OPTIMAL DESIGN AND SYNTHESIS OF RICE SUPPLY CHAIN

LIM JENG SHIUN

UNIVERSITI TEKNOLOGI MALAYSIA

OPTIMAL DESIGN AND SYNTHESIS OF RICE SUPPLY CHAIN

LIM JENG SHIUN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Chemical Engineering)

Faculty of Chemical Engineering
Universiti Teknologi Malaysia

JULY 2013

To my dearest family:

Whose love has nourished and sustained me always.

ACKNOWLEDGEMENT

This thesis would not have been possible without the guidance, assistance and encouragements of kind-hearted people around me.

First and foremost, I would like to express my deepest gratitude to Prof. Dr. Zainuddin bin Abdul Manan, my main supervisor, who is also the Dean of Faculty Chemical Engineering for UTM, for his dedication in guiding me throughout my journey of writing the thesis, despite his heavily occupied administrative work. I thank him for his valuable advice and suggestions, particularly on the art of conveying message articulately. And more importantly, I would also like to thank him for providing me endless opportunities to develop my knowledge and skill beyond the scope of my thesis.

I would like to express my heartiest thanks to my other two co-supervisors, Assoc. Prof. Dr. Haslenda Hashim and Assoc. Prof. Ir. Dr. Sharifah Rafidah Wan Alwi, for their patience and guidance, throughout these few years. I thank Dr. Haslenda for her willingness to share her knowledge and latest industry trend with me. I also thank her for always providing me with honest opinions to improve my work. For Dr. Sharifah, the director of PROSPECT, I thank her for providing such an excellent research platform for the students. Her tireless efforts in bringing the distinguished visiting professors to PROSPECT have benefited us as a whole.

Special thanks to Mr. Ahmad Ridzuan, the former General Manager of Special Project Division of BERNAS. I thank him for exposing me with the actual industry environment and for providing me the invaluable inputs to solve the industrial problems.

Last but not least, I am most thankful to my family and my friends for their continuous spiritual support and encouragement. My dearest mom, aunties and uncles, thank you for all your love and patience in nurturing me. Also, to my cutest nieces and nephews, thank you for the warm embraces and the joyful moments shared.

ABSTRACT

Continuous rise in energy cost and increased competitiveness have motivated rice enterprises to find new ways to improve productivity, reduce resource consumption, minimise waste generation, and ultimately, raise profitability. Consequently, there has been extensive research and development works in the conversion of the by-products from rice mills into value-added products. However, most of the works on the improvement of the rice mill and its downstream processes have been carried out in the piece-meal manner. There is a clear need for a systematic framework to optimise and improve the existing rice mill and its value-added processes in an integrated, resource-efficient way. The new framework developed in this thesis includes four key components as described below. Component 1: A new cost-screening framework that is known as the resource-efficient screening (RES) method to screen the rice value chain and select the products and technologies targeted to maximise profit. Component 2: The framework for an integrated, resource-efficient (IRE) rice mill complex to synthesise the processes by evaluating the trade-off between the product revenue, capital investment and utility consumption. The model also considers the seasonality and degradation of rice resources with time. Component 3: A new framework called the integrated, resource-efficient (MSIRE) framework has also been developed for the rice enterprise that operates a cluster of rice mills at different locations. The MSIRE framework is used to determine the product portfolio for each rice mill, the location of the cogeneration system and its optimal scale, whether to expand the current processing facility or to build a new facility and the configuration of the paddy and rice husk logistic network. Component 4: A framework that combines the optimal logistic network of rice husk, with the rice mill's utility supply network has also been developed. These frameworks were successfully implemented on several case studies involving different scenarios of a national rice enterprise, and produced significant improvement in the enterprise's profitability.

ABSTRAK

Kos tenaga dan daya saing yang semakin meningkat telah mendorong pengusaha kilang beras untuk mencari alternatif bagi mengurangkan penggunaan sumber serta penghasilan sisa, dan seterusnya, meningkatkan keberuntungan. Banyak penyelidikan yang melibatkan penggunaan produk sampingan dalam proses pengilangan beras telah dilaksanakan untuk menghasilkan produk yang mempunyai nilai tambah. Namun begitu, kebanyakan penyelidikan untuk memperbaiki proses pengilangan beras telah dilaksanakan secara terpisah. Oleh itu, rangka kerja yang sistematik bagi mengintegrasi proses yang sedia ada dalam kilang beras dengan proses hiliran, dengan penggunaan sumber dengan cekap adalah amat diperlukan. Kaedah yang dipaparkan dalam tesis ini boleh dibahagikan kepada empat komponen sebagaiman yang dinyatakan di bawah. Komponen 1: Rangka kerja baru yang dikenali sebagai *Resource-Efficient Screening* (RES) melibatkan pemilihan rantaian nilai beras serta produk dan teknologi yang sewajarnya untuk menjana keuntungan yang maksimum. Komponen 2: Satu rangka kerja telah dibangunkan untuk sintesis proses dalam *Integrated, Resource-Efficient (IRE) rice mill complex* dengan menilai imbal-balik antara hasil produk, modal dan kos utiliti. Model *IRE* ini juga mengambil kira sifat bermusim serta potensi degradasi sumber padi dalam jangka masa yang tertentu. Komponen 3: Satu rangka kerja baru yang dipanggil *Multisite Integrated, Resource-Efficient* (MSIRE) juga telah dibangunkan untuk pengusaha kilang beras yang mengoperasikan sekelompok kilang padi di beberapa lokasi yang berbeza. Rangka kerja MSIRE digunakan untuk menentukan portfolio produk bagi setiap kilang beras, lokasi serta skala yang optimum untuk sistem *cogeneration*, keputusan sama ada meningkatkan kapasiti bagi proses yang sedia ada dalam fasiliti atau membina kilang yang baru dan konfigurasi rangkaian logistik bagi padi dan produk beras. Komponen 4: Satu rangka kerja juga dipaparkan untuk konfigurasi rangkaian logistik sekam padi yang optimum di kilang beras, dengan mengambil kira aspek jaringan bekalan utiliti di sesebuah kilang beras. Kaedah-kaedah ini telah berjaya diaplikasikan ke atas beberapa kes kajian industri beras di bawah senario yang berbeza, dan hasilnya menunjukkan peningkatan keberuntungan industri tersebut dengan ketara.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CHF	-	Cyclonic husk furnace
FBD	-	Fluidised bed dryer
FFA	-	Free fatty acid
GAMS	-	Generalised Algebraic Modelling System
IBD	-	Inclined bed dryer
IRE	-	Integrated, resource-efficient
IRRI	-	International Rice Research Institution
LP	-	Linear programming
LP	-	Low pressure
LSU	-	Louisiana State University
MILP	-	Mixed integer linear programming
MILP	-	Mixed integer linear programming
MINLP	-	Mixed interger nonlinear programming
MP	-	Medium pressure
MPR	-	Material-Process-Resource
MSIRE	-	Multisite integrated, resource-efficient
NLP	-	Nonlinear programming
OUL	-	Optimal Utility-Logistc
PSE	-	Process systems engineering
RES	-	Resource Efficient Screening
RES	-	Resource-Efficient Screening
RM	-	Ringgit Malaysia
RPR	-	Resource-Process-Resource

LIST OF SYMBOLS

$AARHJ_i$	-	Annual available RH at internal rice mill *j*
$AARHK_k$	-	Annual available RH from external rice mill *k*
$ACCOSTB_b$	-	Annualised capital cost of biomass boiler *b*
$ACCOSTC_c$	-	Annualised capital cost of CHF *c*
$ACRHJ_j$	-	Annual transportation of rice husk from internal rice mill *j*
$ACRHK_k$	-	Annual transportation of rice husk from external rice mill *k*
$AElecO$	-	Annual electricity required from outsources
$AVAIRES_{t,f,i}$	-	Quantity of available resource *i* at location *f* during period *t*
$AVRES_i$	-	Amoun*t of* available external resource *i*
$AVRES_{ivt}$	-	Amount of available external resource *i* from location *v* during period *t*
$BElecD_t$	-	Basic electricity demand of drying equipment and office accessories at period *t*
B_i	-	By-product indicator of resource *i*
$BYPRO_{it}$	-	Amount of by-product *i* during period *t*
$BYPRO_{t,pc,i}$	-	Amount of by-product *i* from process complex *pc* during period *t*
$BYREV$	-	Revenue of by-product
CAP_{pz}	-	Capacity of process *p* with size *z*
$CCAPIN_{pc,p,z}$	-	Capacity index for process *p* at process site *pc* with capacity type *z*
$CCOST$	-	Capital cost of equipment
$CCRH$	-	Calorific value of rice husk

$CSTCOST_{pc}$	-	Construction cost of the process site at process site *pc*
$DEMPRO_i$	-	Demand of product *i*
$DISFPC_{f,pc}$	-	Distance between field *f* and process site *pc*
$DISPC_{pc,pc'}$	-	Distance between process site *pc* and another process site *pc'*
$DISPCS_{pc,s}$	-	Distance between process site *pc* and sales centre *s*
DOH	-	Number of operating hours per day
DOH_p	-	Daily operating hour of process *p*
$EFFBB_b$	-	Efficiency of biomass boiler
$EFFCHF_c$	-	Efficiency of CHF
$EFFFC$	-	Efficiency of FBD coil
$EFFIC$	-	Efficiency of IBD coil
$EFFTURB_b$	-	Efficiency of condensing extraction turbine *b*
$ElecBB_{bt}$	-	Electricity requirement of biomass boiler and turbine *b* at period *t*
$ElecCHF_{ct}$	-	Electricity requirement of CHF *c* at period *t* (kwh)
$ElecD_t$	-	Electricity demand at period *t*
$ElecF_{ft}$	-	Electricity requirement of FBD at period *t* (kwh)
$ElecGB_{bt}$	-	Electricity generated from condensing extraction turbine *b* at period *t*
$ElecG_t$	-	Electricity generated at period *t*
$ElecI_{it}$	-	Electricity requirement of IBD at period *t* (kwh)
$ElecO_t$	-	Electricity required from outsources at period *t*
Electariff	-	Electricity Tariff (RM/mwh)
$ENBB_b$	-	Enthalpy change across biomass boiler
$ENFBD$	-	Enthalpy change of MP across FBD
$ENIBD$	-	Enthalpy change of LP across IBD
$ENLP_b$	-	Enthalpy change between HP and LP across condensing extraction turbine *b*
$ENMP_b$	-	Enthalpy change between HP and MP across condensing extraction turbine *b*
$EOPE_p$	-	Operation indicator of process *p*

EUI_u	-	External utility indicator to allow for the intake of external utility
EUI_u	-	External utility indicator to allow for the intake of external utility
$EXCESSU_{t,pc,u}$	-	Excess amount of utility *u* at process site *pc* during period *t*
$EXLRES_{ivt}$	-	Amount of external intake resource *i* from venue *v* during period *t*
$EXPCOST_{p,z}$	-	Fixed cost of technology *p* with capacity *z*
$EXRES_i$	-	Amount of external intake resource *i*
$EXRES_{it}$	-	Amount of external intake resource *i* during period *t*
$EXRES_{t,f,pc,i}$	-	Transportation of external resource *i* between external location *f* and process site *pc* during period *t*
$EXU_{t,pc,u}$	-	Amount of external utility *u* at process site *pc* during period *t*
EXU_{ut}	-	Amount of external intake utility *u* during period *t*
FCOST	-	Total construction cost
$HEATCF_{cft}$	-	Heat supplied by CHF c to FBD *f* at period *t*
$HEATCHF_{ct}$	-	Heat supplied by CHF *c* at period *t*
$HEATCI_{cit}$	-	Heat supplied by CHF c to IBD *i* at period t
$HEATF_{ft}$	-	Required heat of FBD at period *t*
$HEATI_{it}$	-	Required heat of IBD at period *t*
$HEATLPI_{it}$	-	Heat supplied by LP stream at period *t*
$HEATMPF_{mt}$	-	Heat supplied by MP stream at period *t*
HP_{bt}	-	HP steam from boiler *b* to condensing extraction turbine *b* at period *t*
$HRPRES_{t,pc,p}$	-	Amount of processing resource for technology *p* at process site *pc* for operating mode *m* during period *t* in one hour
$HRPU_{t,pc,p}$	-	Amount of processing resource at technology *p* at process site *pc* during period *t* in one hour
ICI_{ip}	-	Indicator assigned to input material *i* to constrain the

		capacity of process *p*
$IMRES_{i,pc,t}$	-	Intermediate resource *i* at process site *pc* during period *t*
$INU_{t,pc,p,u}$	-	Utility *u* feed into process *p* at process site *pc* during period *t*
INV_i	-	Inventory indicator for resource *i*
$INVRES_{i,pc,t}$	-	Resource *i* at process site *pc* during period *t* being shifted forward to period *t*+1 as inventory
$INVRES_{it}$	-	Inventory level of resource *i* during period *t*
$LCOST$	-	Total transportation cost
LP_{bt}	-	LP saturated steam extracted from condensing extraction turbine *b* period *t*
LPC_t	-	LP saturated steam extracted from condensing extraction turbine *b* to cooling tower at period *t*
LPI_{it}	-	LP saturated steam extracted from condensing extraction turbine *b* to IBD coil at period *t*
$LWBB_b$	-	Lower bound of biomass boiler *b*
$LWCHF_c$	-	Lower bound of CHF *c*
$LWLP_b$	-	Minimum extraction rate of LP stream at turbine *b*
$LWMP_b$	-	Minimum extraction rate of MP stream at turbine *b*
MAT_{ipmt}	-	Amount of primary material *i* fed into process *p* under operating mode *m* during period t
$MAT_{t,pc,p,m,i}$	-	Material *i* feed into process *p* at process site *pc* under operating mode *m* during period *t*
MCM_{ipm}	-	Material composition matrix of resource *i* feed into operating mode *m* of process *p*
$MINOPE_p$	-	Minimum operating level of process p
MOD_p	-	Monthly operating day of process *p*
MP_{bt}	-	MP saturated steam extracted from condensing extraction turbine *b* at period *t*
MPF_{ft}	-	MP saturated steam extracted from condensing extraction turbine *b* to FBD coil at period *t*
n	-	Life span of equipment

NOS	-	Number of seasons
NPE_p	-	Quantity of equipment that can be purchased for process p.
OCI_{ip}	-	Indicator assigned to system-generated resource i to constrain the capacity of process p
OCU_{up}	-	Indicator assigned to system-generated utility u to constrain the capacity of process p
$OPEINV_i$	-	Amount of opening inventory for resource i
$OPEINV_{i,pc}$	-	Opening inventory of resource i at process site pc
$PCOST$	-	Total processing cost
$PCRHK_k$	-	Purchase cost of rice husk from external rice mill k
PDI_i	-	Product demand indicator to denote the maximum production level of product i
$Period_t$	-	Duration of period t
P_i	-	Product indicator for resource i
$PRCM_{pim}$	-	Process-resource conversion matrix between resource i and operating mode m of process p
$PRES_{pm}$	-	Amount of processing resource in operating mode m of process p
$PRES_{pmt}$	-	Amount of processing resource in process p under operating mode m during period t
$PRES_{t,pc,p,m}$	-	Amount of processing resource at technology p at process site pc under operating mode m during period t
$PRICE_i$	-	Unit price of product i
PRI_i	-	Price of resource i
$PRODEM_{i,s}$	-	Demand of product i at sales centre s
$PROFIT$	-	Annual profit
PRO_i	-	Amount of product i
PRO_{it}	-	Amount of product i during period t
$PRO_{t,s,i}$	-	Amount of product i at sales centre s during period t
$PUCM_{pum}$	-	process-utility conversion matrix between utility u and process p under operating mode m

$PU_{t,pc,p}$	-	Amount of processing utility resource of technology *p* at process site *pc* during period *t* in one hour
r	-	Interest rate
$RCOST$	-	Total resource cost
RES_i	-	Quantity of resource *i* in the system
$RES_{i,pc,t}$	-	Resource *i* at process site *pc* during period *t*
RES_{it}	-	Quantity of resource *i* in the system during period *t*
REV	-	Revenue
RHB_{bt}	-	Amount of biomass feed into boiler *b* at period *t*
RHC_{ct}	-	Amount of rice husk feed into CHF *c* at period *t*
RHJ_{jt}	-	Amount of rice husk transfer from internal rice mill *j* at period *t*
RHK_{kt}	-	Amount of rice husk transfer from external rice mill *k* at period *t*
RH_t	-	Amount of rice husk consumed at period t
$SCU_{t,pc,p,u}$	-	System converted utility *u* by process *p* at process site *pc* during period *t*
$SGRES_{ipm}$	-	Amount of self-generated resource *i* from the operating mode *m* of process *p* within the system
$SGRES_{ipmt}$	-	Amount of system-generated resource *i* from process *p* under operating mode *m* during period *t*
$SGRES_{t,pc,p,m,i}$	-	System-generated resource *i* by process *p* at process site *pc* for operating mode *m* during period *t*
$SGU_{t,pc,p,m,u}$	-	Utility *u* generated by process *p* under operating mode *m* at process site *pc* during period *t*
SGU_{upmt}	-	Amount of system-generated utility *u* from process *p* under operating *m* during period *t*
$TCEXRES_{t,i}$	-	Transportation cost of external resource *i* during period *t*
$TCIMRES_{t,i}$	-	Transportation cost of intermediate resource *i* during period *t*
$TCPRO_{t,i}$	-	Transportation cost of product *i* during period *t*
$TCRHJ_j$	-	Transportation cost of rice husk from internal rice mill *j*

$TCRHK_k$	-	Transportation cost of rice husk from external rice mill *k*
$TRANSPRO_{t,i,pc,s}$	-	Transportation of product *i* from process site *pc* to sales centre *s* during period *t*
$TRANSRES_{t,i,pc,pc'}$	-	Transportation of resource *i* from process site *pc* to process site *pc'* during period *t*
$UCM_{u,m,p}$	-	The bonding index of input utility *u* and process *p* for operating mode *m*
$UCOST$	-	Total utility cost
$UDEM_{t,pc,p,u}$	-	Utility demand *u* of process *p* at process site *pc* during period *t*
$UDEM_{ut}$	-	Demand of utility *u* during period *t*
$ULCOST_{iv}$	-	Unit transportation cost of resource *i* from venue *v*
$UPBB_b$	-	Upper bound of biomass boiler *b*
$UPCHF_c$	-	Upper bound of CHF *c*
$UPCOST_p$	-	Unit processing cost for process *p*
$UPCOST_{pm}$	-	Unit processing cost of process *p* for operating mode *m*
$URCOST_i$	-	Unit resource cost of resource *i*
$UTCOST_i$	-	Unit transportation cost of resource *i*
$UUCM_{p,u}$	-	Conversion yield of utility *u* via process p
$UUCOST_u$	-	Unit utility cost of utility *u*
VUD_{up}	-	Demand of utility *u* for one processing material unit *p*
$Year$	-	Operating hours in a year
$YEXP_{p,pc,z}$	-	Index for purchasing technology *p* with capacity *z* at process site *pc*
YOB_{bt}	-	Binary variable in operating biomass boiler *b* at period *t*
YOC_{ct}	-	Binary variable in operating CHF *c* at period *t*
$YOEXP_{t,pc,p,z}$	-	Index for determining the operation of technology *p* with capacity *z* at process site *pc* during period *t*
YOP_{tpz}	-	Number of process *p* equipment with capacity z being operated during period *t*
YPB_b	-	Binary variable in purchasing biomass boiler *b*
YPC_c	-	Binary variable in purchasing CHF *c*

YPC_{pc}	-	Index for constructing a process complex at process site *pc*
YP_{pz}	-	Number of process *p* equipment with capacity z being purchased

Greek Letters

$\sum$	-	Summation
$\forall$	-	All belong to

Subscripts

b	-	Index for biomass boiler and turbine
c	-	Index for CHF
f	-	Index of for paddy field and external rice mill (Chapter 6)
f	-	Index for fluidised bed dryer (Chapter 7)
i	-	Index for resource
i	-	Index for inclined bed dryer (Chapter 7)
j	-	Index for internal rice mill
k	-	Index for external rice mill
m	-	Index for operating mode
p	-	Index for process technology
pc	-	Index for process complex at process site
s	-	Index for distribution centre
t	-	Index for period

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Rice industry is one of the most important food industries in the world. Three billion people across the world consume rice, as the main product of the industry. This chapter provides an outlook of the global and local rice industry, followed by an introduction of the research background and problem statement. Next, the research objectives and the scope of this work related to the development of new systematic techniques to design an integrated, resource-efficient (IRE) rice mill complex are described. Finally, this chapter highlights five key contributions of this thesis that relevant to the research field and the rice industry.

1.2 Rice Outlook

According to FAOSTAT (2010), the global rice industry produces 672.0 million tonnes of paddy (unmilled rice) in year 2010, as presented in Table 1.1. Asia region alone contributes over 90% with China and India contributing some 29.3% and 17.9% shares of the total global output, respectively. In South East Asia region, Vietnam is the main producer, as it produces 6% of global rice output.

Rice demand is expected to remain strong in the next few decades due to the economic and population growths in many countries across Africa and Asia

(Mohanty, 2008). According to Timmer *et al.* (2010), the total rice consumption will be 450 million tonnes (milled basis) by year 2020, a 6.6 % growth as compared to 422 million tonnes in 2007.

Table 1.1 : Production quantity of paddy of year (FAOSTAT, 2009)

Regions	**Harvested Quantity (million t)**
Africa	22.86
Americas	37.17
Asia	607.33
China	197.21
India	120.62
Indonesia	66.41
Bangladesh	49.36
Vietnam	39.99
Myanmar	33.20
Thailand	31.60
Malaysia	2.55
Europe	4.44
Oceania	0.22
World	672.01

In Malaysia, 2.55 million tonnes of paddy is harvested from planting area of 673,745 hectares in year 2010 (FAOSTAT, 2010). However, in 2011, considering the damages caused by the flood due to the occurrence of “La Nina”, the harvested area has been forecasted to decline to 667,000 hectares. Subsequently, the milled rice production is anticipated to decrease to 1.6 million tonnes. Notwithstanding, the demand for rice is expected to remain strong. Experts predict that the annual rice consumption will increase by 4.2 % to 2.7 million tonnes in year 2011, due to the influx of foreign workers and population growth, whose main staple food is also rice.

To address the demand increase in rice, the Malaysian government has highlighted this issue in Eighth Malaysian Plan (2001-2005) and the Ninth Malaysia Plan (2006-2010). In these plans, Malaysia aimed to achieve 72 % and 90 % of rice self-sufficiency level (SSL) by 2005 and 2010, respectively (Yeong-Sheng *et al.*, 2009). However, in the Tenth Malaysia Plan (2011-2015), the target has been revised to 70 % of rice SSL by 2015 (Ho, 2011). With that, several measures have been taken by the government to stabilise the rice supply, for instance, by maintaining the rice stockpile at 292,000 tonnes or sustained consumption for 45 days. Also, the government will establish a long-term contract with countries to import rice, with the agreements to export palm oil or oil products to the corresponded countries. Note that no new paddy cultivation area will be assigned, with government aim to maintain or improve the rice production rate by upgrading the infrastructure of the existing planting areas.

1.3 Rice Supply Chain in Malaysia

The rice supply chain in Malaysia can be divided into the upstream and downstream industries. Figure 1.1 shows the rice supply chain in Malaysia. The activities of upstream industry consists of paddy harvesting, drying, rice milling and packaging plant, whilst the downstream industry involves value-process industry, for instance, vermicelli plant, rice flour mill, animal feed mill, rice bran oil plant. These products will be delivered to the wholesalers, before reaching the retailers or consumers.

For the upstream industry, Wong *et al.* (2010) reported some important figures in the year 2007, including:

a) 10 seed centres are in operation to supply seed to approximately 138,000 farmers, based on the subsidy figure.
b) The paddy harvested by the farmer was sold to 226 mills.
c) The products from these mills were purchased by 1239 wholesalers.
d) Local and imported rice were supplied to 44,637 retail outlets.

e) These rice products were then sold to 27.17 million of consumers.

Note that the rice mills produce a significant quantity of by-products such as broken rice, rice bran and rice husk. In the current practice, the rice milling company only utilises a small portion of these by-products at full economic potential. Rice husk is utilised as fuel for generating thermal energy that are required by the drying facilities. However, most of the by-products will be sold directly to the downstream industries at a subsistent price.

1.4 Problem Background

Up until now, most researchers, government agencies and rice companies have focused on research related to upstream rice-processing activities, for instance, paddy yield and soil fertility improvement. Yet in a newspaper article titled "Understanding the real causes of padi crisis", Jegatheesan (2003) has stressed that the limited drying capacities of rice mills is the bottleneck of the rice industry. During the peak drying period, the delay in the drying of harvested paddy will cause the quality degradation that can adversely affect the yield and the productivity of rice mills. The loss of productivity will hamper the efforts of government in improving the upstream activities' productivity. Besides, the existing by-products from rice mills are not fully utilised by the rice company (Wong *et al.*, 2010). The aforementioned challenges, along with the continuous rise in the energy cost and stricter environment regulations, have combined to emphasise the growing importance of the optimal planning and synthesis of a resource-efficient network of processes for the rice industry, i.e., IRE rice mill complex.

The IRE rice mill complex can be defined as an optimum rice mill network design that enhances its profitability by efficiently utilising its existing by-products, to produce value-added products and energy products that includes heat and electricity. The IRE complex considers the trade-off between processes, utility system and logistic network.

To date, the concept of an IRE rice mill complex is relatively new for rice industry, although there have been extensive amount of research works on process integration and supply chain integration in the conventional integrated petrochemical industry, pulp and paper industry and the bio-refinery industry. The research works in this study represents the evolution of process engineering applications beyond the domain of traditional chemical processes, into the realm of the rice industry.

Analysis of the existing literature shows that there is only one study focusing on the rice supply chain modelling (Wong, 2004). The contributions of that study were twofold. The first is to identify the bottleneck for the drying and storage capacities for the rice industry. The second is to evaluate the economic performance of the different scenarios that involves the capacity adjustments of rice drying and milling. The study, however, has not considered by-product utilisation and the utility systems. In addition, the study has also assumed that the user has predefined the technology and the equipment capacity. Clearly there is a need for a systematic approach of planning and designing an IRE rice mill that integrates the efficient utilisation of resources utilisation that includes utility systems.

In this work, a new cost-screening framework that known as Resource Efficient Screening (RES) has been introduced to screen and select the product and technology involved in rice value chain with the objective of maximising the profit. Subsequently, the concept of an IRE rice mill complex is introduced and applied for the first time in this work, by deploying a IRE framework that analyse the trade-off between product revenue, capital expenditure and utility consumption. The model is further extended into a multisite integrated, resource-efficient (MSIRE) framework that considers the supply chain management aspects of rice mill complexes at multiple sites. Finally, a framework that designs the optimal logistic network of rice husk in a rice mill that considers the utility supply network has been developed.

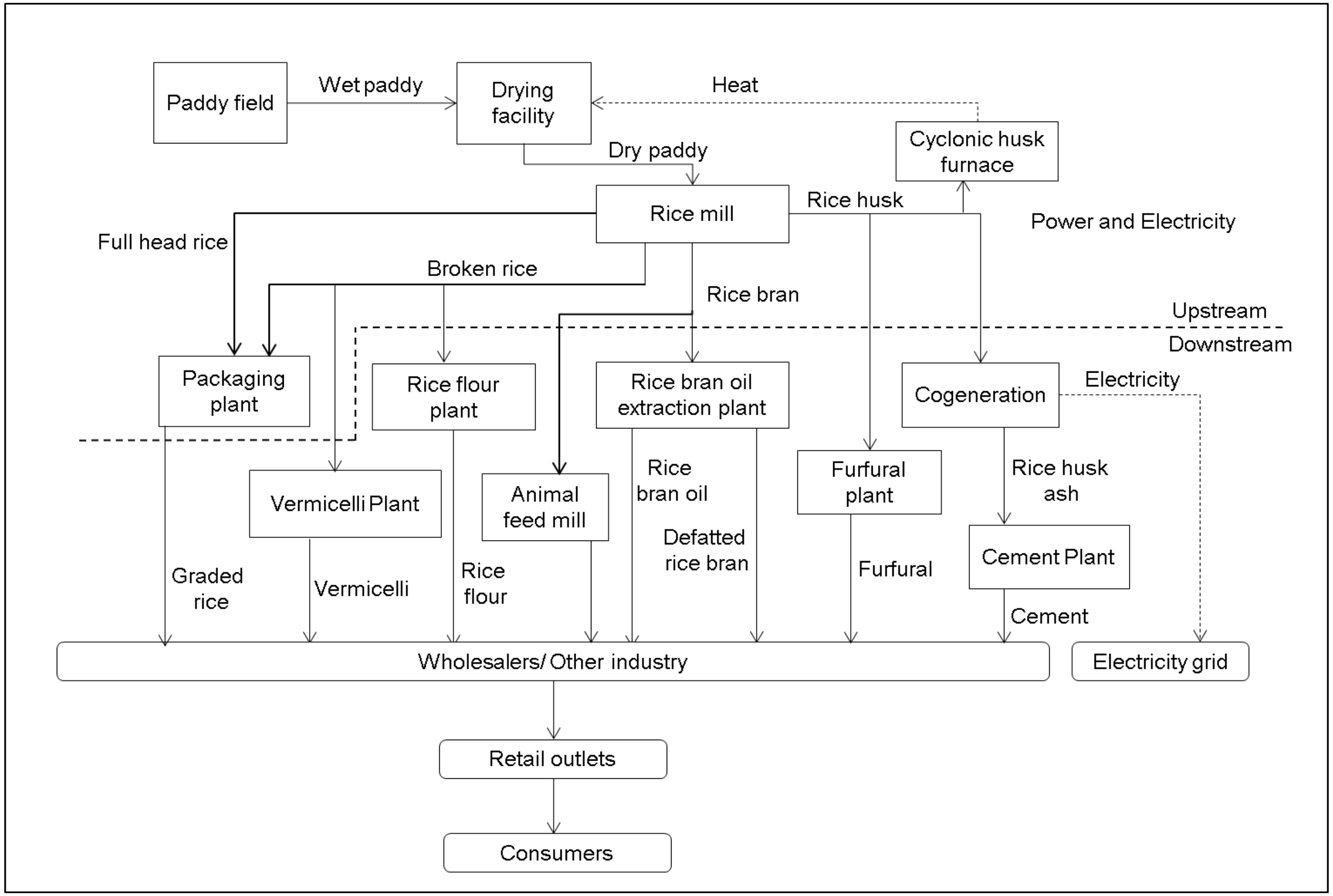

Figure 1.1 The rice supply chain in Malaysia

1.5 Problem Statement

Given a number of resources (materials) and a number of processes, it is desired to synthesise a resource-efficient network of processes that can preferentially utilise by-products of a process to produce energy and value-added products. Given also are the yield of each process, and its supply (inlet) composition. The flowrate of each resource is unknown and is to be determined to maximise the profit.

The flowrate of resources are bounded by their availability in the process complex and may not exceed the specified limits. On the other hand, certain resources and utilities can be purchased from sources external to the rice mill complex. The flowrates of resources are to be determined by considering the overall profit of the resource-efficient process network.

1.6 Research Objective

The main objective of this research is to develop a new systematic framework for designing an IRE process complex for the rice industry. The sub-objectives include performing

1) Optimal resource allocation and profit targeting for a rice value chain
2) Synthesis of an integrated process-utility network for a single-site IRE rice mill complex
3) Design and resource allocation planning for an integrated process-utility-logistic network for a cluster of IRE rice mill complex (multiple sites)
4) Design and configuration of an integrated rice husk logistic and utility network of a rice mill

1.7 Scope of the Work

The scope of this research includes:

1) Analysing the state-of-the-art procedure on supply chain and process optimisation in rice industry, including its features, shortcomings and potential improvement.
2) Identifying the key technologies in processing the by-products.
3) Developing a systematic framework for targeting the maximum profit and resource utilization planning for a set of rice resources. The developed model is then solved using Generalised Algebraic Modelling System (GAMS).
4) Developing a systematic framework for targeting the maximum profit and synthesing the integrated process-utility network for an IRE rice mill complex. The developed model is then solved using Generalised Algebraic Modelling System (GAMS).
5) Developing a systematic framework for rice supply chain planning that caters for both private rice miller and rice enterprise using mixed integer linear programming (MILP). The developed model is then solved using Generalised Algebraic Modelling System (GAMS).
6) Developing a systematic framework for designed the integrated rice husk logistic-utilty network for a rice mill that consist of cogeneration system and cyclonic husk furnace using mixed integer linear programming (MILP). The developed model is then solved using Generalised Algebraic Modelling System (GAMS).
7) Applying the optimisation models on industry case studies to demonstrate the effectiveness of the proposed framework in solving problems.
8) Comparing the economic performance of conventional rice mill and IRE rice mill complex.

1.8 Research Contributions

The key specific contributions of this work are summarised as follows:

1) A new optimisation model known as *Resource-Efficient Screening (RES) model* for synthesising the resource-efficient network for rice value chain.
    - A generic model has been developed to obtain optimal product portfolio and process selection, along with its resource allocation strategy while maximising the profit.
2) A new optimisation model known as *IRE model* to design IRE rice mill complex.
    - The concept of IRE rice mill complex is introduced. A multi-period generic model is able to solve the complex design problem that considers resource availability, shelf-life issue, and variation of heat and electricity demand across the periods, energy supply options, trade-off of by-product selling and further processing, supply and demand constraints to achieve maximum profit.
3) A new optimisation model known as *Multi-Site Integrated, Resource-Efficient (MSIRE) model* for designing IRE rice mill complexes at multiple sites.
    - A generic mixed integer linear programming (MILP) model that is capable of determining the design of IRE rice mill complex, resource allocation and logistic network at different process sites.
4) A new process network for an IRE rice mill complex
    - A process network that incorporates rice milling process with other value-added process.
5) A new optimisation model known as *Optimal Utility-Logistic (OUL) model* to design and configure rice husk logistic and utility network of a rice mill that includes a cogeneration system.
    - A MILP has been developed based on the superstructure of a rice mill that considers rice the husk logistic network and the

utility configuration to simultaneously design the cogeneration system and configure the logistic-utility network.

Appendix highlights all the publications and the corresponding key contributions of this thesis towards the new body of knowledge in designing and planning of an IRE rice mill.

This thesis consists of six chapters. Chapter 1 gives an overview of the rice industry issues, problem background, problem statement, objectives and scope of the research which aims to develop new systematic framework for designing an IRE rice mill complex using the mathematical approach. Chapter 2 of this thesis describes the fundamental theory and relevant literature related to the design of an IRE rice mill complex. Chapter 3 presents a detailed methodology of this study to achieve the targeted objectives. Chapter 4, 5, 6, 7 present the results and discussion from the application of new methods on the rice industry to showcase the effectiveness and advantages of the developed methodology. Finally, Chapter 8 summarises the key contributions of this research, prior to the recommendation of possible future work. Figure 1.2 shows the flow and linkage of the chapters.

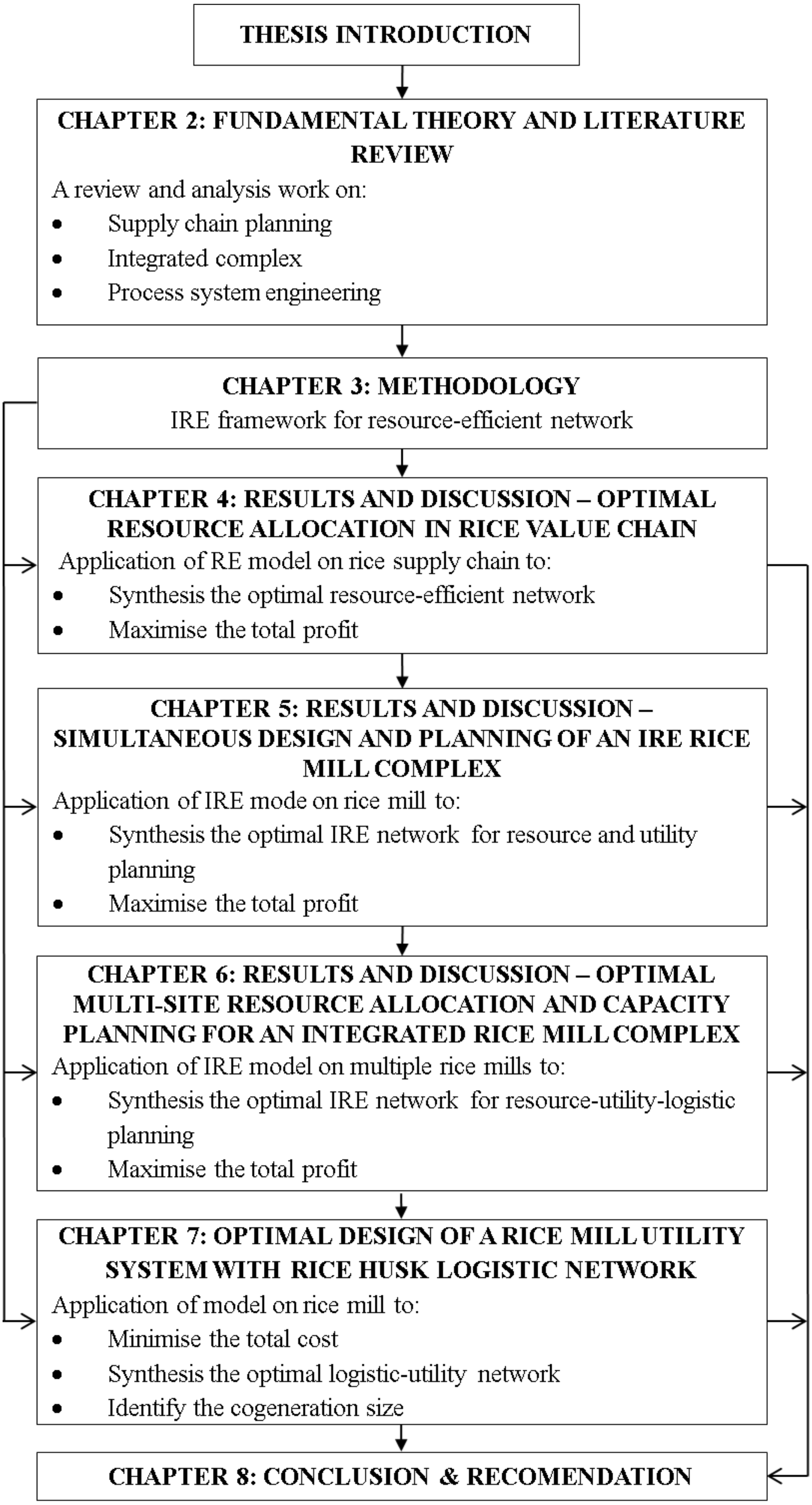

Figure 1.2 Flow diagram illustrating the conceptual link among the chapters

REFERENCES

Afzalinia, S., Shaker, M. and Zare, E. (2002). Comparison of different rice milling methods. *Proceedings of the 2002*, 27-28.

Ahiduzzaman, M. and Islam, A. K. S. (2009). Energy Utilization and Environmental Aspects of Rice Processing Industries in Bangladesh. *Energies*. 2(1), 134-149.

Al-Sharrah, G. K., Alatiqi, I. and Elkamel, A. (2003). Modeling and Identification of Economic Disturbances in the Planning of the Petrochemical Industry. *Industrial & Engineering Chemistry Research*. 42(20), 4678-4688.

Al-Sharrah, G. K., Alatiqi, I., Elkamel, A. and Alper, E. (2001). Planning an Integrated Petrochemical Industry with an Environmental Objective. *Industrial & Engineering Chemistry Research*. 40(9), 2103-2111.

Amarasinghe, B. M. W. P. K., Kumarasiri, M. P. M. and Gangodavilage, N. C. (2009). Effect of method of stabilization on aqueous extraction of rice bran oil. *Food and Bioproducts Processing*. 87(2), 108-114.

Arivalagan, A., Raghavendra, B. and Rao, A. (1995). Integrated energy optimization model for a cogeneration based energy supply system in the process industry. *International Journal of Electrical Power & Energy Systems*. 17(4), 227-233.

Ayrilmis, N., Kwon, J. H. and Han, T. H. (2012). Effect of resin type and content on properties of composite particleboard made of a mixture of wood and rice husk. *International Journal of Adhesion and Adhesives*. 38(0), 79-83.

Bao, B., Ng, D. K. S., Tay, D. H. S., Jiménez-Gutiérrez, A. and El-Halwagi, M. M. (2011). A shortcut method for the preliminary synthesis of process-technology pathways: An optimization approach and application for the conceptual design of integrated biorefineries. *Computers & Chemical Engineering*. 35(8), 1374-1383.

Bautista, E., Aldas, R. and Gagelonia, E. (1996). Rice Hull Furnaces for Paddy Drying: the Philippine Rice Research Institute's Experience. *Proceedings of the 1996*, 253-260.

BERNAS. Standard Sequence of Rice Processing. Retrieved December 2011, from http://www.bernas.com.my/

Bhagiyalakshmi, M., Yun, L. J., Anuradha, R. and Jang, H. T. (2010). Utilization of rice husk ash as silica source for the synthesis of mesoporous silicas and their application to CO2 adsorption through TREN/TEPA grafting. *Journal of Hazardous Materials*. 175(1-3), 928-938.

Bondioli, F., Andreola, F., Barbieri, L., Manfredini, T. and Ferrari, A. M. (2007). Effect of rice husk ash (RHA) in the synthesis of (Pr,Zr)SiO4 ceramic pigment. *Journal of the European Ceramic Society*. 27(12), 3483-3488.

Brown, G. G., Graves, G. W. and Honczarenko, M. D. (1987). Design and operation of a multicommodity production/distribution system using primal goal decomposition. *Management Science*. 1469-1480.

Candler, W., Snyder, J. C. and Faught, W. (1972). Concave Programming Applied to Rice Mill Location. *American Journal of Agricultural Economics*. 54(1), 126-130.

Caputo, A. C., Palumbo, M., Pelagagge, P. M. and Scacchia, F. (2005). Economics of biomass energy utilization in combustion and gasification plants: effects of logistic variables. *Biomass and Bioenergy*. 28(1), 35-51.

Carrocci, L. and James, E. (1991). Cogeneration at alcohol production plants in Brazil. *Energy*. 16(8), 1147-1151.

Chau, N. and Kunze, O. (1982). Moisture content variation among harvested rice grains. *Transactions of the ASAE*. 25(4), 1037-1040.

Chiang, P. Y. and Yeh, A. I. (2002). Effect of Soaking on Wet-milling of Rice. *Journal of Cereal Science*. 35(1), 85-94.

Chuah, T., Azlina, A. G. K. W., Robiah, Y. and Omar, R. (2006). Biomass as the renewable energy sources in Malaysia: an overview. *International journal of green energy*. 3(3), 323-346.

Danielski, L., Zetzl, C., Hense, H. and Brunner, G. (2005). A process line for the production of raffinated rice oil from rice bran. *The Journal of supercritical fluids*. 34(2), 133-141.

Daño, E. C. and Samonte, E. D. (2005). Public sector intervention in the rice industry in Malaysia. *State intervention in the rice sector in selected countries: Implications for the Philippines*.

Dasci, A. and Verter, V. (2001). A continuous model for production–distribution system design. *European Journal of Operational Research*. 129(2), 287-298.

Dhaenens-Flipo, C. and Finke, G. (2001). An integrated model for an industrial production-distribution problem. *IIE Transactions*. 33(9), 705-715.

Dorfman, R., Samuelson, P. A. and Solow, R. M. (1987). *Linear programming and economic analysis*. Dover Pubns.

Douglas, P., Jones, J. and Mallick, S. (1994). Modeling and Simulation of Cross-Flow Grain Dryers. 3. Optimization. *Chemical engineering research & design*. 72(3), 341-349.

Edgar, T. F., Himmelblau, D. M. and Lasdon, L. S. (1988). Optimization of chemical processes. *New York*.

Edgar, T. F., Himmelblau, D. M. and Lasdon, L. S. (2001). *Optimization of Chemical Processes*. McGraw-Hill.

EnergyNexusGroup. (2002). Technology Characterization: Steam Turbines.

FAOSTAT, F. (2009). Agriculture Organization of the United Nations. *Statistical Database*.

FAOSTAT, F. (2010). Agriculture Organization of the United Nations. *Statistical Database*.

Gamou, S., Yokoyama, R. and Ito, K. (2002). Optimal unit sizing of cogeneration systems in consideration of uncertain energy demands as continuous random variables. *Energy Conversion and Management*. 43(9-12), 1349-1361.

Gaucher, S., Le Gal, P. and Soler, G. (2003). Modelling supply chain management in the sugar industry. *Proceedings of the 2003*, 542-554.

Geoffrion, A. M. and Graves, G. W. (1974). Multicommodity Distribution System Design by Benders Decomposition. *Management Science*. 20(5), 822-844.

Geoffrion, A. M. and Van Roy, T. J. (1979). Caution: Common sense planning methods can be hazardous to your corporate health. *Sloan Management Review*. 20(4), 31-42.

Golmohammadi, M., Rajabi-Hamane, M. and Hashemi, S. J. (2011). Optimization of Drying–Tempering Periods in a Paddy Rice Dryer. *Drying Technology*. 30(1), 106-113.

Goodman, D. E. and Rao, R. M. (1985). Effect of Grain Type and Milled Rice Kernel Hardness on the Head Rice Yields. *Journal of Food Science*. 50(3), 840-840.

Grossmann, I. E., Van Den Heever, S. A. and Harjunkoski, I. (2002). Discrete optimization methods and their role in the integration of planning and scheduling. *Proceedings of the 2002*: Citeseer, 150-168.

Grossmann, I. E. and Westerberg, A. W. (2000). Research challenges in process systems engineering. *AICHE Journal*. 46(9), 1700-1703.

Guinet, A. (2001). Multi-site planning: A transshipment problem. *International Journal of Production Economics*. 74(1-3), 21-32.

Gupta, A. and Maranas, C. D. (2003). Managing demand uncertainty in supply chain planning. *Computers & Chemical Engineering*. 27(8-9), 1219-1227.

Higgins, A. (1999). Optimizing cane supply decisions within a sugar mill region. *Journal of Scheduling*. 2(5), 229-244.

Higgins, A., Antony, G., Sandell, G., Davies, I., Prestwidge, D. and Andrew, B. (2004). A framework for integrating a complex harvesting and transport system for sugar production. *Agricultural Systems*. 82(2), 99-115.

Hinman, N., Schell, D., Riley, J., Bergeron, P. and Walter, P. (1992). Preliminary estimate of the cost of ethanol production for SSF technology. *Applied biochemistry and biotechnology*. 34(1), 639-649.

Ho, R. (2011). Malaysia- Grain and Feed Annual *GAIN Report*. USDA Foreign Agricultrual Service.

Iannoni, A. P. and Morabito, R. (2006). A discrete simulation analysis of a logistics supply system. *Transportation Research Part E: Logistics and Transportation Review*. 42(3), 191-210.

Ibrahim, S. (2008). *Transportation Optimization Model Of Palm Oil Products For Northern Peninsular Malaysia*, Universiti Sains Malaysia.

Imoudu, P. B. and Olufayo, A. (2000). The effect of sun-drying on milling yield and quality of rice. *Bioresource Technology*. 74(3), 267-269.

Indira, T., Hemavathy, J., Khatoon, S., Gopala Krishna, A. and Bhattacharya, S. (2000). Water degumming of rice bran oil: a response surface approach. *Journal of Food Engineering*. 43(2), 83-90.

Inprasit, C. and Noomhorm, A. (2001). Effect of Drying Air Temperature and Grain Temperature of Different Types of Dryer and Operation on Rice Quality. *Drying Technology*. 19(2), 389-404.

International Rice Research Institute (IRRI) (2009). Heating System. Retrieved May 2012., from http://www.knowledgebank.irri.org/rkb/dryer-components/heating-system.html

Ismail, M. S. and Waliuddin, A. M. (1996). Effect of rice husk ash on high strength concrete. *Construction and Building Materials*. 10(7), 521-526.

Jegatheesan, S. (2003). Understanding the real causes of padi crisis. *New Straits Time*. Retrieved

Jittanit, W., Saeteaw, N. and Charoenchaisri, A. (2010). Industrial paddy drying and energy saving options. *Journal of Stored Products Research*. 46(4), 209-213.

Jongkaewwattana, S. and Geng, S. (2001). Inter-relationships Amongst Grain Characteristics, Grain-Filling Parameters and Rice (Oryza sativa L.) Milling Quality. *Journal of agronomy and crop science*. 187(4), 223-229.

Ju, Y. and Vali, S. R. (2005). Rice bran oil as a potential resource for biodiesel: a review. *Journal of scientific and industrial research*. 64(11), 866.

Junqueira, R. A. R. and Morabito, R. (2012). Production and logistics planning considering circulation taxes in a multi-plant seed corn company. *Computers and Electronics in Agriculture*. 84(0), 100-110.

Kale, V., Katikaneni, S. and Cheryan, M. (1999). Deacidifying rice bran oil by solvent extraction and membrane technology. *Journal of the American Oil Chemists' Society*. 76(6), 723-727.

Kapur, T., Kandpal, T. and Garg, H. (1997). Rice processing in India: A generalized framework for energy demand estimation. *International Journal of Energy Research*. 21(4), 309-325.

Kawamura, M. S., Ronconi, D. P. and Yoshizaki, H. (2006). Optimizing transportation and storage of final products in the sugar and ethanol industry: a case study. *International Transactions in Operational Research*. 13(5), 425-439.

Kim, Y., Yun, C., Park, S. B., Park, S. and Fan, L. (2008). An integrated model of supply network and production planning for multiple fuel products of multi-site refineries. *Computers & Chemical Engineering*. 32(11), 2529-2535.

Kocher, M., Siebenmorgen, T., Norman, R. and Wells, B. (1990). Rice kernel moisture content variation at harvest. *Transactions of the ASAE*. 33(2), 541-548.

Kopanos, G. M. and Puigjaner, L. (2009). Multi-Site Scheduling/Batching and Production Planning for Batch Process Industries. *Computer Aided Chemical Engineering*. 27, 2109-2114.

Kostin, A. M., Guillén-Gosálbez, G., Mele, F. D., Bagajewicz, M. J. and Jiménez, L. (2012). Design and planning of infrastructures for bioethanol and sugar production under demand uncertainty. *Chemical Engineering Research and Design*. 90(3), 359-376.

Lakkakula, N. R., Lima, M. and Walker, T. (2004). Rice bran stabilization and rice bran oil extraction using ohmic heating. *Bioresource Technology*. 92(2), 157-161.

Lambert, D. M. and Cooper, M. C. (2000). Issues in supply chain management. *Industrial marketing management*. 29(1), 65-83.

Levis, A. A. and Papageorgiou, L. G. (2004). A hierarchical solution approach for multi-site capacity planning under uncertainty in the pharmaceutical industry. *Computers & Chemical Engineering*. 28(5), 707-725.

Lim, J. S., Abdul Manan, Z., Wan Alwi, S. R. and Hashim, H. (2012). A review on utilisation of biomass from rice industry as a source of renewable energy. *Renewable and Sustainable Energy Reviews*. 16(5), 3084-3094.

Lim, J. S., Hashim, H., Manan, Z. A. and Wan Alwi, S. R. (2011). Optimal Design of a Rice Mill Utility System with Rice Husk Logistic Network. *Industrial & Engineering Chemistry Research*. 51(1), 362-373.

Loypimai, P., Moonggarm, A. and Chottanom, P. (2009). Effects of Ohmic Heating on Lipase Activity, Bioactive Compounds and Antioxidant Activity of Rice Bran. *Australian Journal of Basic and Applied Sciences*. 3(4), 3642-3652.

Luenberger, D. G. and Ye, Y. (2008). *Linear and nonlinear programming*. (Vol. 116)Springer Verlag.

Lyon, B. G., Champagne, E. T., Vinyard, B. T., Windham, W. R., Barton, F. E., Webb, B. D., McClung, A. M., Moldenhauer, K. A., Linscombe, S. and McKenzie, K. S. (1999). Effects of degree of milling, drying condition, and final moisture content on sensory texture of cooked rice. *Cereal Chemistry*. 76(1), 56-62.

Mai Thao, P. T., Kurisu, K. H. and Hanaki, K. (2011). Greenhouse gas emission mitigation potential of rice husks for An Giang province, Vietnam. *Biomass and Bioenergy*. 35(8), 3656-3666.

Manan, Z. A., Wan Alwi, S. R. and Lim, J. S. (2011). PERTAMINA Heat Exchanger Network Retrofit Project Report

Mansaray, K. G. and Ghaly, A. E. (1998). Thermal degradation of rice husks in nitrogen atmosphere. *Bioresource Technology*. 65(1–2), 13-20.

Mansoornejad, B., Chambost, V. and Stuart, P. (2010). Integrating product portfolio design and supply chain design for the forest biorefinery. *Computers & Chemical Engineering*. 34(9), 1497-1506.

Matsuoka, S., Ferro, J. and Arruda, P. (2011). The Brazilian experience of sugarcane ethanol industry. *Biofuels*. 157-172.

McCaskill, D. R. and Zhang, F. (1999). Use of rice bran oil in foods. *Food Technology*. 53, 50-53.

Mohanty, S. (2008). Rice crisis: the aftermath. *Rice Today*. 7(4).

Mokhtar, H. (2002). Malaysian Energy Situation. *EC-ASEAN COGEN program phase III, Shah Alam, Malaysia*.

Moraes, C. A. M., Kieling, A. G., Caetano, M. O. and Gomes, L. P. (2010). Life cycle analysis (LCA) for the incorporation of rice husk ash in mortar coating. *Resources, Conservation and Recycling*. 54(12), 1170-1176.

Morandin, M., Toffolo, A., Lazzaretto, A., Maréchal, F., Ensinas, A. V. and Nebra, S. A. (2011). Synthesis and parameter optimization of a combined sugar and ethanol production process integrated with a CHP system. *Energy*. 36(6), 3675-3690.

Mujeebu, M., Abdullah, M. and Ashok, S. (2011a). Husk-Fueled Steam Turbine Cogeneration for a Rice Mill with Power Export—A Case Study. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*. 33(8), 724-734.

Mujeebu, M. A., Abdullah, M. Z. and Ashok, S. (2011b). Husk-Fueled Steam Turbine Cogeneration for a Rice Mill with Power Export—A Case Study. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*. 33(8), 724-734.

Munawar, S., Kapadi, M. D., Patwardhan, S., Madhavan, K., Pragathieswaran, S., Lingathurai, P. and Gudi, R. D. (2005). Integration of planning and scheduling in multi-site plants: Application to paper manufacturing. *Computer Aided Chemical Engineering*. 20, 1621-1626.

Ng, D. K. S. (2010). Automated targeting for the synthesis of an integrated biorefinery. *Chemical Engineering Journal*. 162(1), 67-74.

Ngamnikom, P. and Songsermpong, S. (2011). The effects of freeze, dry, and wet grinding processes on rice flour properties and their energy consumption. *Journal of Food Engineering*.

Nonato, R. N., Mantelatto, P. M. and Rossell, C. R. (2001). Integrated production of biodegradable plastic, sugar and ethanol. *Applied Microbiology and Biotechnology*. 57(1), 1-5.

Omobuwajo, T., Ige, M. and Ajayi, A. (1998). Theoretical prediction of extrusion pressure and oil flow rate during screw expeller processing of palm kernel seeds. *Journal of Food Engineering*. 38(4), 469-485.

Paiva, R. and Morabito, R. (2009). An optimization model for the aggregate production planning of a Brazilian sugar and ethanol milling company. *Annals of Operations Research*. 169(1), 117-130.

Pan, Z., Khir, R., Godfrey, L. D., Lewis, R., Thompson, J. F. and Salim, A. (2008). Feasibility of simultaneous rough rice drying and disinfestations by infrared radiation heating and rice milling quality. *Journal of Food Engineering*. 84(3), 469-479.

Patel, M. and Naik, S. (2004). Gamma-oryzanol from rice bran oil: a review. *Journal of scientific & industrial research*. 63, 569-578.

Pham, V. and El-Halwagi, M. (2012). Process synthesis and optimization of biorefinery configurations. *AICHE Journal*. 58(4), 1212-1221.

Phongpipatpong, M. and Douglas, P. (2003a). Synthesis of rice processing plants. I. Development of simplified models. *Drying Technology*. 21(9), 1595-1610.

Phongpipatpong, M. and Douglas, P. (2003b). Synthesis of rice processing plants. II. MINLP optimization. *Drying Technology*. 21(9), 1611-1629.

Phongpipatpong, M. and Douglas, P. (2003c). Synthesis of rice processing plants.. III. Sensitivity analysis. *Drying Technology*. 21(9), 1631-1610.

Pourali, O., Salak Asghari, F. and Yoshida, H. (2009). Simultaneous rice bran oil stabilization and extraction using sub-critical water medium. *Journal of Food Engineering*. 95(3), 510-516.

Proctor, A. and Bowen, D. (1996). Ambient-temperature extraction of rice bran oil with hexane and isopropanol. *Journal of the American Oil Chemists' Society*. 73(6), 811-813.

Ramezanzadeh, F. M., Rao, R. M., Prinyawiwatkul, W., Marshall, W. E. and Windhauser, M. (1999a). Effects of Microwave Heat, Packaging, and Storage Temperature on Fatty Acid and Proximate Compositions in Rice Bran. *Journal of Agricultural and Food Chemistry*. 48(2), 464-467.

Ramezanzadeh, F. M., Rao, R. M., Windhauser, M., Prinyawiwatkul, W., Tulley, R. and Marshall, W. E. (1999b). Prevention of hydrolytic rancidity in rice bran during storage. *Journal of Agricultural and Food Chemistry*. 47(8), 3050-3052.

Rao, P. S., Bal, S. and Goswami, T. (2007). Modelling and optimization of drying variables in thin layer drying of parboiled paddy. *Journal of Food Engineering*. 78(2), 480-487.

Rice, C. W. H. (1952). Method of stabilizing rice products. Google Patents.

Richardson, J. F., Coulson, J. M., Harker, J. and Backhurst, J. (2002). *Chemical Engineering: Particle technology and separation processes*. (Vol. 2)Butterworth-Heinemann.

RISE (2007). Product Catalog. Rice Engineering Supply CO., Ltd.

Rogers, E., Rice, S., Nicolosi, R., Carpenter, D., McClelland, C. and Romanczyk, L. (1993). Identification and quantitation of γ-oryzanol components and simultaneous assessment of tocols in rice bran oil. *Journal of the American Oil Chemists' Society*. 70(3), 301-307.

Roy, P., Shimizu, N., Okadome, H., Shiina, T. and Kimura, T. (2007). Life cycle of rice: Challenges and choices for Bangladesh. *Journal of Food Engineering*. 79(4), 1250-1255.

Sammons Jr, N., Yuan, W., Bommareddy, S., Eden, M., Aksoy, B. and Cullinan, H. (2009). A Systematic Approach to Determine Economic Potential and Environmental Impact of Biorefineries. In Jacek, J. & Jan, T. (Eds.) *Computer Aided Chemical Engineering* (Vol. Volume 26, pp. 1135-1140).Elsevier.

Sammons Jr, N. E., Yuan, W., Eden, M. R., Aksoy, B. and Cullinan, H. T. (2008). Optimal biorefinery product allocation by combining process and economic modeling. *Chemical Engineering Research and Design*. 86(7), 800-808.

Santibañez-Aguilar, J. E., González-Campos, J. B., Ponce-Ortega, J. M. a., Serna-González, M. and El-Halwagi, M. M. (2011). Optimal Planning of a Biomass Conversion System Considering Economic and Environmental Aspects. *Industrial & Engineering Chemistry Research*. 50(14), 8558-8570.

Sarmento, C., Ferreira, S. and Hense, H. (2006). Supercritical fluid extraction (SFE) of rice bran oil to obtain fractions enriched with tocopherols and tocotrienols. *Brazilian Journal of Chemical Engineering*. 23(2), 243-249.

Schrijver, A. (1998). *Theory of linear and integer programming*. John Wiley & Sons Inc.

Shafie, S., Mahlia, T., Masjuki, H. and Ahmad-Yazid, A. (2012). A review on electricity generation based on biomass residue in Malaysia. *Renewable and Sustainable Energy Reviews*. 16(8), 5879-5889.

Sharma, A., Khare, S. and Gupta, M. (2001). Enzyme-assisted aqueous extraction of rice bran oil. *Journal of the American Oil Chemists' Society*. 78(9), 949-951.

Shen, Z., Palmer, M. V., Ting, S. S. T. and Fairclough, R. J. (1997). Pilot scale extraction and fractionation of rice bran oil using supercritical carbon dioxide. *Journal of Agricultural and Food Chemistry*. 45(12), 4540-4544.

Shimizu, N., Katsuragi, Y., Kimura, T., Toriyama, K., Heong, K. and Hardy, B. (2005). Status of rice milling and use of by-products. *Proceedings of the 2005*: International Rice Research Institute (IRRI), 299-301.

Shiun, L. J., Hashim, H., Manan, Z. A. and Wan Alwi, S. R. (2011). Optimal Design of a Rice Mill Utility System with Rice Husk Logistic Network. *Industrial & Engineering Chemistry Research*. 51(1), 362-373.

Soponronnarit, S. and Prachayawarakorn, S. (1994). Optimum strategy for fluidized bed paddy drying. *Drying Technology*. 12(7), 1667-1686.

Soponronnarit, S., Swasdisevi, T., Wetchacama, S., Shujinda, A. and Srisawat, B. (2000a). Cyclonic rice husk furnace and its application on paddy drying. *International Energy Journal*. 1(2), 67-75.

Soponronnarit, S., Swasdisevi, T., Wetchacama, S., Shujinda, A. and Srisawat, B. (2000b). Cyclonic rice husk furnace and its application on paddy drying. *International Energy Journal*. 1(2), 67.

Soponronnarit, S., Yapha, M. and Pracbayawarakorn, S. (1995). Cross-flow fluidized bed paddy dryer: prototype and commercialization. *Drying Technology*. 13(8), 2207-2216.

Sopornonnarit, S., prachayawarakorn, S. and Sripawaatakul, O. (1996). Development of cross-flow fluidized bed paddy dryer. *Drying Technology*. 14(10), 2397-2410.

Steffe, J., Singh, R. and Miller, G. (1980). Harvest, drying and storage of rough rice. *Rice production and utilization. BS Luh. AVI Pub Co. Inc. Westport CT.*

Subramani, S., Nagarajan, G. and Lakshmi Narayana Rao, G. (2008). High Free Fatty Acid Crude Rice Bran Oil – A Renewable Feedstock for Sustainable Energy and Environment. *CLEAN – Soil, Air, Water*. 36(10-11), 835-839.

Swasdisevi, T., Soponronnarit, S., Shujinda, A., Wetchacama, S. and Thepent, V. (1997). Rice husk furnace for fluidized bed paddy dryer. *Proceedings of the 1997,*

Takamatsu, T. (1983). The nature and role of process systems engineering. *Computers & Chemical Engineering*. 7(4), 203-218.

Tao, J., Rao, R. and Liuzzo, J. (1993). Microwave heating for rice bran stabilization. *Journal of microwave power and electromagnetic energy*. 28(3), 156-164.

Tay, D. H. S., Ng, D. K. S., Sammons, N. E. and Eden, M. R. (2011). Fuzzy Optimization Approach for the Synthesis of a Sustainable Integrated Biorefinery. *Industrial & Engineering Chemistry Research*. 50(3), 1652-1665.

Thanonkaew, A., Wongyai, S., McClements, D. J. and Decker, E. A. (2012). Effect of stabilization of rice bran by domestic heating on mechanical extraction yield, quality, and antioxidant properties of cold-pressed rice bran oil (Oryza saltiva L.). *LWT - Food Science and Technology*. 48(2), 231-236.

Timmer, C. P., Block, S. and Dawe, D. (2010). Long-run dynamics of rice consumption, 1960-2050. *Rice in the Global Economy: Strategic Research and Policy Issues for Food Security*. 139.

Uran, V. (2006). Optimization system for combined heat and electricity production in the wood-processing industry. *Energy*. 31(14), 2996-3016.

Van Heiningen, A. (2006). Converting a kraft pulp mill into an integrated forest products biorefinery. *Proceedings of the 2006*: Pulp and Paper Technical Association of Canada; 1999, 167.

Van Roy, T. J. (1989). Multi-level production and distribution planning with transportation fleet optimization. *Management Science*. 1443-1453.

Verderame, P. M. and Floudas, C. A. (2009). Operational planning framework for multisite production and distribution networks. *Computers & Chemical Engineering*. 33(5), 1036-1050.

Webb, B. (1991). Rice quality and grades. *Rice utilization*. 2, 89-116.

Webb, B., Pomeranz, Y., Afework, S., Lai, F. and Bollich, C. (1986). Rice grain hardness and its relationship to some milling, cooking, and processing characteristics. *Cereal Chem*. 63, 27-30.

Wilasinee, S., Imran, A. and Athapol, N. (2010). Optimization of Rice Supply Chain in Thailand: A Case Study of Two Rice Mills. *Sustainability in Food and Water*. 263-280.

Wising, U. and Stuart, P. (2006). Identifying the Canadian forest biorefinery. *Pulp and Paper Canada*. 107(6), 25-30.

Wong, L. C. Y., Emrus, S. A., Bashir, B. M. and Tey, J. Y. S. (2010). Malaysian padi and rice industry: Applications of supply chain management approach. *Proceedings of the 2010*, 28-30.

Wong, S. Y. (2004). *Modeling the Rice Supply Chain in Malaysia*, Malaysia University of Science and Technology

Wongpornchai, S., Dumri, K., Jongkaewwattana, S. and Siri, B. (2004). Effects of drying methods and storage time on the aroma and milling quality of rice (Oryza sativa L.) cv. Khao Dawk Mali 105. *Food Chemistry*. 87(3), 407-414.

Wongrat, W., Younes, A., Elkamel, A., Douglas, P. L. and Lohi, A. (2011). Control vector optimization and genetic algorithms for mixed-integer dynamic optimization in the synthesis of rice drying processes. *Journal of the Franklin Institute*. 348(7), 1318-1338.

Yandra, Y., Jamaran, I., Marimin, M., Eriyatno, E. and Tamura, H. (2007). An Integration of Genetic Algorithm and Fuzzy Logic for Optimization of Agroindustrial Supply Chain Design. *Proceedings of the 2007*,

Yeh, A. I. (2004). Preparation and applications of rice flour. *Rice chemistry and technology. 3rd ed. St. Paul, Minn.(USA): American Association of Cereal Chemists. p*. 495-539.

Yeong-Sheng, T., Darham, S., Mohd Noh, A. F. and Idris, N. (2009). Acreage response of rice: A case study in Malaysia. *MPRA Paper*.

Zullaikah, S., Lai, C. C., Vali, S. R. and Ju, Y. H. (2005). A two-step acid-catalyzed process for the production of biodiesel from rice bran oil. *Bioresource Technology*. 96(17), 1889-1896.

Zuo, M., Kuo, W. and McRoberts, K. L. (1991). Application of mathematical programming to a large-scale agricultural production and distribution system. *Journal of the Operational Research Society*. 639-648.