the report including:

- producing styrene from dilute refinery ethylene
- recovering ethylene from cat cracker offgas (CCOG)
- producing olefins from methanol
- producing polyester terephthalate (PET) from so-called medium quality terephthalic acid

Refinery – Petrochemical Interface

Integration of existing refinery operations with petrochemical production has proven to be a workable and mutually beneficial solution of finding ways to add value without compromising operations by refiners and petrochemical producers. Industry developments demonstrate the growing importance of integration. Integration with a refinery is a key feature of several of the largest ethylene plants now under development. It enhances the cost competitiveness of new plants and is a prerequisite for any new facility based on naphtha and heavier feedstocks. There are major savings to be achieved in refinery/petrochemical integration, including significant savings in transportation and terminaling, utilities, management, and other expenses. In addition, considerable flexibility is derived through feedstock optimization, which allows balancing due to the seasonality of refining with the feedstock requirements of the petrochemical industry.

Refineries produce a number of streams which can be used directly as petrochemical feedstocks. The nature and quantity of material available depends on crude type; refinery configuration and complexity; and other operating variables, such as value added in alternative refinery use, as shown in the table below.

Refineries Streams Used for Petrochemicals

Refinery Stream	Petrochemicals	Alternative Use for Refinery Stream
FCC offgas (CCOG)	Ethylene, MEG	Fuel gas
FCC olefins	Propylene, butylenes	Alkylation/polygasoline
Reformate	Benzene, toluene, xylenes (BTX)	Gasoline blending
Naphtha	Olefins	Gasoline
Gas oil	Olefins	Diesel, jet kerosene, heating fuel
LPG	Olefins	Domestic heating/cooking fuel
FCC ethylene	Ethyl benzene (EB) / styrene (SM)	Fuel gas
FCC propylene	Cumene/phenol, polypropylene, isopropanol, oligomers	Alkylation/polygasoline
FCC butylenes	MEK, MTBE, secondary butanol	Alkylation/polygasoline
Kerosene	Normal paraffins	Jet fuel
FCC light cycle oil	Naphthalene	Diesel, heating/gas oil blendstock after hydrotreating

This topic is discussed further in the report. In this section the following examples of refinery/petrochemical integration are given:

- novel integration scheme between a refinery and steam cracker by Kellogg, Brown and Root LLC (KBR)
- possible integration of a steam cracker with an aromatics extraction unit by Ethylene Consultants
- products that can potentially be produced by each petrochemical block starting with a typical 200 thousand barrel per day (kBPD) refinery including a 40 kBPD reformer and a 50 kBPD FCC unit

Refinery/Olefins/Aromatics Synergies

Traditionally, refinery and ethylene plant stream exchanges have been built upon a few simple principles. Ethylene plants have a preference for paraffinic feeds (especially the light naphtha cut) versus naphthenic and aromatic feeds when production is targeted for maximum ethylene yields. Pyrolysis gasoline (pygas) from ethylene plants is a valuable supplement in the refinery gasoline pool, as well as feed to an aromatics facility.

The aromatics facility also has synergies with both the refinery and the ethylene plant. While light naphtha is the preferred feed for an ethylene plant, the heavy naphtha is preferred for reforming to produce gasoline within a refinery.

The topic is expanded upon in the report, including a brief outline of an aromatics facility's high integration with respect to the various operating units.

- Recovery of olefins from Refinery Streams (e.g., fluid catalytic cracker (FCC) offgas and delayed coker offgas streams) is discussed.

Steam cracker feedstocks and other feedstock streams, logistics, hydrogen aromatics and fuel systems integration are briefly outlined; as are ethylene and aromatics plant products.

Downstream Synergies

Developing value chains to include the market sectors helps to explore the full integration potential. An example of what can be done in terms of downstream integration is briefly discussed.

Other Opportunities for Integration

A GE CONCEPT based on integration between the upstream production facilities (i.e., gas plant) and the steam cracker (ethylene plant) are outlined.

ECONOMIC ANALYSIS

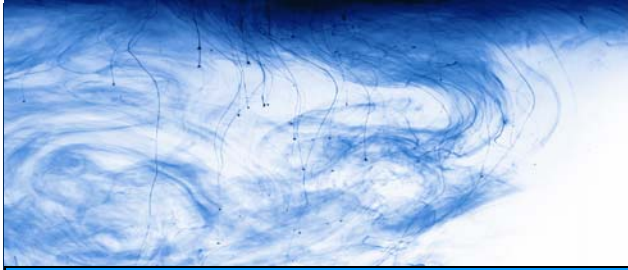
OSBL estimated savings due to integration have been calculated for ethylene, *para*-xylene, MEG, SM, PTA, and PET plants of specified capacity. Cost estimate curves for the investment associated with storage facilities, for a recirculating cooling water system, steam boiler, investment for various buildings are provided.

Cost of production estimates for the following have been carried out:

- Ethylene production via steam cracking of light naphtha for a stand-alone, refinery integrated and refinery integrated with CCOG facilities
- *para*-Xylene production for a stand-alone and a refinery integrated plant, respectively. The *para*-xylene is produced in an aromatics facility that includes naphtha hydrotreating, CCR reforming, *para*-xylene adsorption, isomerization (ethylbenzene dealkylation catalyst), and toluene disproportionation (TDP). The integrated case integrates the upstream refinery with the aromatics facility.
- Ethylene glycol (MEG) production for a stand-alone and integrated plant, respectively. The latter case integrates the upstream steam cracker with the ethylene glycol facility.
- Styrene monomer (SM) production stand-alone unit, an integrated unit with an upstream ethylene plant, and integrated unit with a refinery (i.e., using dilute ethylene from CCOG), respectively. The middle case integrates the upstream steam cracker and aromatics facility with the ethylbenzene and styrene facilities.
- Terephthalic acid (PTA) production for a stand-alone and integrated plant, respectively. The PTA is produced via conventional oxidation/hydrogenation process. The integrated case integrates the upstream *para*-xylene production facilities with the PTA facility.
- PET production for five cases:
    1. A PET stand-alone case
    2. PET integrated upstream with PTA
    3. PET integrated upstream with MEG
    4. PET integrated upstream with both PTA and MEG
    5. PET integrated upstream with both PTA and MEG, both of which are further integrated upstream with an aromatics facility and ethylene facility, respectively.

COMMERCIAL ANALYSIS

Many refineries have already taken advantage of petrochemical integration opportunities to add value to their existing operations. While the degree of integration between refineries in each region varies, a number of refineries have become highly integrated with petrochemicals production. As part of the commercial analysis for this report, Nexant *ChemSystems* has focused on three companies that have employed a high degree of integration between their refining and petrochemical facilities, one each in the United States (ExxonMobil), Europe (Total) and Asia (Reliance).



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