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METRICS FOR EVALUATING ETHYLENE PRODUCTION USING OXIDATIVE DEHYDROGENATION

Dr. Anne Gaffney[*1], Aaron Beinstein, B.S. [2], Amanda Peterman, M.S. [3], Dr. Gennaro Maffia[4]
[*] Idaho International Laboratory, USA

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ABSTRACT

An economic and environmental approach for analyzing the potential of a new chemical processing technology for multiple grades of ethylene is described. In order to optimize the design and implementation of a new process, a set of performance metrics were identified and calculated for ethylene production. These performance metrics could be used by the chemical industry to analyze the potential of new technologies. Economic evaluations are based on the Cost of Production in relation to current market pricing, spot or contract. The Cost of Production is calculated from the Required Netback and is a methodology practiced in industry to define instantaneous production economics. The Required Netback represents the sum of the variable costs, fixed costs and capital recovery of production; all of which is expressed as US dollars per kilogram of the main product: ethylene. This is then compared to current pricing; if the Required Netback is less than the market price then the technology will have favorable economics. This approach also includes current steam pyrolysis technology as a baseline for evaluating the promise of a novel technology. In the case of ethylene via oxidative dehydrogenation, the improvement in Cost of Production comes from a drastic reduction in capital cost and energy requirements. In this current analysis, Oxidative Dehydrogenation of Ethane is compared with Conventional Steam Pyrolysis and is shown to be superior in all of the performance metrics. The expected Cost of Production for polymer grade ethylene is $0.25 per pound.

KEYWORDS: Ethylene, Cost of Production, Oxidative Dehydrogenation, Production Economics, Energy Sustainability

1. INTRODUCTION

Currently the Chemical Processing Industry (CPI) in the United States is undergoing a transformation due to the availability of low-cost feedstock such as ethane contained in natural gas [1]. New chemical processing technologies are being considered throughout the CPI. The United States Department of Commerce has developed *Manufacturing USA*®, a National Network for Manufacturing Innovation (NNMI) that is dedicated to bringing manufacturing back to the US with the focus on investing in the research, development, and demonstration of lower cost, cleaner, and more energy efficient technologies [2]. This will also lead to federal investments for the training of a workforce qualified in this new CPI.

With the availability of low-cost feedstock and in response to an expected 25-50% increase in ethylene demand, over 11 new ethane crackers are currently under construction in the United States by both domestic and foreign producers. The production of some of the expected facilities are shown in Figure 1 [3].

Historically, liquid crackers have had strong margins due to the low price of fuel based feedstock and the abundance of high valued by-products, however the high capital cost caused by the high hydraulic loading reduced the margins and the rate of returns.

Generating the Metrics

Metrics can be generated from components of the Required Netback (RNB), posited in per mass unit of the ethylene product, and can be used to assess advantages of new technology versus conventional processing. The metrics generated are divided into several categories: process economics, energy productivity, process intensification, and environmental impact. These industry metrics are applied to new technologies and are used to decide investments.

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With the availability of low cost shale based ethane, the recent past and projected future margins for ethane cracking will be substantial and skew production strategies towards gas cracking. With the possibility of C2-ODH, all of the cost components are greatly reduced as well as the capital expense.

2. MATERIALS AND METHODS

Process Economics

Cost of Production (COP) is an economic model used to analyze the start-up of new and conventional technologies. Figure 2 is a flowchart illustrating the dependency of economic variables needed to calculate margins of production. COP has three separate components: variable costs, fixed costs, and capital recovery. The margin for ethylene pricing is defined as the difference between market price and the cash cost (sum of Fixed and Variable Costs). Positive margins are favorable for new technology and result in significant returns on investment.

Cash costs, fixed and variable costs, and capital recovery, capital expenses for a chosen payback period, are summed to calculate the required realizations. The required realization is used to calculate the selling price needed to achieve for a chosen rate of return (ROR). Approximately 1.5% of the required realization calculated is added back to the required realization, accounting for selling, general, and administrative (SG&A) expenses to get an RNB. RNB is a common metric used to evaluate the potential margins for investing in a new plant or technology; it is the selling price needed to cover capital investments, operating expenses, raw materials, etc. for a chosen payback period. RNB incorporates a "hurdle rate" to the required realization giving the price per kg of product. Spot price, the current selling price of any product, is compared to a calculated RNB to understand economic impacts. If the RNB of a new technology is lower than the market price, then the technology shows economic promise. Further comparison can be done to compare state-of-the-art technologies' COP to the new technology to see if shutdown economics are reached. Shutdown economics refer to a new technology that has lower RNB than conventional technologies' cash costs. The 10-year history of the spot price of ethylene is shown in Figure 3. Examples of margins of ethylene are shown in Figure 4.

Fixed costs are those incurred regardless of production rate. Fixed costs include labor, foreman, supervision, maintenance, plant overhead, direct overhead, and insurance. For instance, fixed costs due to labor is calculated by dividing the operating expenditure of labor per year by the production capacity. The plant capacity is needed to reference labor cost as cost per kg of product produced. The product of usage, shifts, and a rate is the capital expenditure of labor per year. The usage refers to number of engineers per shift. The rate refers to the salary of an engineer per annum. Foreman costs are typically to be 1/3 of the labor costs. Supervision costs are assumed to be 7.5% of the labor costs.

Variable costs are dependent on the production rates and are usually just raw materials and utilities. By-products are added as negative raw materials. Utilities are charged as the type of energy that is required. Consequently, utilities and raw materials are the main components of variable costs.

Capital recovery is defined as the capital cost divided by a capital factor that represents the return on investment. The greater the return on investment, the greater the capital recovery figure. The number of years for a capital investment to "break-even" is noted as a payback period before taxes. A relationship between the before tax payback period and the ROR, noted as the After Tax Return on Investment (ATROI), can be generated as outlined in Figure 5 with a basis of 15-year plant life. The payback period is given in years.

Energy Productivity

Metrics to evaluate the overall improvement of energy productivity in a chemical plant can be split into two sections: energy efficiency and energy availability. The metrics are used to evaluate the overall improvement of energy productivity in an ethylene plant, including the required furnace energy and the required compression energy. A goal of at least an order of magnitude improvement in energy productivity is an aggressive guideline for assessing promising new technologies.

The energy productivity metrics can be defined using capacity costs, operating costs, and capital recovery. Determining the energy productivity improvement of a new technology over conventional technologies is important to assessing the sustainability of process systems. Additionally, integrating new technologies into conventional plants as add-on units while maintaining plant energy levels as described by the energy availability can offer further reduction of capacity costs. The units of energy productivity have historically been defined as and energy amount, BTU or KJ, per mass of ethylene.

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Process Intensification

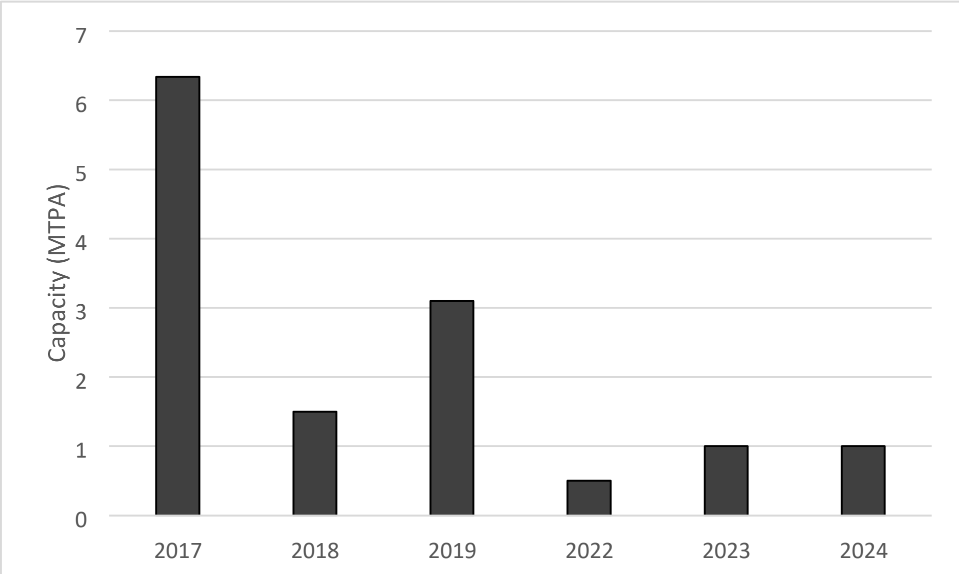
The number of sections in a plant is defined as process intensification. The ability to reduce the scope of the plant using C2-ODH and improve process intensification is illustrated in Figure 6 and shows the reduction in the number of unit operations.

Environmental Impact

Environmental metrics are based on the energy system and byproducts created by a technology. Carbon footprint is analyzed by looking at kg of carbon dioxide produced per kg of product. Reaction yields and combustion chemistry of required fuels are summed to find the overall carbon footprint.

For CSP, the carbon footprint is calculated by summing the carbon dioxide created from reaction yield and from the utilities for a gas cracker. The utilities are based on hydraulic loading which for a conventional ethylene plant the value is historically 6000 BTU per pound of ethylene produced. For safe operation of the C2-ODH process, operating conditions must remain outside of the explosive limits of C2-oxygen-water mixtures at elevated temperatures and pressures and below the Limiting Oxygen Concentration (LOC).

Figure 1:



Ethylene Production Capacity Planned per Year across Multiple Plants

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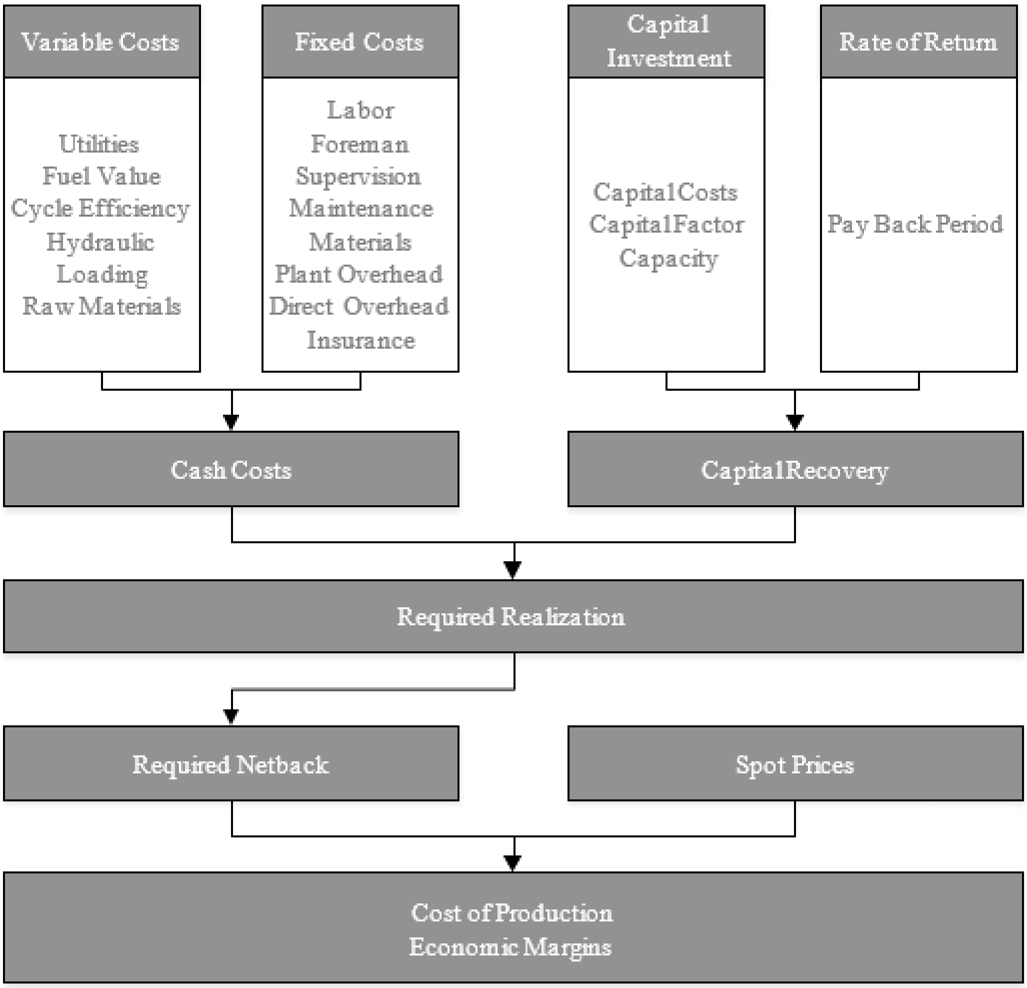
Figure 2:



Components of Cost of Production

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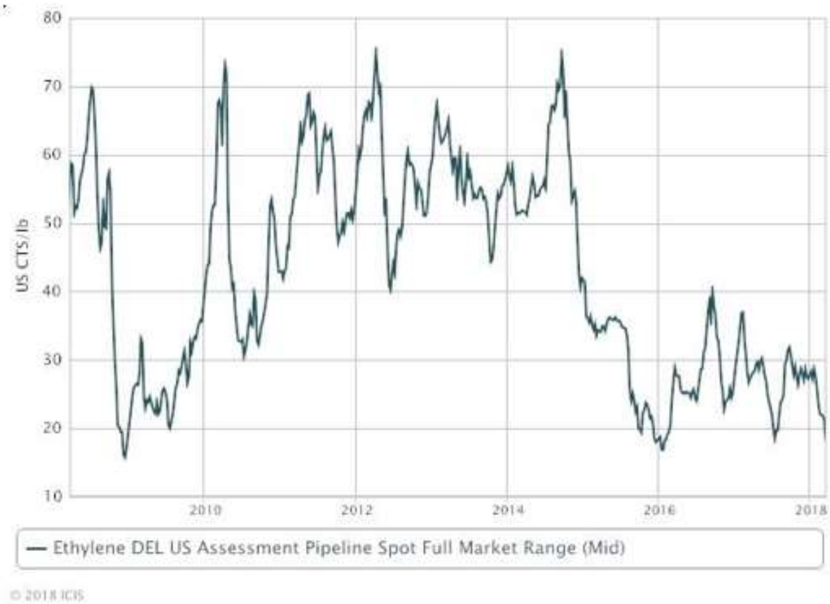
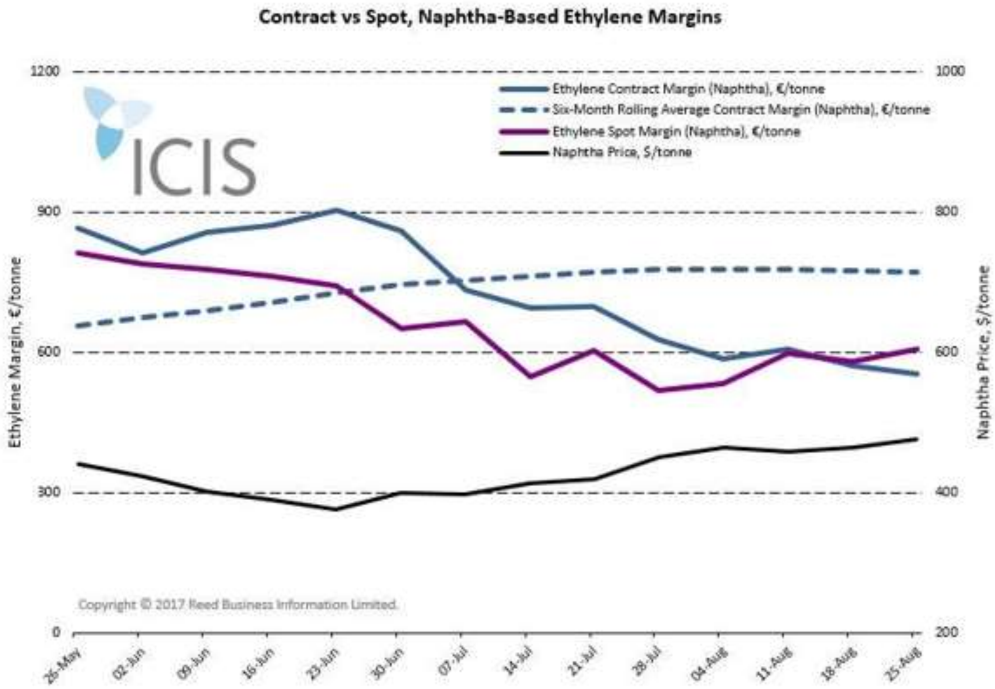
Figure 3:



10-Year Spot Pricing for Ethylene [4]

Figure 4:



Ethylene Margins in €/tonne of Ethylene [5]

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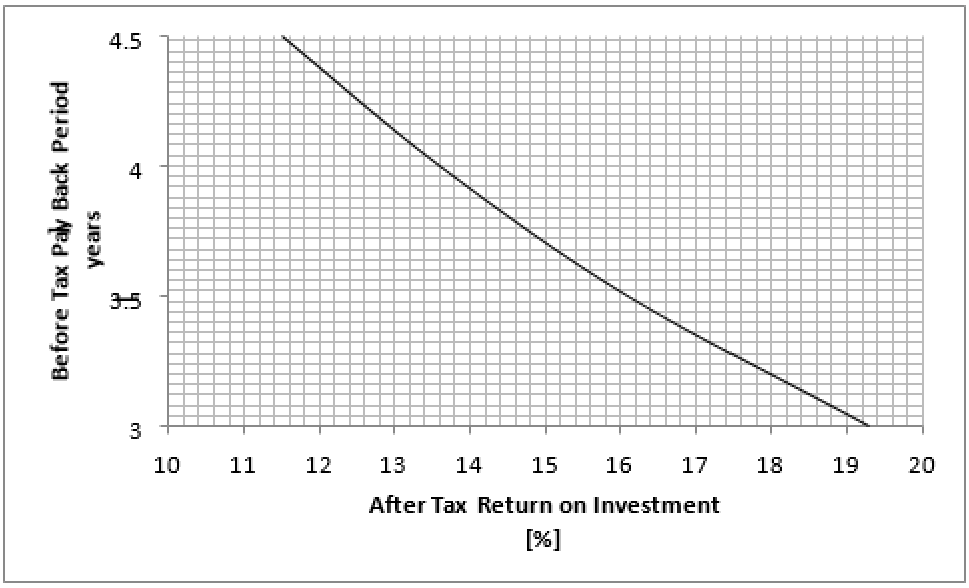
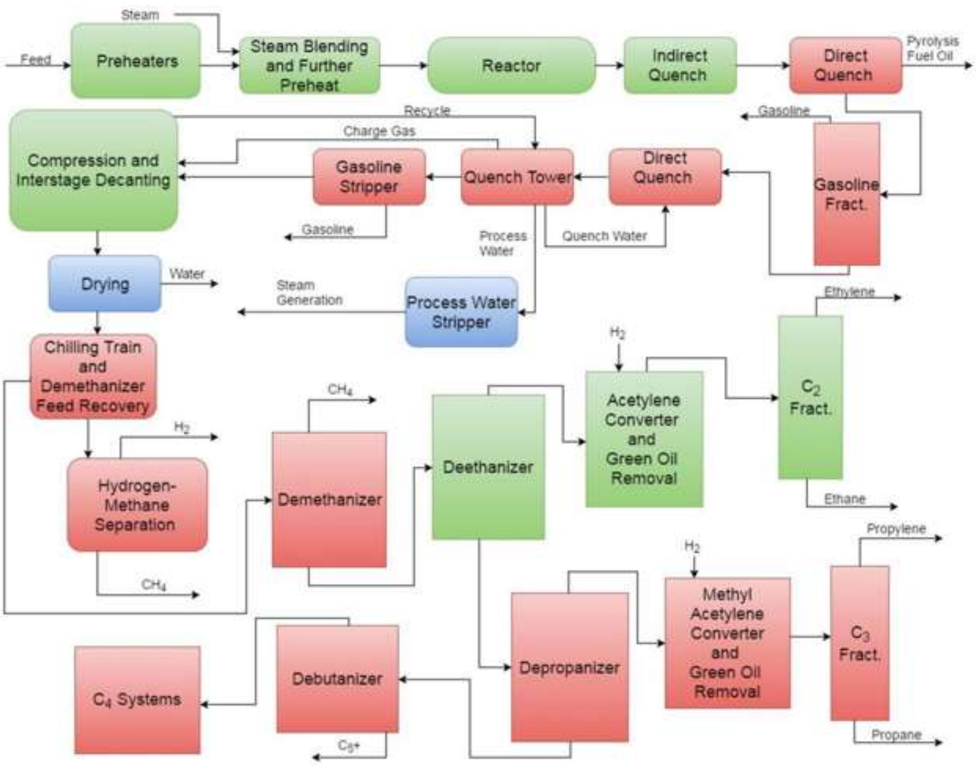
Figure 5:



Payback Period for an ATROI

Figure 6:



Process Flow Diagram for C2-ODH for Ethylene Production (areas in red are not needed in ODH plants; areas in blue are the same in CSP and C2-ODH plants) [8]

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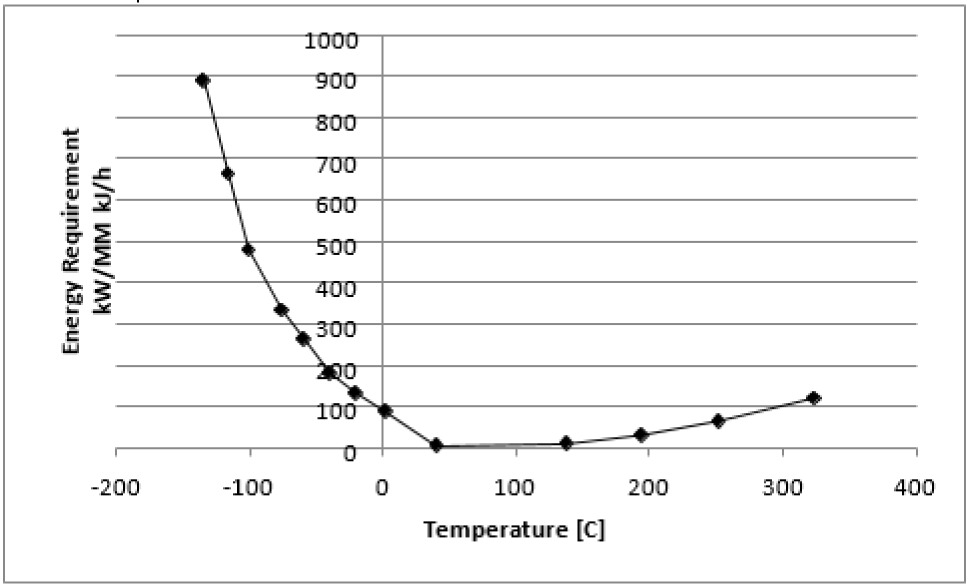
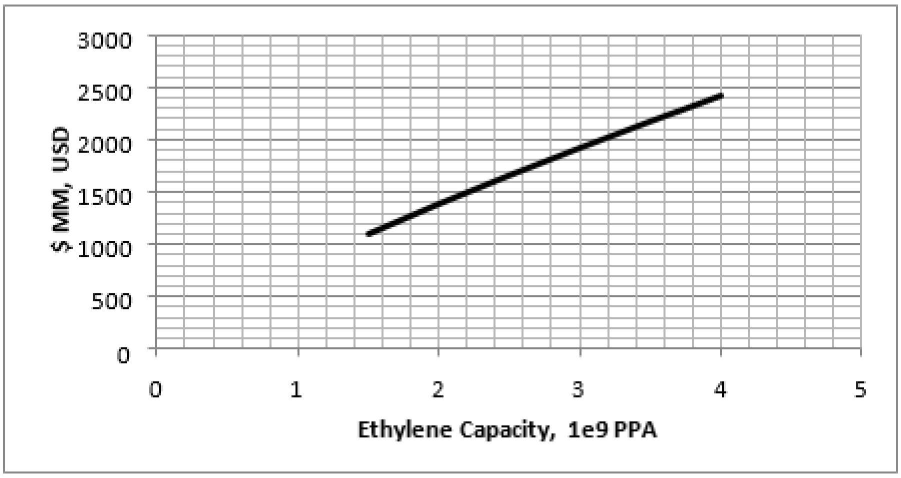
Figure 7:



Energy Availability in a Petrochemical Plant

Figure 8:



RNB and CC of Ethylene

3. RESULTS AND DISCUSSION

Process Economics

The results and discussion may be combined into a common section or obtainable separately. They may also be broken into subsets with short, revealing captions.

Energy Productivity

The comparison of the energy efficiency C2-ODH to Conventional Steam Pyrolysis is shown in Table 2. The calculations were based on information gathered using Aspen HYSYS V10. The capacity cost and capital recovery comparison is shown in Table 3. The availability of energy in a plant is important in maintaining the energy "levels" of chemical plants. The average levels of energy available in a petrochemical plant are shown in Figure 7.

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Process Intensification

Table 4 summarizes the process units required for CSP and C2-ODH. As shown in Table 4, Conventional Steam Pyrolysis is a raw material and capital cost intensive process for producing ethylene. Interestingly, with the availability of low-cost of ethane, economic margins are still attractive even though the technology has not changed much in 40 years [6].

Environmental Impact

A 13.5% ROR for a 4-year payback period is used. Figure 8 shows the RNB and CC figure of ethylene. A reduction in carbon footprint is calculated to be greater than 50% for C2-ODH over conventional means.

Tables:

Table 1. COP values of CSP and ODH

COP Metric	**CSP**	**C2-ODH[1]**
Capacity	1.5 MTPA	1.5 MTPA
Capital Investment	$2.46 bn	$1.26 bn
Variable Costs	$0.15 / kg	$ 0.11 / kg
Fixed Costs	$ 0.09 / kg	$ 0.05 / kg
Capital Recovery	$ 0.17 / kg	$ 0.08 / kg
Required Netback	$ 0.39 / kg	$ 0.24 / kg
Margins	$ 197 MM / year	$ 703 MM / year

1 25% contingency applied

Table 2. Energy Efficiency Metrics of CSP vs C2-ODH

Energy Efficiency Metrics	CSP – gas feed	C2-ODH – gas feed	Improvement
Overall Energy Efficiency (kJ/kg ethylene product)	2700	1300	50%
Furnace Energy (MJ/kg ethylene product)	3 - 6 (Endothermic) (Pyrolysis Furnace – Radiant Duty)	0 (Exothermic)	100%
Compression Energy (kW/MM kg ethylene/Y)	100	17	83%

Table 3. Capacity Cost and Capital Recovery of CSP vs C2-ODH

Energy Productivity	CSP	ODH
Capacity Cost ($ MM per B PPY ethylene produced)	1500	700
Capital Recovery ($/kg ethylene)	0.173	0.079

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Table 4. Required Process Units CSP vs C2-ODH

	CSP	ODH
Reactor Arrangement	20 in parallel	1-3 in series
Reaction Temperature	840°C	325-350°C
Number of Plant Sections	25	10
Compression	Large Scale	Minimal
Cryogenics	Methane, Ethane, and Propane Cascades	Minimal
Demethanization and H_2 Recovery/Purification	Required	Not Required

4. CONCLUSION

Using preliminary engineering analyses, performance metrics are revealed to be very important in measuring process economic, energy productivity, process intensification, and environmental impacts of new technologies. The analyses of C2-ODH show promising margins and improvements over CSP. Further engineering demonstrations and laboratory studies around C2ODH provide clarity in assumptions and typical heuristics.

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