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Exploiting arbitrage opportunities on commodity futures market as a chemical plant

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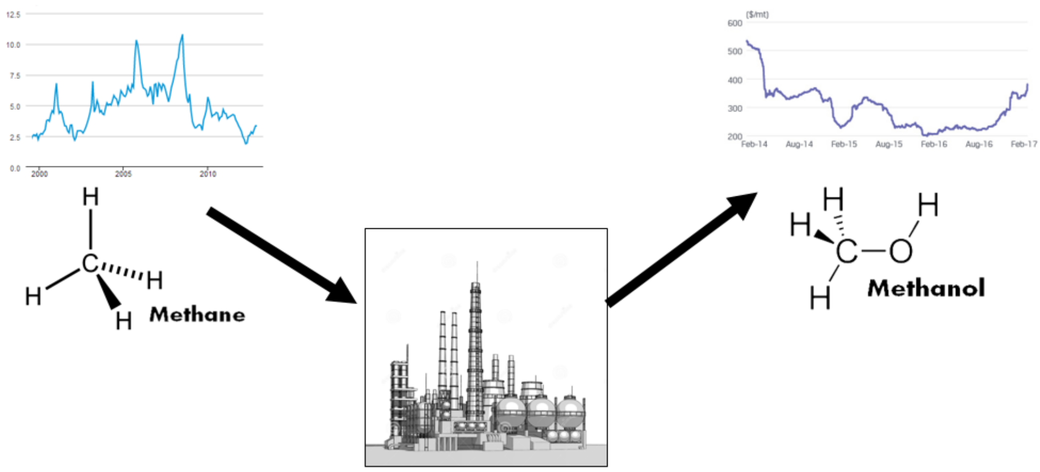
Abstract

This paper presents an implementation of an automated arbitrage spotter powered by market and physical data applied to two scenarios: conversion of natural gas to methanol and crude palm oil to biodiesel. The programme searches for opportunities to make additional profit by analysing the futures market prices for both the reagent and the product. It considers cost of storage and conversion (other feedstock, steam, electricity and other utilities) derived from physical simulations of the chemical process. It is assumed that the plant is located in Singapore and operates with a long-term production contract. Two scenarios considered are natural gas-to-methanol conversion and crude palm oil-to-biodiesel (FAME) conversion. Analysis conducted on 11.06.2018 in the former scenario no trade should be made in order to avoid making a loss. However, in the latter case up to 219.28 USD per tonne of biodiesel can be earned by buying contracts for delivery of crude palm oil in July 2018 and selling contracts for delivery of biodiesel in August 2018 in a ratio of 4 to 1. It is shown that there may be a realistic scope for increasing profitability of a chemical plant by exploiting the opportunities across different commodity markets in an automated manner. Additionally, the results suggest that direct arbitrage with natural gas may not be possible as the markets are efficient and transporting natural gas tends to be more expensive than methanol.



Highlights

- An implementation of an automated arbitrage spotter powered by market and physical data is presented.
- Two specific applications are considered: conversion of natural gas to methanol and crude palm oil to biodiesel.
- Analysis based on futures market data from 11.06.2018 indicates that profit can be made by arbitration of crude palm oil to biodiesel.

Contents

1 Introduction

Most organisations participating in industrial parks are profit-seeking companies. Sometimes investment and energy-saving opportunities present themselves, but cannot be exploited due to significant risks and absence of relevant data or a physical model with sufficiently strong predictive capabilities. For example, a chemical plant, with spare production capacity, could make additional earnings by exploiting the price differences between its feedstock and product on the commodity markets. However, straying from the established throughput without an accurate simulations may lead to decreased product quality or even damaging equipment.

Industry 4.0 introduces many concepts relevant to taking advantage of the aforementioned opportunities, including machine-to-machine (M2M) communication, cyber-physical systems (CPSs) and the Internet of Things (IoT) [22, 23]. M2M communication refers to the ability of industrial components to communicate with each other. CPSs can monitor physical processes, create virtual copies of the physical world and make decentralised decisions. IoT is a dynamic network where physical and virtual entities have identities and attributes and use intelligent interfaces.

A system could be established that gathers and analyses market (local and global) and physical (from sensors and simulations) data about the relevant industrial processes and advises on potential investments and energy savings. It is conceivable that in the future an entire production plant or even an entire industrial park would autonomously seek and fulfill such opportunities.

Furthermore, exploring and exploiting such possibilities within an industrial park may encourage closer cooperation of participants' plants leading to a transformation into an eco-industrial park (EIP). An EIP is an industrial park where businesses cooperate with each other and, at times, with the local community to reduce waste and pollution, efficiently share resources (such as information, materials, water, energy, infrastructure, and natural resources), and minimize environmental impact while simultaneously increasing business success [21, 29, 30].

Numerous studies have been written on trading commodities and their futures on an exchange, for example, Campa [4], Fung and Hsieh [14], Garcia and Leuthold [15], Szakmary et al. [36]. A number of publication considers the interactions between the production and the commodity markets. Smith and Stulz [34] examine the reasons why firms hedge and what risks do they choose to hedge and develop a theory of the hedging behavior of value-maximizing corporations. Bjorgan et al. [3] study the issues of financial risk management in the energy sector and explores impact of financial contracts (such as futures) for scheduling policies of the companies in the industry. The paper by Tanlapco et al. [37] examines risk-minimizing hedging strategies using futures contracts in an electricity market and finds that the use of electricity futures contracts is superior to using other related futures contracts such as crude oil. Spinler et al. [35] present a theoretical analysis of options contracts for physical delivery which shows how spot market price risk, demand and cost risk can be shared between buyer and seller. They conclude that such a contingency may complement financial risk management instruments capital-intensive firms such as those in the chemical industry. Ding et al. [8] explore integrated operational and financial hedging decisions faced by a global firm. The study found that financial hedging strategy ties closely to, and can have both quantitative and qualitative impact on, the firm's operational strategy. The publication by Kannegiesser et al. [20] presents a planning model for coordinating sales and supply decisions for commodities in a chemical industry. The impact of elasticities, variable raw material consumption rates and price uncertainties on planned profit and volumes are demonstrated.

A number of studies develop and apply modelling techniques in order to aid companies with financial risk management. Ryu [33] discusses two multi-period planning strategies used to minimise negative impact of varying conditions on a company's profitability. One is to modify the external condition, *e.g.* demands, and the other is to expose explicit constraints limiting capacity expansion. Park et al. [31] and Ji et al. [19] present financial risk management methods in the petrochemical industry. The former demonstrates a two-stage stochastic programming framework for operational planning and financial risk management of a refinery. The method optimised the contract sizes (long-term, spot and futures) and the plant's operational plan. The latter presents a one-stage stochastic programming model for the integration of operational hedging and financial hedging strategy in the crude oil procurement process subject to oil price fluctuation. This approach uses Conditional Value-at-Risk as the risk measure and considers futures contracts, put options and call options during optimisation. A publication by Longinidis et al. [25] presents a supply chain network design model that yields the optimal configuration under a variety of exchange rate realizations and integrates operational hedging actions that mitigate exchange rate risk. Kwon et al. [24] describe and demonstrate a two-stage programming framework for maximizing profit of a petrochemical company. The two stages are hedge trading (minimising costs of raw materials) and production planning (maximising sales profits). The procedure simultaneously optimises timing, amount, and price of raw materials and the strategies for facility operation and product sales. An example of a Korean petrochemical company is used to present that this approach can improve profitability.

While many studies theoretically explore trading commodities and their futures on an exchange and develop methods for optimising this activity, none among the found literature have investigated and implemented a system gathering market and physical data in order to make recommendations about and act on opportunities for saving energy and increasing profitability.

The purpose of this paper is to present an automated arbitrage spotter powered by market and physical data applied to two scenarios: conversion of natural gas to methanol and crude palm oil to biodiesel (fatty acid methyl ester - FAME). This paper is structured as follows: section 2 provides design and implementation details of the arbitrage spotter; section 3 describes and discusses results of the analysed case studies; section 4 summarizes the main findings.

2 Automated arbitrage spotter

2.1 Design and implementation

This section describes the design and implementation of the automated arbitrage spotter for a chemical plant converting a reagent into a product. The spotter searches for opportunities to make additional profit by analysing the futures market prices for both the reagent and the product. It considers costs of storage, transport and conversion (steam, electricity and other utilities) and produces an investment recommendation. It is assumed that the plant is located in Singapore and operates with a long-term production contract.

The implementation involves the following steps:

1. downloading market data from an appropriate online source (the considered scenarios include the Chicago Mercantile Exchange [18] and Zhengzhou Commodity Exchange [10]),

2. performing a feasibility analysis based on the downloaded data and physical data provided by a simulation of the chemical plant under consideration (the included scenarios employ Aspen Plus [2] and Aspen HYSYS [1]).

Both steps are executed by scripts written in Python 3.5.0 [13]. Market data is downloaded on a daily basis as it is updated at the same rate. The second step determines potential profit to be made on delivering a single unit of the product. The required quantities of the reagent contracts, utilities (steam, water, heating fuel and electricity), transport to and from the plant and storage volume are calculated and costed. The utility, transport and storage prices were determined based on specifications of a biodiesel plant designed by Lurgi GmbH in 2007 and the available literature. Necessary currency conversions were done with data from Oanda [28], XE.com [38], while Coinnews Media Group LLC [6] was used to adjust for inflation.

The programme solves the following equation for all contracts in the correct chronological order (*i.e.* delivery of the product must be scheduled at least a month after delivery of the reagent) in order to determine profit per unit of the product:

$$P_p - T_p - (S_p \oplus (S_r \times R)) \times d - R \times (P_r - T_r) - U \qquad (1)$$

where subscripts p and r refer to the product and the reagent respectively, P to price, T to transport cost, S to storage cost, R to units of the reagent per unit of the product, d to the storage duration and U to the cost of utilities per unit of the product. Note that $\oplus$ indicates that the programme assumes either the product or the reagent are stored for the entire time between reception of latter and delivery of the former. In the considered scenarios P was taken from Chicago Mercantile Exchange [18] and Zhengzhou Commodity Exchange [10] and T, R, S and U were calculated using the data from Tables 2 and 4 and Aspen Plus and Aspen HYSYS plant simulations.

Finally, the software will return the most profitable contract and storage schedule combination.

2.2 Software

Aspen Plus V8.8

Aspen Plus [2] is a process modelling and optimisation software used by the bulk, fine, specialty, and biochemical industries, as well as the polymer industry for the design, operation, and optimisation of safe, profitable manufacturing facilities. Its capabilities include:

- optimisation of processing capacity and operating conditions,
- assessment of model accuracy,
- monitoring safety and operational issues,
- identifying energy savings opportunities and reduce greenhouse gas (GHG) emissions,
- performing economic evaluation,
- improving equipment design and performance.

Aspen HYSYS V8.8

Aspen HYSYS [1] is a process modeling tool used by the petrochemical industry for process simulation and process optimization in design and operations. Its uses include, but are not limited to:

- designing various components in a petrochemical plant,
- detecting abnormal operating conditions,
- modeling steady state and dynamic processes.

Python 3.5.0

Python [13] is a high-level, interpreted programming language for general-purpose programming. It emphasizes readability and an expressive syntax. In this study it was used to download online data, perform calculations and connect to Aspen Plus and Aspen HYSYS. The last activity was performed using Microsoft Component Object Model (COM) interface which is a platform-independent, binary-interface standard enabling creation of objects and communication between them [27]. COM object (also known as COM component) is defined as a piece of compiled code that provides a service to the rest of the system.

3 Results and discussion

3.1 Crude palm oil-to-biodiesel conversion

Biodiesel plant simulation

A process producing 24.334 tonnes per hour of biodiesel was modelled in Aspen Plus V8.8 using the UNIFAC-DMD property method [16] (including steam tables for calculations involving pure water). The flow sheet model includes two reaction stages (modelled using continuously stirred tank reactors - CSTRs), a separation stage, a methanol recycle loop, a gas-fuelled steam generation section and auxiliary equipment, see Fig. 1. The final fuel, fatty acid methyl ester, is produced via trans-esterification pathway where triglycerides react with methanol to form methyl ester and glycerol in the presence of an alkaline catalyst. The flow sheet was based on an existing plant designed by Lurgi GmbH. In the process tripalmitine oil is reacted with methanol in the CSTRs to produce glycerol and methylpalmitate (biodiesel), then passed through a flash drum and a decanter and washed with water to separate the remaining methanol and glycerol. Finally, dry air is used to remove water from the product. The simulation is solved for steady-state operation and produces a wide variety of chemical and physical information ranging from throughput to heat duties of individual equipment. It is assumed that crude palm oil can be directly fed into this processing line.

Financial analysis

This scenario involves the following steps:

1. downloading market data from the website of Chicago Mercantile Exchange [5, 17],
2. performing a feasibility analysis based on the downloaded data and physical data provided by Aspen Plus [2] model of a chemical plant converting crude palm oil into biodiesel, see Fig. 4.

It is important to note that both futures markets deal with financially settled contracts, but it is assumed that their prices are an accurate approximation of the physically settled ones. For transportation purposes it is assumed that the delivery location of crude palm oil is in Malaysia and of biodiesel in southern China. The contract details can be seen in Table 1. A plot of the prices can be viewed in Fig. 2.

The required quantities of crude palm oil contracts, utilities (steam, water, heating fuel and electricity), transport to and from the plant and storage volume are calculated and costed per tonne of biodiesel. The prices were determined based on the plant specifications (provided in the documentation of Lurgi GmbH's biodiesel plant design) and the literature (references provided in Table 2). The summary of prices can be found in Table 2. To calculate the profit the programme solves eqn. 1 outlined in Section 2.

The best contract and storage schedule combination is chosen based on this information using an exhaustive search, results of which can be seen in Fig. 3. The result of the

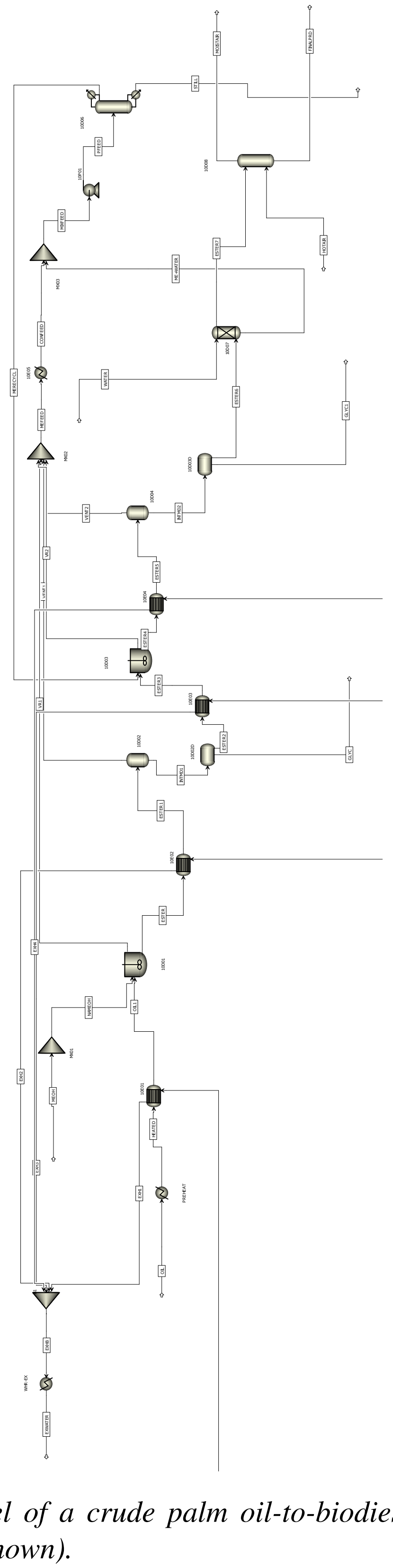


Figure 1: *Aspen Plus model of a crude palm oil-to-biodiesel plant (steam generation equipment not schown).*

Table 1: *Details of the futures contracts.*

	Crude palm oil	**Biodiesel**
Exchange	Chicago Mercantile Exchange [17]	Chicago Mercantile Exchange [5]
Contract Unit	25 t	100 t
Currency	USD	USD
Delivery location	Malaysia	Southern China

Table 2: *Storage, transport and utility prices (all quantities that do not have a reference are provided in the documentation of Lurgi GmbH's biodiesel plant design.)*

Storage		
Crude palm oil	0.2075	USD per month-tonne
Biodiesel	0.2075	USD per month-tonne
Transport		
Crude palm oil [12]	5.0	USD per tonne
Biodiesel [12]	40.0	USD per tonne
Utilities		
Electricity [9]	0.0000386	SGD per kJ
Fuel gas	0.0000093	USD per kJ
Steam (low pressure)	0.01264	USD per kg
Steam (high pressure)	0.00349	USD per kg
Cooling water	0.00174	USD per kg
Process water	0.00033	USD per kg

analysis from 11.06.2018 is 219.28 USD per tonne of biodiesel can be made. This can be achieved by buying contracts for delivery of crude palm oil in July 2018 and selling contracts for delivery of biodiesel in August 2018 in a ratio of 4 to 1. The largest cost contribution comes from transportation. Note that it is assumed that all crude palm oil was converted instantaneously (relatively to the timescales involved). Duration of storing the reagent and the product is irrelevant as their storage costs are the same, as visible in Fig. 3.

This result indicates that there may be a realistic scope for increasing profitability of a chemical plant by exploiting the opportunities across different commodity markets. It is also shown that this can be achieved in an automated manner.

3.2 Natural gas-to-methanol conversion

Methanol plant simulation

A process producing around 56.791 tonnes per hour (1085 mmBTU per hour) of methanol was modelled in Aspen HYSYS V8.8 using the Peng-Robinson property method [32]. The flow sheet model can be divided into two parts: natural gas-to-syngas conversion and syngas-to-methanol conversion. Overall, they include two reaction steps (modelled using

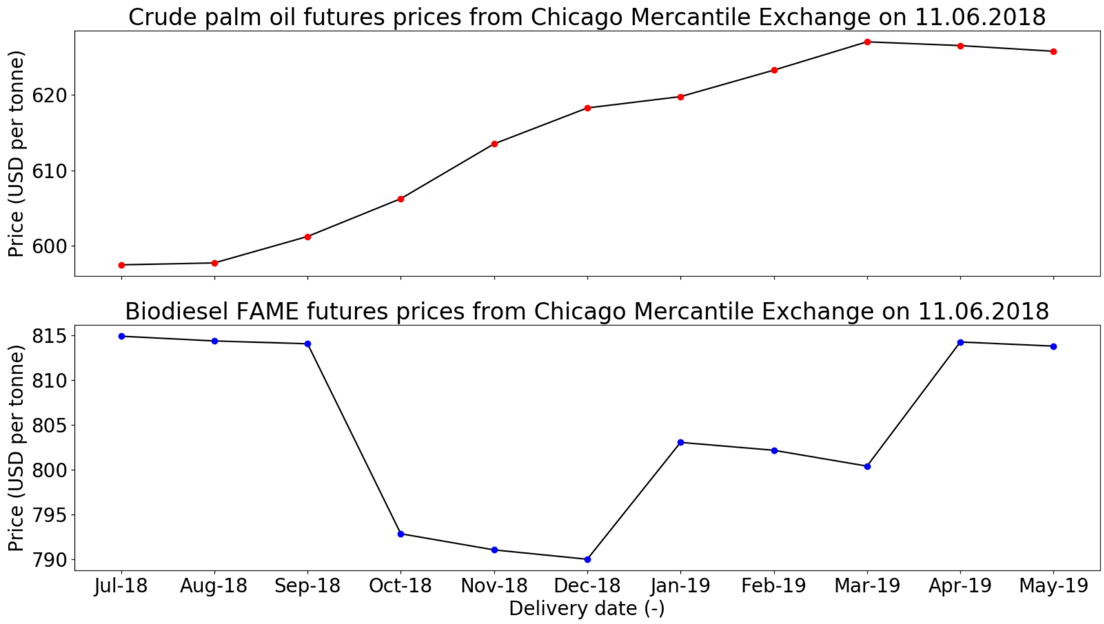


Figure 2: *Plot of the crude palm oil and biodiesel futures prices from 11.06.2018. For example, a contract for future delivery of crude palm oil in September 2018 can be bought (or sold) at approx. 605 USD per tonne.*

plug flow reactors - PFRs), three separation steps, three recycle loops, a water top-up section and auxiliary equipment, see Fig. 1. Natural gas (mostly composed of methane, but also ethane and propane) is stripped of any pollutants (such as sulphur compounds) and then converted into syngas (a mixture of carbon monoxide and hydrogen) via steam reforming. Water is removed from the mixture, which is then converted into methanol in a PFR. Lastly, the product is purified up to the desired specifications. The simulation is solved for steady-state operation and produces a wide variety of chemical and physical information ranging from throughput to heat duties of individual equipment.

Financial analysis

This scenario involves the following steps:

1. downloading market data from the websites of Chicago Mercantile Exchange [18] and Zhengzhou Commodity Exchange [10] (the contract details can be seen in Table 3, while a plot of the prices can be viewed in Fig. 5),

2. performing a feasibility analysis based on the downloaded data and physical data provided by Aspen HYSYS [1] model of a chemical plant converting natural gas into methanol, see Fig. 4.

The required quantities of natural gas contracts, utilities (steam, water, heating fuel and electricity), transport to and from the plant and storage volume are calculated and costed

Table 3: *Details of the futures contracts.*

	Natural gas	**Methanol**
Exchange	Chicago Mercantile Exchange [18]	Zhengzhou Commodity Exchange [10]
Contract Unit	10 mmBTU	1 tonne (approx. 19.1 mmBTU)
Currency	USD	CNY
Delivery location	Henry Hub pipeline	Zhengzhou Exchange

Table 4: *Storage, transport and utility prices (all quantities that do not have a reference are based on the documentation of Lurgi GmbH's biodiesel plant design.)*

Storage		
Natural gas [7]	0.121	USD per month-mmBTU
Methanol	0.2075	USD per month-tonne
Transport		
Natural gas [11]	approx. 7	USD per mmBTU
Methanol [26]	22.9	USD per tonne
Utilities		
Electricity [9]	0.0000386	SGD per kJ
Fuel gas	0.0000093	USD per kJ
Steam (low pressure)	0.01264	USD per kg
Steam (high pressure)	0.00349	USD per kg
Cooling water	0.00174	USD per kg
Process water	0.00033	USD per kg

per tonne of methanol. The prices were determined based on the plant specifications (based on the documentation of Lurgi GmbH's biodiesel plant design) and the literature (references provided in Table 4). The summary of prices can be found in Table 4.To calculate the profit the programme solves eqn. 1 outlined in Section 2.

The best contract and storage schedule combination is chosen based on this information using an exhaustive search, results of which can be seen in Fig. 6. The analysis from 11.06.2018 recommends that no trade should be made in order to avoid making a loss. The least loss of approximately 70284 USD per tonne of methanol can be achieved by buying contracts for delivery of natural gas in September 2018 and selling contracts for delivery of methanol in December 2018 in a ratio of 3 to 1. The largest cost contribution comes from the utilities. Note that it is assumed that all natural gas was instantaneously (relatively to the timescales involved) converted on arrival and methanol was stored until delivery date. However, as visible in Fig. 6 the impact of storage cost is relatively small.

This result indicates that direct arbitrage with natural gas may not be possible since the markets are efficient (*i.e.* market prices reflect all relevant information) and the natural gas prices in Asia due to the so called "Asian premium" (*i.e.* additional transport and storage costs). Additionally, it is cheaper to produce methanol at the source of natural gas as the former is significantly cheaper to transport than the latter.

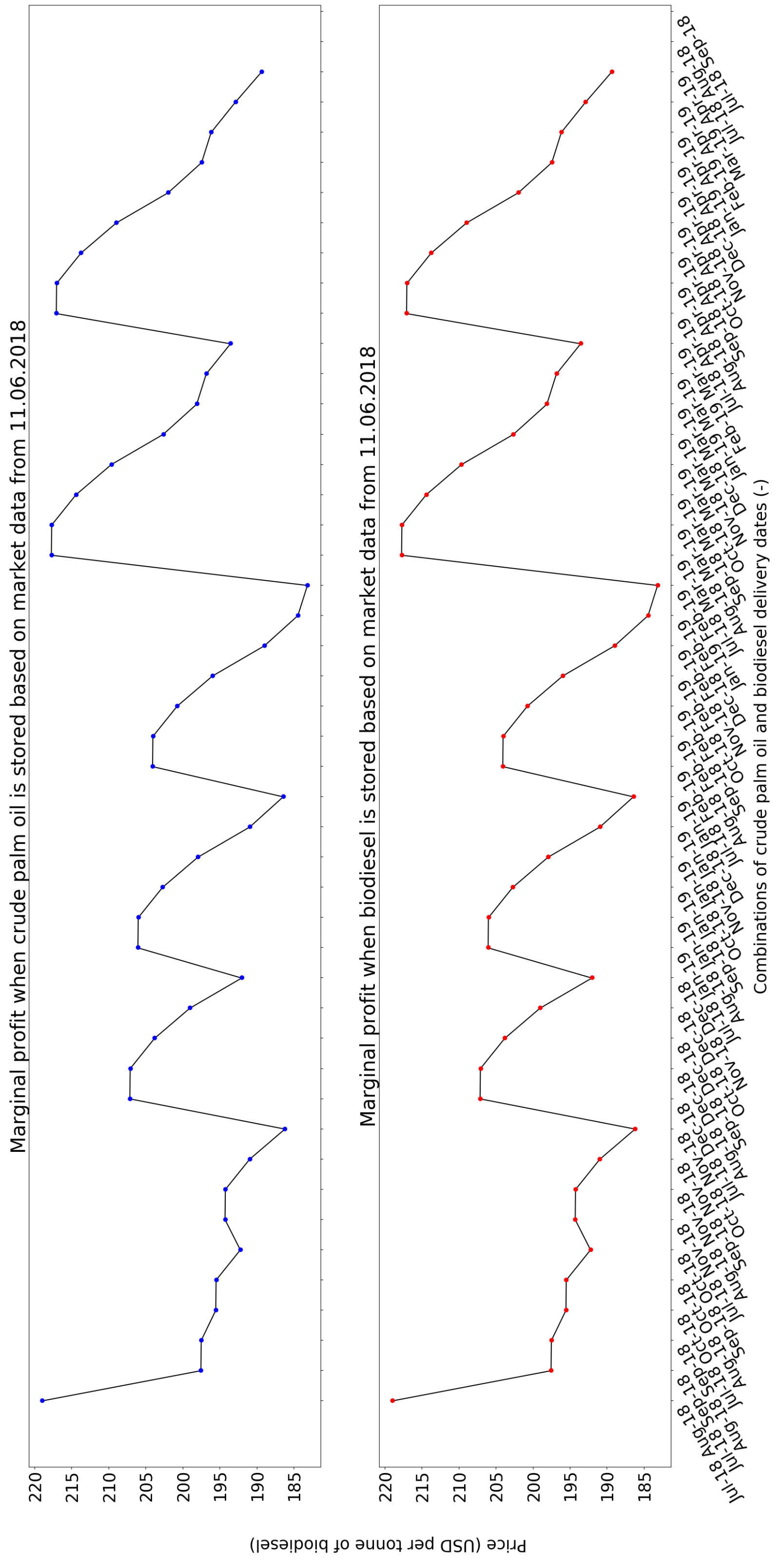


Figure 3: *Plot of marginal profit per tonne of biodiesel against different dates of crude palm oil and biodiesel deliveries based on futures prices from 11.06.2018. For example, the first point corresponds to accepting a delivery of crude palm oil in July 2018 and delivering biodiesel in August 2018.*

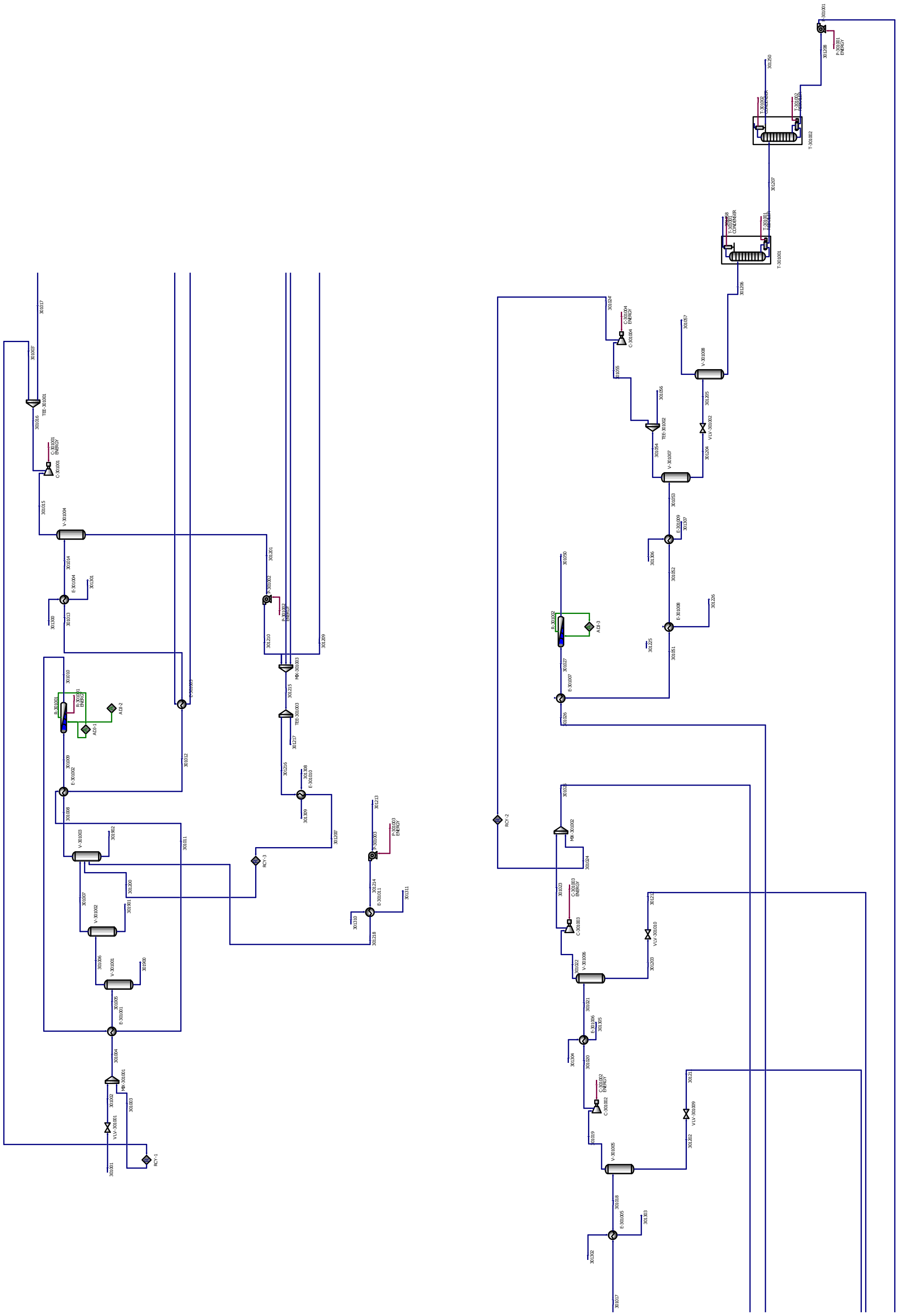


Figure 4: *Aspen HYSYS model of a natural gas-to-methanol plant. The upper section converts natural gas into syngas, while the lower syngas into methanol.*

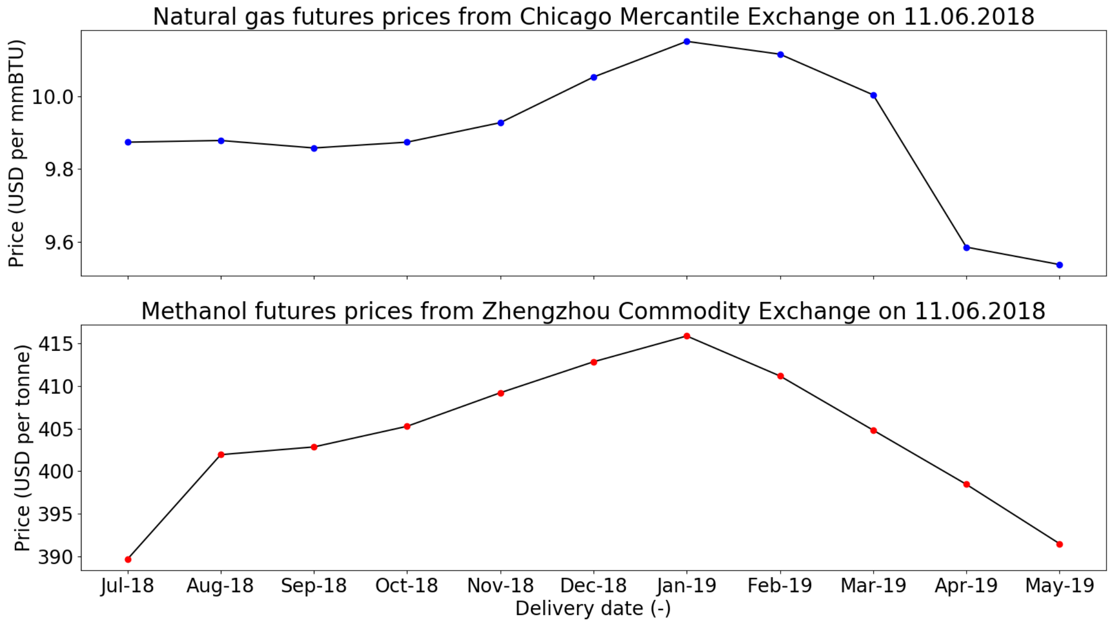


Figure 5: *Plot of the natural gas and methanol futures prices from 11.06.2018. For example, a contract for future delivery of methanol in September 2018 can be bought (or sold) at approx. 9.9 USD per mmBTU.*

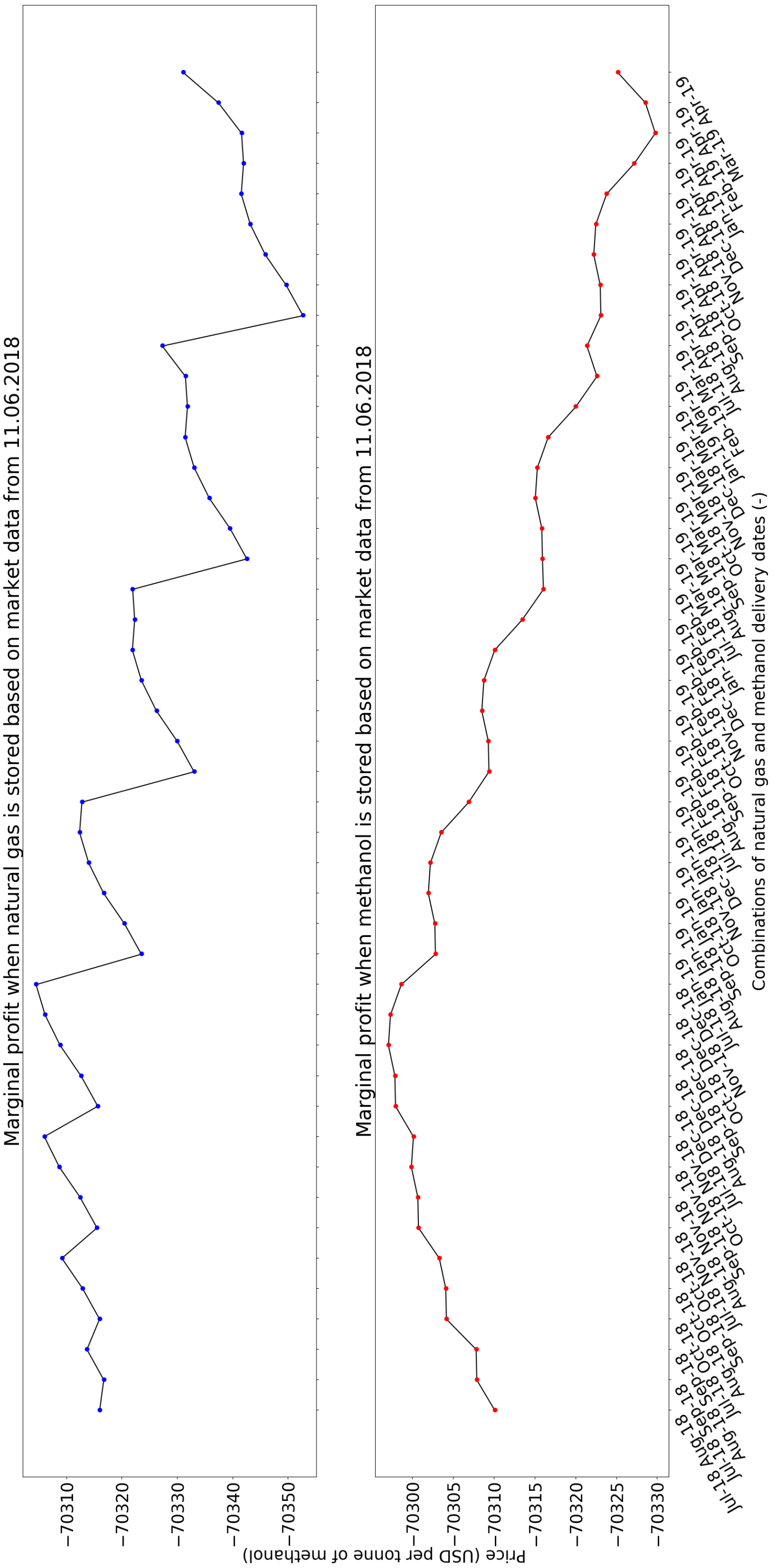


Figure 6: *Plot of marginal profit per tonne of methanol against different dates of natural gas and methanol deliveries based on futures prices from 11.06.2018. For example, the first point corresponds to accepting a delivery of natural gas in July 2018 and delivering methanol in August 2018.*

4 Conclusions and future work

This paper presents an implementation of an automated arbitrage spotter powered by market and physical data applied to two scenarios: conversion of natural gas to methanol and crude palm oil to biodiesel. The programme searches for opportunities to make additional profit by analysing the futures market prices for both the reagent and the product. It considers cost of storage and conversion (other feedstock, steam, electricity and other utilities) derived from physical simulations of the chemical process. It is assumed that the plant is located in Singapore and operates with a long-term production contract. Two scenarios considered are natural gas-to-methanol conversion and crude palm oil-to-biodiesel (FAME) conversion. Analysis conducted on 11.06.2018 in the former scenario no trade should be made in order to avoid making a loss. However, in the latter case up to 219.28 USD per tonne of biodiesel can be earned by buying contracts for delivery of crude palm oil in July 2018 and selling contracts for delivery of biodiesel in August 2018 in a ratio of 4 to 1. Duration of storing the reagent and the product is irrelevant as their storage costs are the same. It is shown that there may be a realistic scope for increasing profitability of a chemical plant by exploiting the opportunities across different commodity markets in an automated manner. Additionally, the results suggest that direct arbitrage with natural gas may not be possible as the markets are efficient and transporting natural gas tends to be more expensive than methanol.

Future work will involve employing the automated arbitrage spotter in conjunction with J-Park Simulator (JPS) [22, 29]. The JPS is a cyber-physical system for designing, computer-aided process engineering (CAPE) and managing an eco-industrial park (EIP). This combination will enable the application of the current findings to larger networks and different types of commodities, machine-to-machine market creation (spot and futures) and introduction of more complex trade deals. Additionally, a greater variety of models and dynamic behaviour (*e.g.* a simulation of a process line during start-up and shut-down) can be introducted.

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