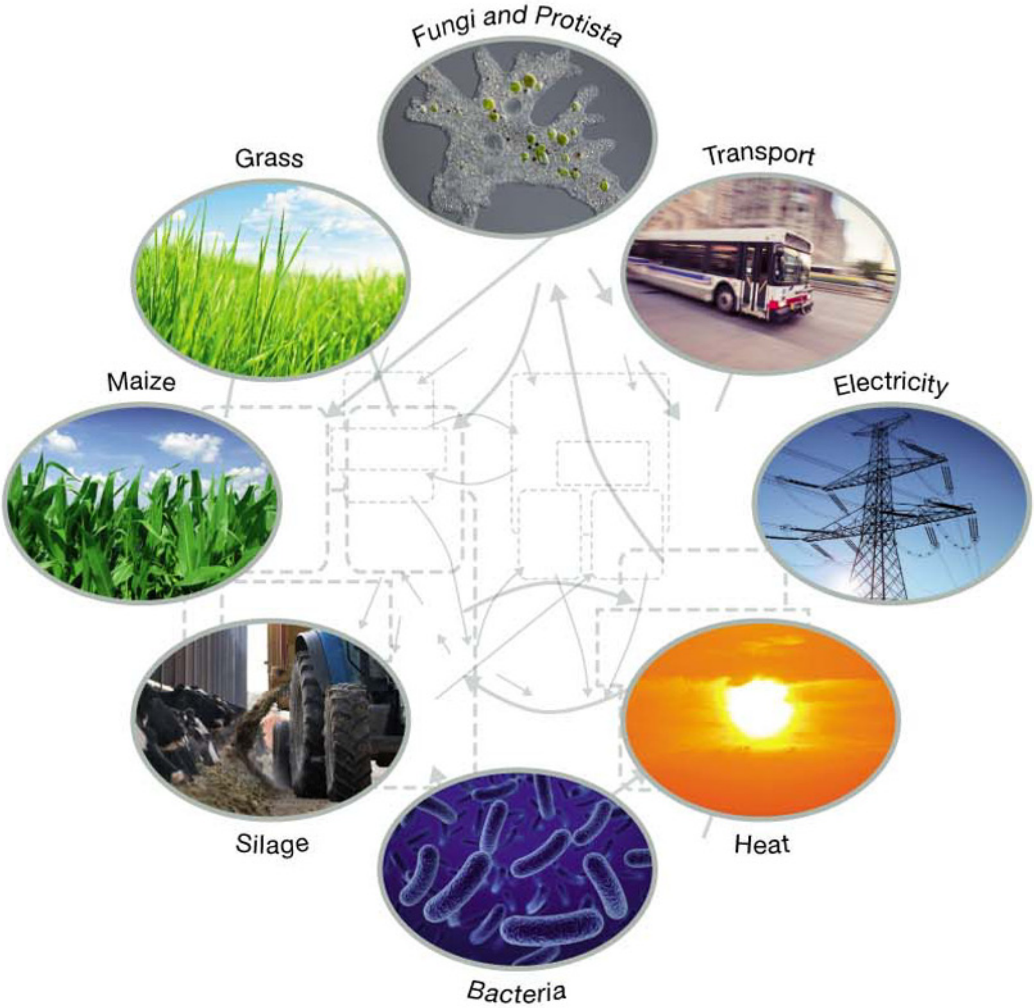
Bioenergy Production by Anaerobic Digestion

Using agricultural biomass and organic wastes



Edited by

Nicholas E. Korres, Padraig O'Kiely,
John A. H. Benzie and Jonathan S. West

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Interest in anaerobic digestion (AD), the process of energy production through the production of biogas, has increased rapidly in recent years. It comes as the need to seek alternative renewable energy sources to fossil fuels, as well as reduce landfill waste and greenhouse gases, has accentuated. Agricultural and other organic waste are important substrates that can be treated by AD.

This book is one of the first to provide a broad introduction to anaerobic digestion and its potential to turn agricultural crops or crop residues, animal and other organic waste, into biomethane. The substrates used can include any non-woody materials, including grass and maize silage, seaweeds, municipal and industrial wastes. These are all systematically reviewed in terms of their suitability from a biological, technical and economic perspective. In the past the technical competence and high capital investment required for industrial-scale anaerobic digesters has limited their uptake, but the authors show that recent advances have made smaller-scale systems more viable through a greater understanding of optimising bacterial metabolism and productivity. Broader issues such as life cycle assessment and energy policies to promote AD are also discussed.

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A large part of this book was completed in a hospital room where, for the past 3 years, I was keeping company to my mother Sophia Korres while she was fighting against her illness. I dedicate this book to her memory because she taught me the value of hard and honest work but above all how to pursue my dreams with dignity.

Nicholas E. Korres

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Preface

Lignocellulosic biomass and organic wastes are the most investigated type of feedstock used for biomethane production because they are some of the most abundant resources with wide availability in most countries. It has been projected that a major part of the European renewable energy production, for example, will originate from farming and forestry and at least 25 per cent of all bioenergy in the future will originate from biogas, produced from wet organic materials such as animal manure, whole crop silages, wet food and feed wastes. In addition, while electricity and heat can be produced by a variety of renewable sources, the only alternative to fossil resources for production of liquid and gas fuels and chemicals is biomass. Anaerobic digestion is the most appropriate technology to convert the available biomass and other organic wastes to biomethane. The frame under which modern agriculture operates including the significant role agriculture can hold in energy production and in environmental pollution reduction under the need for agriculture diversification and sustainability is discussed in Chapter 1. The potential and significant role of agriculture in the energy sector is enhanced by the current trends and changes in the legal framework of many countries which have triggered the emergence of energy crop-based biogas digesters. These issues are discussed extensively in Chapter 2. Land use and land use change is one of the main topics in the debate of food production vs. biofuels that merits further consideration. Some initial thoughts concerning this important subject are discussed in Chapter 3. These chapters form Part I of this book which focuses on legislation and energy policy matters.

Second-generation biofuels, i.e. these originated from lignocellulosic biomass such as grass and grass silage, maize silage, as well as micro- and macro-algae but also non-food resources such as organic solid and industrial wastes, have started to gain pace in the race of biofuel research. Part II of the book deals with the production and/or processing of selected feedstocks and their utilisation for optimum biomethane production. Chapters 4 to 8 discuss holistically and analytically the important issues on the production of second-generation biofuels by anaerobic digestion by taking grass and maize silage, micro- and macro-algae, organic and industrial wastes as model feedstocks. More particularly, Chapter 4 analyses the suitability of grass species as a potential feedstock in anaerobic digestion in terms of their fitness, ecophysiology and husbandry. Maize as a sole energy crop or as part of a mixed substrate, consisting usually of manure and other agricultural residues, has been proven to be an invaluable resource for biomethane production. An extensive analysis is performed in Chapter 5. Microalgae and seaweeds could not be excluded from the list of highly desirable lignocellulosic feedstocks for the production of second-generation biomethane. Macro- and micro-algae production systems, productivity rates and biogas production potential along with economic production issues and future trends are comprehensively discussed in Chapter 6. The potential use of the organic and industrial wastes as feedstock for biomethane production through anaerobic digestion is discussed in Chapters 7 and 8. More specifically, Chapter 7 focuses on organic origin wastes (e.g. household wastes, human and animal excreta, biodegradable wastes, agricultural refuse and the organic fraction of municipal solid waste) and summarises general aspects of their anaerobic digestion and potential. Chapter 8 focuses on industrial wastes (e.g. abattoir wastes, slaughterhouse wastes, bioethanol production wastes, brewery residues, olive oil production wastes and wastes from sugarbeet processing facilities) and analyses in detail their availability, potential, possible bottlenecks and economics along with production processing.

Part III of this book consists of chapters related to anaerobic digestion technology. Technological issues such as digester design and configurations, biogas upgrading and biogas/biomethane storage are discussed in detail in Chapters 9 to 11. As such, Chapter 9 discusses digester design, substrate properties, variable biogas yields from similar digester types and biomethane potential assays, suggesting future research needs on factors that may affect anaerobic digester design. Chapter 10 discusses technologies of biogas upgrading for biomethane production with emphasis on CO_2 removal. More particularly, it refers to biogas contaminants and their treatment followed by an extensive report on CO_2 and various technologies for its removal. The comparison of various biogas upgrading techniques in terms of technical availability, energetic performance, economic assessment, investment and maintenance cost occupies a large part of this chapter. Environmental pollution of upgrading and biomethane compression and storage complete this chapter. Chapter 11 discusses various biogas storage options. Storage prerequisites and more common low pressure storage options such as floating cover, gas bags, rigid digester cover and flexible membrane cover are explained. Medium and high pressure storage options accompanied with biogas distribution and transportation conclude this chapter. The cumulative variation in biomethane production due to numerous factors and the need for monitoring in order to increase biomethane yield potential is discussed in Chapter 12. More particularly, the inter- and intra-feedstock variation, the pre-treatment (i.e. physical, chemical and biological) and the variation resulting due to process parameters (i.e. temperature, pH, C/N ratio, alkalinity, loading rate, retention time, volatile fatty acids etc.) is analysed and discussed comprehensively. The need for process monitoring is clearly established and process control systems (i.e. instrumentation, programmable logic controller, human machine interface and supervisory control and data acquisition programmes) are described. It is widely known that constraints exist in the exploitation of current knowledge and available information in anaerobic digestion. A consequence of this is that decision-making processes often lack scientific support. Chapter 13 attempts to highlight the benefits that biogas production stakeholders could gather by the incorporation, into the existing monitoring and decision-making system, of two of the most important techniques of knowledge development from databases – namely data warehouse and data mining techniques. Conceptual examples in data warehousing as these of multidimensional data modelling (i.e. star schema and data cubes) have been employed to highlight the usefulness of the data warehouse technique. Additionally, data mining techniques, particularly these under classification (i.e. naïve Bayes, time series, decision trees, neural networks etc.) and regression (linear and non-linear) categories support the integration of these data analytics into the anaerobic digestion system. Hierarchical clustering, a descriptive data mining technique, is also analysed in detail and completes the third part of the book.

In the last few decades, technological progress in molecular biology has become of major significance in the study of the physiology of gene function of microorganisms. Therefore, it is highly appropriate to discuss these subjects like population dynamics, molecular biology and molecular genetics of the anaerobic bacteria as described in Chapter 14 and Chapter 15 respectively. These topics form Part IV of the book. Chapter 14 deals with the variety of microorganisms present in anaerobic digestion and the dynamic changes that occur in these populations over time process. The kinetics and modelling of methanogenesis and future trends concerning the development of accurate microbial population dynamics models for better process understanding complete this chapter. The biochemistry of anaerobic digestion in relation to various substrates and the description of the biochemical pathways in anaerobic digestion is provided in the first half of Chapter 15. The second half of this chapter summarises the techniques for molecular genetic analysis applied to anaerobic digestion and the impact these have had on understanding these systems. Principal among those recognised are the ability to identify and enumerate the biological community involved in anaerobic digestion, the dissection of their metabolic process and the growing capability to genetically engineer organisms for more efficient gas production.

Part V, the final part of this book, analyses sustainable biogas/biomethane production issues along with methods to investigate them. Biomethane production from agricultural biomass and organic residues can be an efficient technique to minimise emissions from energy production. This feature is most probably the reason for the wide applicability of life cycle assessment (LCA) in the renewable/biogas production sector, particularly when it is used as transport fuel. This is analysed in Chapter 16 where the general working protocol for LCA application supported by examples based on various feedstocks for biogas/biomethane production are discussed. The recycling of digestate, a residue of anaerobic digestion, to land is regarded as the best practicable environmental option in most circumstances, completing both natural nutrient and carbon cycles. Chapter 17 discusses the use of the digestate as a substitute for manufactured fertilisers and examines how valuable this can be proved in relation to sustainability of the anaerobic digestion and biomethane production. More specifically, the quality of the digestate and standards in relation to microbial pathogens, heavy metals, stability and physical contaminants is discussed in detail. Digestate properties, i.e. nutrient content, organic matter, heavy metal concentration etc. along with its financial values, carbon footprint, land application controls and its integration with manufactured fertilisers conclude this chapter. Chapter 18 discusses in detail the sustainability of small-scale anaerobic digesters and their contribution to climate change mitigation in relation to national and international policy incentives that support anaerobic digestion. The factors influencing the development of small-scale anaerobic digestion and the effect of quality of feedstock on their revenue flow is discussed along with process monitoring controls. An important part of this chapter is based on valuing the social benefits of greenhouse gas emissions reduction from small-scale anaerobic digesters based on the shadow price of carbon in a social cost-benefit analysis. The final part of this book closes with Chapter 19 in which the benefits of anaerobic digestion in developing countries are extensively discussed. The negative impacts of conventional energy use in comparison with biomethane are analysed. The production of biogas from local resources along with various socio-economic benefits for developing countries is mentioned. Finally, an extensive reference is made to biogas development for a number of representative developing countries. The book closes with the final conclusions and future needs for a sustainable biogas and/or biomethane production.

The editors are grateful to the chapter authors and publishers in bringing this collection of key information relating to bioenergy production into the format of a book.

Despite the great effort that editors have invested in this work and the extensive checks conducted by many experts in the field of anaerobic digestion and biogas/biomethane production, mistakes may have been made. We would like to highlight that any comments or suggested changes to improve and update the book contents for future editions are welcomed.

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Acronyms and abbreviations

16S RNA	16S ribosomal RNA
ABP	animal by-products
AD	anaerobic digestion
ADAM	anaerobic digestion analytical model
ADF	acid detergent fibres
ADL	acid detergent lipids
ADQP	anaerobic digestate quality protocol
AFLP	amplified fragment length polymorphism
BC	buffering capacity
BCR	benefit-cost ratio
BDTC	Biogas Development and Training Centres
bioCNG	blend of biomethane and compressed natural gas
BMP	biomethane potential
BMW	biodegradable municipal waste
BOD	biological oxygen demand
BSE	bovine spongiform encephalopathy
BSG	brewers' spent grains
BSP	Biogas Support Programme
BSS	biogas spent sludge
CAD	centralised anaerobic digestion
CAP	Common Agricultural Policy
CBA	cost-benefit analysis
CBM	compressed biomethane
CBP	community biogas plants
CCM	corn cob mix
CDM	clean development mechanism
CERs	certified emission reductions
CH_4	methane
CHP	combined heat and power
CMO	Common Market Organisation
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2e	CO_2-equivalent
CoA	coenzyme A
COD	chemical oxygen demand
CP	crude protein
CSTR	continuously stirred tank reactor

DDBJ	DNA Data Bank of Japan
DDGS	distillers × dried grains with solubles
DGGE	denaturing gradient gel electrophoresis
dH	German degrees
DM	dry matter
DMI	dry matter intake
DMN	data mining
DMo	desugared molasses
DNA	deoxyribose nucleic acid
DS	dry solids
DSS	decision support system
DWH	data warehouse
E	exa- ($\times 10^{18}$)
EDP	ecosystem damage potential
EEA	European Environment Agency
EEIOEF	environmentally extended input–output emission factor
EEPROM	electrically erasable programmable read-only memory
EF	emission factor(s)
EMBL	European Molecular Biology Laboratory
EMP	Emden–Meyerhof–Parnas pathway
EPROM	erasable programmable read-only memory
ETL	extract, transform and load
EU	European Union
FAS	Farm Accounts Survey
FAS	farm assurance schemes
FBS	Farm Business Survey
FERC	Federal Energy Regulatory Commission
FIRR	financial internal rates of return
FISH	fluorescent in-situ hybridization
FIT	feed-in-tariff
FLC	fuzzy logic control
FM	fresh matter
GAEC	good agricultural and environmental condition
GDP	gross domestic product
GHG	greenhouse gas
GOLD	Genomes OnLine Database
GWh	gigawatt hour
GWP	global warming potential
H_2S	hydrogen sulphide
ha	hectare
HACCP	hazard analysis and critical control point
HANPP	human appropriation of net primary production
HDPE	high-density polyethylene
HHs	households
HHV	higher heating value
hl	hectolitre
HMI	human–machine interface
HPWS	high pressure water scrubbing
HRT	hydraulic retention time
IBP	institutional biogas plants
IC	internal combustion
IEA	International Energy Agency

ILUC	indirect land use change
INC	initial national communication
IPCC	Intergovernmental Panel on Climate Change
IRG	Italian ryegrass (*Lolium multiflorum*)
ISO	International Standards Organisation
ITDG	Intermediate Technology Development Group
J	joule
k	kilo- ($\times 10^3$)
KDD	knowledge discovery in databases
ktoe	thousand tonnes of oil equivalent
KVIC	Khadi and Village Industries Commission
kWh	kilowatt hour
LBM	liquefied biomethane
LCA	life cycle assessment
LCFA	long chain fatty acids
LCI	life cycle inventory
LCIA	life cycle impact assessment
LDC	least developed countries
LDPE	low-density polyethylene
LHV	lower heating value
LNG	liquefied natural gas
LUC	land use change
MDGs	Millennium Development Goals
MFIT	micro-feed-in-tariff
MJ	megajoule
$MMTCO_2e$	million metric tons of carbon dioxide equivalents
MPS	massively parallel sequencing
mRNA	messenger RNA
MSW	municipal solid waste
MT	megatonne
NBMMP	National Biogas and Manure Management Programme
NBP	night-soil based biogas plants
NDF	neutral detergent fibre
NDP	natural degradation potential
NGO	non-governmental organisation
NGV	natural gas vehicle
NIRS	near-infrared spectroscopy
Nm^3	normal cubic metres
NTG	*N*-methyl-*N*'-nitro-*N*-nitrosoguanidine
NVZ	nitrate vulnerable zones
ODM	organic dry matter
OFMSW	organic fraction of municipal solid waste
OLAP	online analytical process
OLR	organic loading rate
OLTP	online transaction processing
OM	organic matter
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
OMSW	olive mill solid waste
OMW	olive mill wastewater
OPA	Ontario Power Authority
OUT	operational taxonomic unit
PCF	product carbon footprint

PCR	polymerase chain reaction
PHA	polyhydroxyalkanoates
PLC	programmable logic controller
ppm	parts per million
PRG	perennial ryegrass (*Lolium perenne*)
PSA	pressure swing adsorption
RAN	readily available nitrogen
RAPD	random amplification of DNA
RBP	residual biogas potential
RD	rational protein design
RECs	Renewable Energy Certificates
RETs	renewable energy technologies
RFLP	restriction fragment length polymorphism
RHI	Renewable Heat Initiative
ROCs	Renewable Obligations Certificates
RPS	Renewable Portfolio Standard
RT-PCR	real-time PCR
SBP	sugar beet pulp
SCADA	supervisory control and data acquisition
SCF	standard cubic feet
SDM	site-directed mutagenesis
SGIP	small generator interconnection process
SNV	Netherlands Development Organisation
SOM	soil organic matter
SPC	shadow price of carbon
SRI	Silage maize Ripeness Index
SSADs	small-scale anaerobic digesters
SSM	soft system methodology
SSU rRNA	small subunit ribosomal RNA
STP	standard temperature and pressure
SVM	support vector machine
SW	slaughterhouse wastes
T	tera- ($\times 10^{12}$)
t	tonne
TA	total acids
TKN	total Kjeldahl nitrogen
TOC	total organic carbon
toe	tonnes of oil equivalent
TS	total solids
TSE	transmissible spongiform encephalopathy
UASB	upflow anaerobic sludge blanket
UK	United Kingdom
UNDP	United Nations Development Programme
US	United States of America
UV	ultraviolet
VFA	volatile fatty acid
VFR	vertical flow reactor
VS	volatile solids
Wh	watt hour
WI	Wobbe index
WSC	water-soluble carbohydrates
WWTP	wastewater treatment plant

Part I

Legislation and energy policy

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Chapter 1

Sustainable agriculture and greenhouse gas emissions

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Introduction

At a time when oil reserves are running out and carbon emissions from human activities are widely acknowledged to be causing environmental change, there has been an increasing emphasis on alternative 'clean' energy sources. Coupled with this is the challenge to increase food production to feed the world's population. Currently over 1 billion people do not have enough to eat (www.fao.org), but the population is predicted to increase by over 35 per cent in the next 40 years, from 7 billion now to over 9 billion by 2050 (Beddington, 2010; Anon., 2011). Already, a reduction in global food stocks has occurred in recent years due to increased demand and decreased yields as a result of environment change (principally insufficient rainfall) and changes to diet (increased meat consumption, associated with increasing affluence) (Anon., 2011). Additionally, the use of some potential food materials such as maize grain for bioenergy production has led to instability in food prices with food price spikes in 2007–8 associated with food export bans in some countries and even riots (Anon., 2012). Without new developments in science and technology, the problem can only worsen as the world's population increases, water sources continue to be overexploited (currently 70 per cent of water is used for agriculture, much extracted from rivers and aquifers) and particularly if a sub-set of food-crops such as oilseeds, maize or wheat grain is used for biofuel production, since there will then be less food available. This may not seem a problem where food is plentiful or for countries with enough wealth to import food, but the problem is passed on to other regions, usually in tropical climates. As a result, more land in tropical countries is being converted from forest to agriculture, often by burning areas of forest. This land use change causes a release of carbon from the burnt vegetation and also from carbon that was stored in the soil. This, together with the loss of productive forest area (which efficiently sequesters carbon) more than cancels out the benefits of biofuel production in the temperate areas. As such, when considered globally, certain biofuels are not 'carbon neutral' as claimed.

Fortunately, new scientific advances show great promise in delivering sustainable production of both food (through genetic improvement of crops such as wheat, rice and oilseed rape) and bioenergy. Of course renewable forms of energy are available from wind, wave or tidal action, hydroelectric or geothermal sources but these each produce electricity, rather than a liquid or gas that can be used in conventional engines for transport. Liquid bioethanol, produced from sugarcane (effectively a non-food crop) in Brazil is available for this purpose. However, other liquid fuels such as bio-diesel (produced from oilseed rape/

canola) and ethanol (from cereals and particularly maize grain) have the disadvantage of using a potential food source, vegetable oil or carbohydrates, as their respective starting materials (Parry and Hawkesford, 2010; Parry and Jing, 2011). Therefore it is desirable to use non-food crops or waste materials from crops as a feedstock for production of biofuels such as biomethane and many new biofuel crop species are currently being investigated and genetic improvements are being made both for production of liquid and solid biofuels (Karp et al., 2011; Mariani et al., 2010). The EU 2003 biofuels directive targets an increase in biofuel transport energy from 5.75 per cent in 2010 to 10 per cent by 2020 (Anon., 2007). In addition to this, biomass derived liquid or gaseous fuels could substitute current transport fuels and natural gas used for domestic and industrial purposes. Conversion of lignin, cellulose and other carbohydrates in plant cell walls is a potential approach to produce biofuel from non-food and perennial crops or waste-products.

Agriculture and carbon emissions

In addition to producing fuels from renewable biological sources, it is also desirable to reduce the carbon footprint of all agricultural activities associated with food production. Agriculture currently contributes a significant proportion of global carbon emissions. Globally, greenhouse gas (GHG) emissions from agriculture are estimated to amount to 10–12 per cent of all emissions (Smith et al., 2007). For example, GHG emissions from the UK agricultural sector amounted to 7 per cent of the UK total in 2007 (43.3 Mt CO_2 eq out of 618.6 Mt CO_2 eq) (National Atmospheric Emissions Inventory; www.naei.org.uk). This is similar to other parts of Western Europe and the UK is committed to reducing agricultural GHG emissions in England by 3 Mt CO_2 eq by 2020 (UK Committee on Climate Change; www.theccc.org.uk/sectors/non-co2-gases/agriculture). Much of the agricultural GHG emissions in northwestern Europe are associated with animal production (particularly as methane) and new research on diets, breeds and species of animals is in progress to produce animal products with much lower GHG emissions (Smith et al., 2007). For arable crops, the largest contribution to GHG emissions is by the manufacture and use of fertilisers; for example over 79 per cent of emissions associated with the production of a typical hectare of winter oilseed rape is associated with the manufacture of nitrogen-containing fertiliser (1433 kg CO_2 eq/ha) and a further 1242 kg CO_2 eq/ha is associated with the breakdown of a proportion of the applied nitrogen-containing fertiliser into N_20, which is a powerful greenhouse gas (Figure 1.1; Mahmuti et al. 2009).

In comparison, only 9.41 kg CO_2 eq/ha or 0.3 per cent of emissions were associated with the manufacture of the pesticides (herbicides, insecticides and fungicides) typically used. Yet fungicides alone were found to increase yields of winter oilseed rape by an average of 12.7 per cent having contributed to 0.04 per cent of GHG emissions in their use (Mahmuti et al. 2009). In the UK, fungicide treatment is estimated to have reduced GHG emissions by 1.64 Mt CO_2 for four major UK arable crops (winter barley, spring barley, winter wheat, and winter oilseed rape) in 2009 compared with releases calculated to have occurred by producing the same yield on the necessarily increased land area but without fungicide-based crop protection (Hughes et al. 2011). Globally, diseases are associated with losses of 16 per cent of crops and more generally losses to pests, weeds and diseases amount to 40 per cent of annual yields (Oerke, 2006). Climate change may itself alter the severity of crop disease epidemics (Evans et al. 2008; Madgwick et al. 2011). Recent studies by Berry et al. (2008), Mahmuti et al. (2009) and Hughes et al. (2011) illustrate that disease control measures

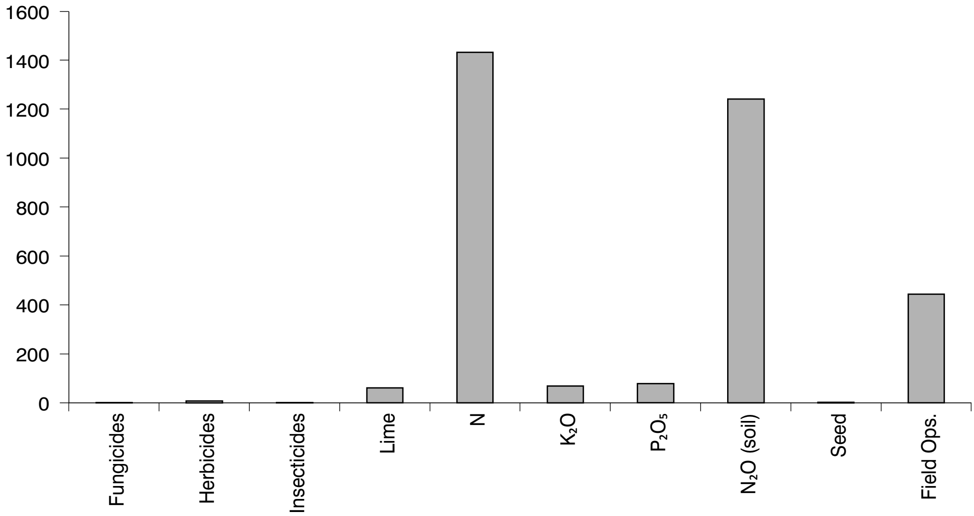

Figure 1.1 GHG emissions (CO_2 equivalents per hectare) associated with the production of a typical winter oilseed rape crop in the UK (data from Mahmuti et al., 2009). 'Field ops.' describes GHG emissions associated with mechanical equipment such as tractors and combine harvesters.

can not only reduce crop losses but also reduce the carbon footprint of crop production per tonne of grain produced and play a substantial part as a strategy to reduce agricultural GHG emissions by producing food efficiently on a smaller land area. A substantial reduction in GHG emissions is therefore possible by optimising and even increasing crop protection and by breeding crops that use nutrients more efficiently so that less nitrogen and other fertilisers need be applied. Good crop protection alongside effective application of nutrients and improved plant varieties has delivered substantial increases in yields over the last 60 years in particular (Figure 1.2).

Land use and carbon sequestration

An additional benefit to crop protection and GHG emissions has been realised recently by Berry et al. (2010) in research that has shown that growing arable crops efficiently using good crop protection products, elite cultivars and optimised fertiliser inputs not only increases yield per hectare and reduces the carbon footprint per tonne of grain produced but also means that less land area is required for this food production. This releases land for additional food production and/or for perennial biofuel crops, permanent grassland or woodland, which each sequester CO_2 into their soils to reach a steady state in which a larger amount of CO_2 is stored than in soils of arable crops. Less efficient crop production would require a larger land area to be cropped and Berry et al. (2010) show that this land use change (from pasture to arable crops) will lead to the release of CO_2 stored in converted grassland soils. In terms of GHG emissions associated not only with food production but also with land use, sustainable intensive arable crop production can therefore be considered as a climate-smart, environmentally conscious form of farming, using integrated pest management to reduce the carbon footprint of food production.

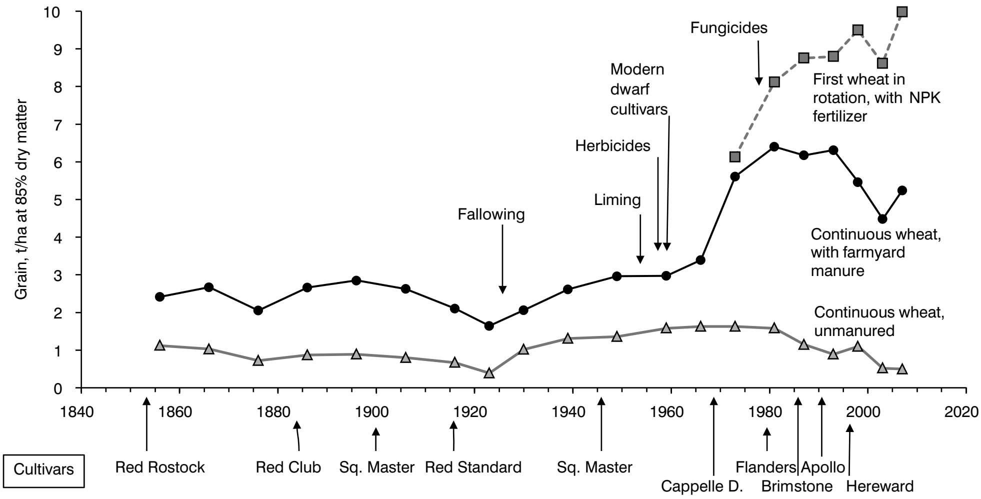

Figure 1.2 Effects of changes in farming practices on yields of winter wheat grown in the Broadbalk wheat experiment at Rothamsted Research, UK, since 1843. This dataset is part of the Long-Term Experiments National Capability at Rothamsted Research, funded by the UK Biotechnology and Biological Sciences Research Council and the Lawes Agricultural Trust. NPK = nutrients: Nitrogen, Phosphorus and Potassium, respectively.

Conclusions

To quote Sir John Beddington, Chief Scientific Advisor to the UK Government, "Food production must increase through climate-smart sustainable intensive arable crop production and this will need new scientific advancements, including use of some biotechnology approaches, improved crop varieties and species, and enhanced crop protection to produce more food with decreased associated GHG emissions". Simultaneously, the policy of the EU and some national governments towards the choice of biofuels must place a strong emphasis on the use of grasslands and (non-food) waste products, rather than grains and oilseeds, since grasslands serve a dual purpose in carbon sequestration in soil and production of a clean form of energy – biomethane – without decreasing food production. Biomethane uses the principle of anaerobic digestion for its production and this is discussed in more detail in later chapters. Financial incentives must be made available to encourage the uptake of this technology. Advances in microbiology, molecular and cellular biology, biochemistry, synthetic biology and bioengineering offer potential solutions towards biofuel production as part of a sustainable form of agriculture that minimises GHG emissions. These solutions are discussed in subsequent chapters along with methods of biomass production.

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Chapter 2

Energy and agricultural policy in relation to biomethane, with particular reference to the transport sector

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Introduction

The use of biomethane for transport is an area of growing interest, with ongoing research into feedstock suitability, anaerobic digestion, gas upgrading, grid injection techniques, and vehicle and filling station technology (e.g. Bordelanne et al., 2011; Gerin et al., 2008; Hagen et al., 2001; Lehtomäki et al., 2008; Nizami and Murphy, 2010; Petersson and Wellinger, 2009). Due to the complex nature of the biomethane-for-transport industry, which is comprised of the areas mentioned above, a wide range of existing policies, particularly those in energy and agriculture, have both direct and indirect impacts on the sector.

Despite the importance of policy for the biomethane-for-transport industry, there exists limited information on the impact of policy on the industry. The aim of this chapter is to start fill that knowledge gap and to explore energy and agricultural policy in relation to biomethane. The various policies and policy instruments are discussed and a number of case studies are presented, showing experience of both successful and unsuccessful industries. Drawing on the case studies and policy discussion, a policy roadmap for a successful industry is developed. The focus of the chapter is on biomethane injected into the gas grid for use as a transport fuel, although many of the aspects discussed also pertain to biomethane used (on- or off-site) for heat or electricity generation.

Background to biomethane

Biogas, biomethane and bioCNG

Biomethane is biogas that has been upgraded to the same standard as natural gas, and is typically composed of 97 per cent methane (CH_4), 3 per cent carbon dioxide (CO_2) and some minor constituents. Biogas is produced through the anaerobic digestion (AD) of organic materials and typically consists of 55–70 per cent CH_4 (but this can be higher), 30–45 per cent CO_2 and some minor constituents, e.g. hydrogen sulphide (H_2S) and water. Many feedstocks are suitable for anaerobic digestion, including crops such as grass and maize, agricultural wastes such as animal slurries and slaughterhouse waste, industrial wastes, the organic fraction of municipal solid waste (OFMSW) and sewage sludge. Biogas composition depends on the feedstock, e.g. biogas from grass contains around 55 per cent CH_4 (Smyth et al., 2009), whereas biogas from chicken slurry contains 60–80 per cent CH_4 (Steffen et al., 1998). The digested feedstock that remains at the end of the AD process is known as digestate and can be used as a substitute for conventional manufactured fertiliser (Chapter 17 of this book).

Biomethane is mixable and interchangeable with natural gas and can be used in all applications intended for natural gas. It can be used directly for heat and/or electricity generation, or can be compressed for use in natural gas vehicles (NGVs). Compressed biomethane mixed (in any proportion) with compressed natural gas (CNG) is known as bioCNG. There is a considerable existing market for gas as a transport fuel, with over 14.7 million NGVs worldwide (NGV, 2012). Iran, Pakistan and Argentina have the largest fleets globally, each with over two million NGVs. Within Europe, the largest NGV fleet is in Italy (approximately 760,000), while Germany, Bulgaria and Sweden also have significant fleets, with around 95,000, 61,000 and 36,000 NGVs respectively (NGV, 2012). The use of biomethane as a vehicle fuel is increasing; biomethane accounts for over 60 per cent of fuel used in Swedish NGVs (Petersson, 2011), and Austria aims to replace 20 per cent of natural gas used in the transport sector with biomethane (Jönsson, 2006).

The potential biomethane resource is large. Using European Environment Agency (EEA) data, Åhman (2010) reported that the potential biogas supply in 2030 in the EU from 'wet' manure, sewage sludge and food processing residues is 0.8 EJ, and a further 2.15 EJ of environmentally compatible biogas (i.e. that which can be produced in line with environmental policies and assuming that there are no additional pressures on biodiversity, soil and water resources compared with the business-as-usual situation) is estimated to be available from agricultural crops. This compares to 0.25 EJ of biogas production in 2007. If all this biogas were converted to biomethane, it would account for 20 per cent of transport fuel in 2030 (business as usual) or 31 per cent under an energy-efficient scenario (Åhman, 2010). A 1998 US study concluded that it is feasible to capture and use over a third of the biogas potential of animal waste, sewage sludge and landfill in the country. If all this biogas were used for transport, it would displace 38 billion litres (10 billion gallons) of petrol equivalent per year (USDOE, 2011). Total US petrol (gasoline) consumption in 2011 was about 507 billion litres (134 billion gallons) (USEIA, 2012).

Biomethane policy in the literature

Progress in the renewable energy sector is inextricably linked to policy, but there is no "one size fits all" and different types of policies are needed for different technologies and applications (Gross et al., 2003). Very few countries have long-term policy experience of a mature biofuel market (Worldwatch Institute, 2007), let alone a mature bioCNG market, and there exists no step-by-step guide on how to promote biofuels (Bomb et al., 2007) or, indeed, biomethane.

There is limited information relating specifically to policies for biomethane or bioCNG for transport, although research on general biofuel policies and on particular aspects of the biomethane-for-transport industry (e.g. NGVs, AD) is more prevalent and is helpful in discussing the effect of policy on a biomethane-for-transport industry.

The research most relevant to biomethane policy is an article by Thamsiriroj et al. (2011), which developed a country-specific roadmap for a bioCNG industry in Ireland and recommended a range of supports, including an obligation for a minimum percentage of biomethane in gaseous transport fuel and subsidies for biomethane facilities. The paper was specific to the Irish context and had a strong focus on national legislation and resources. Work by Patterson et al. (2011) evaluated the policy and techno-economic factors affecting the use of biomethane as a transport fuel in the UK (a country with very low penetration of NGVs), and discussed in detail available biogas upgrading technologies and the economic viability of upgrading biogas for use as a vehicle fuel. Although not focused on biomethane, Yeh (2007) conducted an empirical analysis of the adoption of NGVs in eight countries and discussed policies and other factors influencing the industry.

More generally, Wisenthal et al. (2009) analysed the strengths and weaknesses of biofuel support policies implemented in the EU, while Bomb et al. (2007) investigated the biofuel industries in Germany and the UK, and discussed policy issues with a focus on the early stages of a biofuel industry. Also focusing on the initial stages of the industry, van der Laak et al. (2007) analysed various projects in the Netherlands and put forward guidelines for policy development in the Dutch biofuel sector. Silvestrini et al. (2010) looked at experience with biofuels in the EU cities of Berlin, London, Milan and Helsinki, and highlighted the importance of cities as test cases for policies that may in future be implemented at national level.

The findings of these studies with relevance to policy in the biomethane-for-transport industry are discussed in the following sections.

Energy and agricultural policy in the biomethane industry

Energy policy

Renewable energy

Arising from concerns over climate change, increasing energy prices, dwindling fossil fuel supplies and security of energy supply, policies and targets have been put in place to promote renewable sources of energy. Although renewable energy targets have been set in all three energy sectors (heat, electricity and transport), transport lags behind in terms of the penetration of renewable resources. In the EU, where there is a target for 10 per cent renewable transport energy by 2020 (EC, 2009a), progress has been relatively slow and in 2010 there was less than 5 per cent biofuels penetration, which is below the 2003 Biofuels Directive target of 5.75 per cent for 2010 (EurObserv'ER, 2011). The relatively slow development of renewable energy in the transport sector means that considerable growth is required if targets are to be met. If renewable energy policies are to drive the biomethane-for-transport industry, they must be translated into specific energy, transport and biofuel policies with a direct impact on AD and biomethane production and use.

Anaerobic digestion, biogas and biomethane

Renewable energy policy can encourage the production of biogas through, for example, grants for the construction of anaerobic digestion plants. The use of that biogas, i.e. for heat, electricity or transport, is then also dictated by policy. In the EU, biogas energy is mainly recovered in the form of electricity. In 2009, primary biogas energy output in the EU was 8346 ktoe, and gross biogas electricity output was 2164 ktoe. Biogas heat output in the EU in the same year was 174 ktoe (EurObserv'ER, 2010). The quantity used as vehicle fuel for trains, buses and other vehicles is relatively minor, although it is growing (REN21, 2011).

For biogas to be used as a vehicle fuel, it must first be upgraded to biomethane standard and then delivered to the point of use. The most efficient means of transporting biomethane is through use of the existing natural gas pipeline network (where available), although transport by pressurised container is also possible. For biomethane to be injected in to the grid and used as a vehicle fuel, plant operators, the gas network operator, and vehicle and filling station providers, need to be involved in the development of policies to ensure that biomethane meets quality and safety standards.

In the EU, Directive 2009/73/EC on the natural gas market (EC, 2009b) states that biogas should be granted non-discriminatory access to the gas system. Several countries, e.g. Sweden, Germany and Switzerland, have national policies for biomethane injection to the gas grid and/or use in vehicles, but the EU Directive has yet to be implemented through national policy in all countries in the EU, and despite considerable discussion there is as yet no European-wide standard for biomethane injected into the gas grid.

Energy in transport and biofuels

Targets for renewable transport energy can be met through different sources, including electric vehicles, hydrogen and biofuels. Depending on the specifics of the renewable transport energy policy that is in place, biomethane may or may not be supported by the policy. Brazil, for example, set a target for 5 per cent biodiesel by 2013 and for ethanol to account for 20–25 per cent of current petrol usage (Worldwatch Institute, 2007). Previous targets in the US focused on ethanol (e.g. 2.8 billion litres by 2012), as did targets in a number of Canadian states and in China (Worldwatch Institute, 2007). EU policy (Directive 2009/28/EC) includes support for biomethane, but demands that certain sustainability criteria are met in order for the renewable transport energy source to be counted towards meeting the target for renewable energy in transport. The Directive stipulates that biofuels (including biomethane) must effect greenhouse gas (GHG) savings of 35 per cent compared with the fossil fuel replaced, rising to 60 per cent for new facilities in 2018 (EC, 2009a). GHG savings are calculated from GHG balances, which, along with energy balances, are critical for assessing the sustainability of bioenergy systems (Buchholz et al., 2009). For an energy balance, a cradle-to-grave life-cycle assessment is carried out and the parasitic energy demands of the system, e.g. energy use in agriculture, are subtracted from the gross energy of the feedstock to determine the net energy of the biofuel. A GHG balance is conducted in a similar manner by comparing the emissions saved through fossil fuel replacement with the net emissions from biofuel production. Biofuels with higher net energy values and higher GHG savings are considered preferable to those with poor energy and GHG balances.

Biomethane can be produced from many different feedstocks, including crops (such as grass and maize) and wastes (such as agricultural slurries and the organic fraction of municipal solid waste), and the GHG savings of biomethane are heavily dependent on the feedstock used. Typical GHG savings for biomethane from different feedstock are presented in Table 2.1, along with values for ethanol and biodiesel. The GHG savings of biomethane compare well to conventional temperate biofuels, and even when mixed with natural gas to form bioCNG considerable emissions savings can still be achieved. Dedicated CNG vehicles running on natural gas have emissions that are around 17 per cent lower than petrol vehicles (Bordelanne et al., 2011). In addition to the associated GHG benefits, transport policies promoting CNG prior to the introduction of bioCNG and biomethane are beneficial to the biomethane industry (Silvestrini et al., 2010). Countries with successful biomethane-for-transport industries, e.g. Sweden and Austria, began by promoting compressed natural gas (CNG) as a transport fuel, followed by the introduction of biomethane to the market (by

Table 2.1. GHGs and other sustainability issues of selected biofuels (adapted from Smyth et al. 2010b).

Feedstock and fuel	*GHG savings with no LUC*[a] *(%)*			*GHG savings with LUC*[b] *(%)*		*Other environmental and sustainability issues*
	Process/ process fuel	*Typical*	*Default*		*Previous land use*	
Grass biomethane		75 (range 22–150)[c]				Existing grassland is used for livestock and the expansion of a grass biomethane industry may result in competition with existing agriculture (and food production).[d]
Maize/corn biomethane		60[e]				Maize is generally grown in rotation, so additional land is required under contract. Arable land is needed for maize; its use for energy crops may result in competition with food supplies. There are considerable environmental concerns[f] when maize is grown as a monoculture.
Municipal waste (OFMSW) biomethane		80	73			Compared with composting, AD of OFMSW leads to reduced emissions of GHGs; AD of OFMSW reduces waste volume.[g] Digestate needs to be dealt with carefully.
Manure biomethane		84–86	81–82			Slurry has a relatively low biogas yield per unit volume (due to high water content), leading to higher production costs per unit energy.[h] Digested slurry contains nutrients in a form more easily absorbed by plants.[i] Digestate needs to be dealt with carefully.
Slaughter waste biomethane		>100[j]				Animal by-products regulations restrict the use of certain slaughter wastes for AD. Digestate needs to be dealt with carefully.
Palm oil biodiesel	Methane capture at oil mill	68	65	–135	Forestland in Malaysia	Excellent energy balance, but there are concerns over land use change from the expansion of palm oil plantations.[k]
				–185	Forestland in Indonesia	
				–12	Grassland in Malaysia	
				–84	Grassland in Indonesia	

Rapeseed biodiesel		45	38	–569	Forestland in UK	Generally poor energy balance, although the use of by-products, such as straw and rape cake, improves the efficiency of the system.[k]
				–123	Grassland in UK	
Sugarcane ethanol		71	71			Excellent energy balance, but there are concerns over land use change and displacement effects.[k]
Wheat ethanol	Lignite (CHP plant)	32	16			Poor energy balance, although the use of by-products such as straw improves the efficiency of the system.[k] Wheat is generally grown in rotation, so additional land is required under contract. Arable land is needed; its use for energy crops may result in competition with food supplies.
	Natural gas (CHP plant)	53	47			
	Straw (CHP plant)	69	69			
Corn/maize ethanol	Natural gas	56	49	–93	Worldwide displacement	Poor energy balance, although use of by-products such as straw improves the efficiency of the system.[k] See notes on maize biomethane for further issues concerning the crop.
Sugar beet ethanol		61	52			Good energy balance.[k] Sugar beet is generally grown in rotation, so additional land is required under contract. Arable land is needed; its use for energy crops may result in competition with food supplies.

AD = anaerobic digestion; CHP = combined heat and power; GHG = greenhouse gas; LUC = land use change; OFMSW = organic fraction of municipal solid waste

[a] Values taken from EC (2009a), unless otherwise stated
[b] Searchinger et al., 2008; Upham et al., 2009
[c] Korres et al., 2010
[d] Smyth and Murphy, 2011
[e] Baxter, 2010
f Uekoetter, 2011
[g] Borjesson and Mattiasson, 2007
[h] Smyth et al., 2010a
[i] Yiridoe et al., 2009
[j] Singh and Murphy, 2009
[k] Smyth et al., 2010b

blending with CNG to form bioCNG) and increasing the percentage in the blend as the industry developed.

Returning to sustainability, biofuel policies often impose further requirements. The EU Renewable Energy Directive requires the exclusion of biofuels from peatlands and land with high biodiversity value or high carbon stock, as well as the assessment of social sustainability, food prices and other development issues.

Agricultural policy

Energy crops and land use

Agricultural policy can drive the availability of energy crops by encouraging farmers to grow crops for energy purposes. The Common Agricultural Policy (CAP) in the EU is a system of subsidies and support programmes for agriculture and is the main vehicle used to deliver agricultural policy. Council Regulation EC No. 1782/2003 (EC, 2003) established the Single Payment Scheme and introduced a payment of €45 per hectare per annum for areas under energy crops. Any agricultural raw material may be grown under the scheme, provided that the crops are intended primarily for energy purposes, i.e. for biofuels (including biogas), electric or thermal energy. It should be highlighted, however, that not all energy crops policies support biogas production. Also under the CAP are mechanisms to promote the cultivation of oilseed crops on set-aside land but only if contracted solely for the production of biodiesel or other industrial products (Schnepf, 2006).

Where there is general support for energy crops for biogas production, a decision must be made on which crop to grow. Although many crops are technically suitable for anaerobic digestion, there are numerous other factors and related policies which influence energy crop choice. Crop yield, energy balance and GHG savings (Table 2.1) are all important, as is the type of land needed for the crop.

Agricultural policies may place restrictions on land use change (LUC) or on the use of certain land types for energy crops. Direct LUC can be said to occur when land is converted from a previous use to bioenergy crop production; indirect land use change (ILUC) occurs when, for example, grassland or forest is converted to cropland to meet the demand for commodities which have been displaced by the production of biofuel feedstock elsewhere (Plevin et al., 2010).

In the EU, cross-compliance regulations, which are part of the CAP, require that the ratio of the area of permanent pasture to the total agricultural area of each member state must not decrease by 10 per cent or more from the 2003 reference ratio (EC, 2004), thus limiting the conversion of grassland to arable cropping. The expansion of the cultivation of energy crops that require arable land may therefore have an impact on existing arable crops grown for food, fibre, feed or energy purposes. In Germany, there has been considerable development in the use of maize for biogas production over the last few years. Between 2008 and 2009, the area under energy maize increased by 29 per cent, and by a further 40 per cent between 2009 and 2010 (BMELV, 2011). Maize in Germany has traditionally been grown for animal fodder and the increase in the area under energy maize has mainly been at the expense of this fodder maize, i.e. there is direct competition between food and biofuels. According to government, this direct change in land use has negatively affected the landscape and biodiversity in some areas, as well as leading to rent increases, and as a result the German government has changed its support schemes for certain energy crops (BMELV, 2011; Strauch and Krassowki, 2012). Widespread use of monocultures and the resultant homogeneous land use is a serious concern for both long-term agricultural productivity and the environment (Uekoetter, 2011).

Although generally not yet covered by agricultural or biofuel policy, the issue of indirect effects, particularly ILUC, is an area of growing concern. The "corn connection" in the US is one such example; subsidies for corn bioethanol have led to a move from soy to corn, resulting in decreased soy output and increased soy and beef prices (soy is used for animal feed). This in turn has led to increased production of soy and beef in South America and is strongly linked to deforestation (Laurance, 2007). It is argued (Liska and Perrin, 2009) that the emissions from ILUC caused by biofuel production should, if significant, be considered when calculating the GHG impact of the biofuel. However, measuring the emissions from ILUC is considerably more difficult than measuring those from direct LUC (Liska and Perrin, 2009), as the causal effects assumed in such calculations are open to interpretation. The assumptions and data inputs used to calculate the magnitude of potential LUC associated with biofuels have been questioned (CBES, 2009). It has been argued that the relationships between biofuels, commodity prices, trade and land-cover changes that are assumed by current modelling approaches are not consistent with historic data for initial land conversion and expansion. Empirical verification of ILUC due to recent expansion of the biofuel industry is problematic because those expansions constitute a very small driver relative to global LUC, so the biofuel impact is likely to be overshadowed by other causes (Liska and Perrin, 2009).

Agricultural wastes

Agri-environmental policies can direct improved management and treatment of agricultural wastes, such as agricultural slurries and slaughterhouse waste, which can in turn promote anaerobic digestion as a method for treating these wastes. In Denmark in the 1980s, concerns over nitrate leaching from agriculture led to tightening of agri-environmental legislation, including a requirement for farmers to have sufficient capacity for 6–9 months manure storage. Farmers were only permitted to spread manure when the risk of nitrate leaching was low and had to store manure for the remainder of the year. Arising from this, farmers began to participate in centralised anaerobic digestion (CAD) plants, which managed the transportation, storage and distribution of manure and digestate (Raven and Gregersen, 2007).

Similar policies were introduced in Sweden in the 1980s to reduce nitrogen leakage from the agricultural sector. Measures, such as increased seasonal manure storage, exclusion periods for manure spreading and the construction of AD plants, were implemented. These measures have resulted in significant environmental benefits, for example, the Laholm biogas plant in west Sweden, which was built in 1992 due to environmental concerns, has substantially reduced regional eutrophication and nitrogen leakage in to the Laholm Bay area (IEA Bioenergy, 2005). The plant treats 28,000 t of animal manure and 20,000 t of other wastes (including vegetable and slaughterhouse waste) per year, and recycles the digestate to 17 farms in the surrounding area (IEA Bioenergy, 2005).

The use of AD for the treatment of agricultural wastes can reduce GHG emissions from the agricultural sector, and so assist in complying with GHG reduction policies. Agricultural slurry applied directly to land results in uncontrolled GHG emissions, whereas if the slurry is treated in an anaerobic digester, methane is captured in the form of biogas. The biogas can then be used for energy purposes, including transport, thus replacing fossil fuel and reducing GHG emissions from the energy sector. Taking into account the reduction in GHG emissions from both slurry treatment and fossil fuel replacement, GHG savings of 82 per cent have been reported for cattle slurry biomethane compared with fossil diesel (Singh and Murphy, 2009).

Digestate

Following the production of biogas, the material that remains at the end of the AD process is known as digestate. Digestate consists of a solid and a liquid fraction, and can be used as a fertiliser; its use as a fertiliser is controlled by agri-environmental policy. Like for conventional fertiliser, the spreading of digestate on agricultural land must follow regulations designed to prevent nutrient leaching and protect ground and surface water. Depending on the feedstock, further policies relating to the use of animal by-products (ABP) may also apply. The purpose of these policies is to safeguard human and animal health, and to minimise the risk of contaminants entering the food chain. In the EU, the AD of animal wastes and the use of digestate as fertiliser are controlled by the Animal By-Products Regulations (EC, 2009c). These regulations lay down requirements for the collection, transport, storage, handling, processing and use or disposal of all ABP. Requirements include specific hygienisation steps during the processing of the ABP, and restrictions on grazing and on the type of crops that can be grown on land fertilised with digestate.

The interpretation of the ABP Regulations varies between countries, with stricter interpretation in some countries than in others. In Ireland, for example, past food and animal health scares, the importance (and reputation) of agriculture in the export economy, and limited experience of AD have led to strict interpretation of the regulations. Certain slaughter wastes, such as blood, are not permitted in Irish AD plants under the national regulations (DAFF, 2009), even though they are allowed under EU regulations and are used in AD plants throughout Europe. Very strict interpretation can act as a barrier to the industry, through, for example, stringent controls on the processing of feedstock (which can add considerable cost) and restrictions on the type of feedstock that can be used for AD.

While there is no doubt that regulations concerning ABP are necessary, it is also recognised that very strict interpretation of these regulations can cause problems for the development of the AD industry (Farrar, 2009). Policy-makers can look to successful AD industries, such as those in Germany and Sweden, and use the experience gained there to develop policies that both regulate the safe use of ABP and facilitate AD.

Other policies

Waste policy

In many cases it is advantageous for AD plants to co-digest wastes with energy crops due to increased methane yields (Uzodinma and Ofoefule, 2009) and the gate fees that can be charged for treating wastes (Smyth et al., 2010a). Policy relating to waste can therefore have a significant impact on the AD and biomethane industries. Increased landfill tariffs or policies demanding treatment of organic wastes can be an indirect driver of anaerobic digestion. Waste-related energy policies can also drive biogas and biomethane production, such as the EU Renewable Energy Directive (EC, 2009a), which offers double credits for renewable transport fuels produced from wastes. On the downside, other waste-related policies can pose barriers to AD, such as policies relating to digestate disposal, transport and handling of wastes, and planning permission for waste treatment facilities.

Environmental policy

At the biogas production end, the use of AD as part of a waste treatment strategy can help to achieve targets set by environmental policy, as GHG emissions and pollution from poor waste management are reduced (Börjesson and Mattiasson, 2007; Yiridoe et al., 2009).

The use of digestate as a replacement for conventional fertiliser, as long as it is applied following best practice guidelines, can bring benefits of reduced pollution. This is because digestate contains nutrients in a form more easily absorbed by plants (Yiridoe et al., 2009), thus reducing the risk of run-off into water sources, as well as the risk of nitrogen losses by ammonia emissions (DCMNR and SEI, 2004). In addition, the pathogen content of animal slurries (which are commonly spread as fertiliser in their raw form) can be reduced by AD as a result of the temperatures reached during the digestion process. A specific pasteurisation step can also be added to the process (Lukehurst et al., 2010).

When it comes to the use of the fuel, biomethane can assist in compliance with targets for improved air quality. In terms of local pollutants, methane (whether it is biomethane or natural gas) is much cleaner burning than many other fuels and, when used as a replacement for oil, can benefit air quality, especially in urban areas, leading to improved public health and associated cost reductions in the health sector (Goyal and Sidhartha, 2003; Mediavilla-Sahagún and ApSimon, 2003; Rabl, 2002).

The reduction in pollution from agricultural wastes is promoted by numerous policies, including, in the EU, the Nitrates Directive, the Water Framework Directive, Biodiversity Action Plan and national agri-environmental schemes.

Policy instruments for promotion of biomethane

This section discusses different policy instruments that can be used to promote biomethane. As experience of biomethane (and bioCNG) markets is limited, general biofuel policies are also included.

Regulatory and economic instruments

Tax exemptions

Tax exemptions have been found to be very successful in promoting biofuels, both in the EU and in the US (Wisenthal et al., 2009). There is a strong relationship between the level of tax reduction and the penetration of biofuels; a full tax exemption in Germany resulted in a 3.75 per cent biofuels share in 2005, compared with no tax exemption and no biofuels penetration in Finland (Silvestrini et al., 2010). There is a solid argument for permanent tax breaks for biofuels because of the associated environmental benefits (Bomb et al., 2007) and the fact that conventional technologies are currently subsidised, with fossil fuels receiving very little or no penalty for their negative environmental impacts (Silveira, 2005).

Maintaining the price of bioCNG below that of petrol and diesel can be an effective method of developing the market. A study of existing NGV markets by Yeh (2007) found that keeping natural gas fuel prices 40–50 per cent below petrol and diesel prices, along with a payback period of 3–4 years or lower, was very important for the development of a mainstream NGV market.

An advantage of tax exemptions over other means of promoting biofuels is that it is a low-cost method that can make use of the existing administrative and collection system

(Ryan et al., 2006). On the downside, tax exemptions can result in a loss of revenue for the government as the biofuel market grows. In Belgium, this has been compensated for by a simultaneous increase in the tax on fossil fuel, making the policy budget-neutral. Other EU member states have switched from tax exemptions to an obligation or mixed system to reduce losses to the exchequer (Wisenthal et al., 2009).

Obligation systems

Compared with tax exemptions, which can be revised every year, an obligation system provides stability to the market by setting a long-term framework for biofuels (Wisenthal et al., 2009). An advantage of obligation systems over tax exemptions is that, with an obligation system, the government can control the quantity of biofuel produced and/or used. A popular obligation system is to set a requirement for blended fuels, but, while low-level blending is straightforward and relatively cheap to implement, it may not be sufficient to achieve significant penetration of biofuels (Bomb et al., 2007). Obligation systems may well increase overall biofuel consumption, but they are relatively ineffective at promoting particular biofuels (Wisenthal et al., 2009) and are unlikely to result in a step-change in behaviour.

Subsidies

Subsidies can play an important part in the development of a bioCNG industry, especially in the early stages. Subsidies for specific crops or for growing crops for a particular purpose, e.g. transport fuel, can assist in feedstock availability for AD plants. Subsidies are also of importance to consumers. Research has shown that customers purchase "cheap rather than green" (Bomb et al., 2007). The additional cost of purchasing and maintaining NGVs is a barrier to the industry; a study in the UK (where there is no mainstream NGV market) found that support in this area could result in the rapid expansion of the industry (Patterson et al., 2011). Once the industry has been established, the level and availability of subsidies should be reviewed.

Information instruments

Demonstration projects

Demonstration projects have a number of valuable roles; they bring new technologies into the public eye and can help garner public acceptance, as well as providing opportunity for research and development, and the dissemination of results and information. In the AD and upgrading industry, demonstration projects are particularly important in countries where there are limited existing plants. Farm visits can also be arranged to showcase novel energy crops and improved techniques for growing existing crops.

For the wider public acceptance of bioCNG vehicles, demonstration projects involving fleet vehicles are common practice; a review of biofuels in the Netherlands describes such projects as having an exemplary role (van der Laak et al., 2007). The development of biomethane for transport in other countries has often been based on an existing CNG market, and the development of CNG has often begun with the introduction of CNG to captive fleets (e.g. buses, waste collection lorries, taxis) followed by private cars (Smyth et al., 2010a). As fleet vehicles return to a depot each day, an advantage, especially in the early stages of market development, is that only one filling station is required. Such filling stations can also be open to the public. However, while niche markets, such as fleet vehicles, can be an important part of the early stages of an alternative vehicle market, they are insufficient to develop the market into mainstream (McNutt and Rodgers, 2004, cited in Yeh, 2007).

Stakeholder involvement

For a biomethane (i.e. upgraded biogas) industry, there must be a biogas/AD industry, and, for a biomethane-for-transport industry, it is beneficial if a conventional CNG transport industry exists. Stakeholders in a biogas/biomethane industry include farmers, the waste sector, and AD and upgrading plant operators (Thamsiriroj et al., 2011). Stakeholders in an NGV industry include the fuel suppliers, suppliers of natural gas industry equipment (e.g. fuelling stations and vehicles) and consumers (Yeh, 2007). The general public, all levels of government, research institutes and NGOs (non-governmental organisations), such as environmental groups, are important stakeholders at all stages of a bioCNG industry (Figure 2.1).

Regular meetings should be held between stakeholders (van der Laak et al., 2007). Communication between the industry and the general public is important, particularly when it comes to the benefits of the industry (e.g. improved air quality), as this can help create a demand pull. The demand pull and the technology push (through technology- or fuel-based regulation) work together with consumer and producer incentives to promote the adoption of alternative fuels (Yeh, 2007).

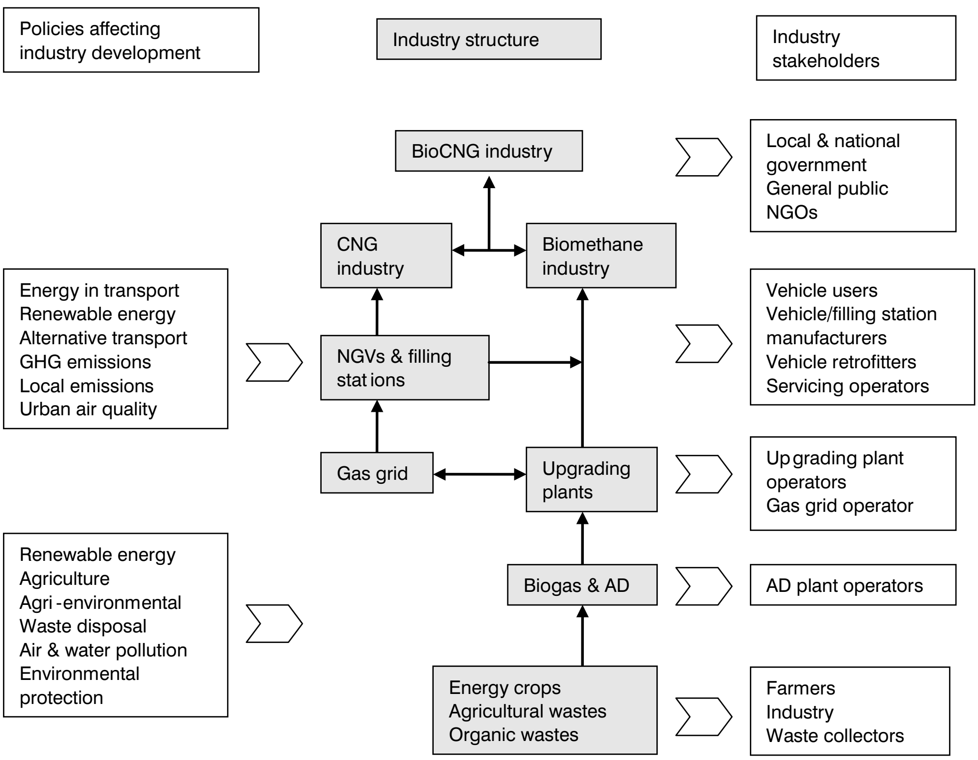

Figure 2.1 Policy, industry structure and stakeholders in the bioCNG industry.

Experience with biomethane and CNG for transport

Two success stories: Sweden and Germany

Sweden

In 2009, Sweden had 230 biogas plants (including 12 farm plants, 21 co-digestion plants and 136 municipal sewage treatment plants) and 48 upgrading plants (Petersson, 2011). Annual biogas production in the same year was 1363 TWh and 26 per cent of this was used as vehicle fuel (Petersson, 2011). The NGV market began in Sweden in the mid-1990s and there are now around 32,000 NGVs and almost 170 filling stations. In 1999, there were about 1400 NGVs served by 22 filling stations (NGV, 2011).

Initially based solely on CNG, the amount of biomethane in the bioCNG vehicle fuel mix has been increasing year-on-year and there is now over 60 per cent biomethane infiltration in the market (Petersson, 2011). A suite of measures has been put in place to promote the use of biomethane as a vehicle fuel. Taxation measures include energy tax, CO_2 tax and CO_2 differentiated vehicle tax. Market-based mechanisms include carbon emissions trading, while support systems are in place that offer investment grants, agricultural grants, support for filling stations and green cars, including reduced vehicle tax and free parking. Regulations also demand the availability of renewable fuel at filling stations (Petersson, 2011).

Germany

Germany, a country with only around 100 biogas plants in the early 1990s, had an estimated 7200 agricultural plants in 2011 (FNR, 2012; Linke, 2011). There were about 50 upgrading plants in operation in 2010, rising to 83 at the end of 2011 (FNR, 2012). Biomass crops account for 49 per cent of substrates in biogas plants by mass and over 70 per cent by energy content (FNR, 2012; Linke, 2011). Of the 12,000 kha of agricultural crop land in Germany, 650 kha (5 per cent) were under cultivation for biogas in 2010, and the area was predicted to rise to 800 kha by the end of 2011. The areas under cultivation for biodiesel and bioethanol in 2010 were 940 kha and 240 kha respectively (FNR, 2012). Animal wastes are another major substrate for AD, accounting for 43 per cent by mass or 11 per cent by energy content; the majority of German biogas plants use more than 30 per cent manure by mass content in their daily substrate blend (FNR, 2012; Linke, 2011; Weiland, 2010).

The German AD and biogas upgrading industries have benefited from an effective tariff structure based on graded tariffs, which depend on feedstock type, plant size and AD technology type, among other factors. The produced biogas and biomethane is used for heat and electricity as well as for vehicle fuel. The International Energy Agency (IEA) has stated that the high investor security provided by the German feed-in-tariff has resulted in a rapid deployment of renewables, the entrance of many new actors to the market and a subsequent reduction in costs (IEA and OECD, 2007). It should be noted, however, that government support schemes are regularly revised. For example, arising from concerns over the expansion of maize cultivation for biogas production, the 2012 Renewable Energy Act limits the proportion of maize and other cereal grains in the biogas substrate mix, while biogas production from municipal biowaste, other residues and pastureland is being enforced (BMELV, 2011; Strauch and Krassowki, 2012).

Coupled with policies promoting a strong agricultural biogas sector in Germany are policies leading to the successful introduction of biofuels, including biomethane, to the market (Silvestrini et al., 2010). Also key to the development of the biomethane in the transport sector was full tax exemption on biofuels from the outset, receptive agricultural and automotive sectors and the promotion of natural gas as a transport fuel (Silvestrini et al., 2010). There has been significant growth in the CNG sector since the 1990s; in 2010, there were almost 92,000 NGVs being served by 900 filling stations, rising from only 50 filling stations and 3245 NGVs in 1999 (NGV, 2011).

Policy barriers and lessons learned

Ireland – conflicting policies

Despite the many benefits of biomethane and its success in some countries, it is still a relatively niche area. A recurring theme in faltering biomethane industries is a lack of consistent and cohesive policy. Policy relating to energy and agriculture, as well as to waste, GHG emissions, transport, and air and water quality all affect the development of a bioCNG industry and, if there is no joined-up thinking, the industry will struggle (Smyth et al., 2010b; Thamsiriroj et al., 2011; Yeh, 2007). For example, while waste legislation may support the treatment of organic wastes by AD and agri-environmental policy promotes reducing fossil fertiliser usage, the spreading of digestate can be severely restricted by ABP regulations, presenting challenges for the AD sector. The strict ABP controls in Ireland are largely due to the importance of the agricultural sector to the economy and concerns over the impact that problems from poor digestate management could have on the sector, particularly on the export market. Uncertainty in the waste collection sector can also limit the development of AD plants, since a secure supply of feedstock is required. There has been much discussion in Ireland over waste ownership and preferred waste treatment options, with little consensus from the various government parties and planning authorities. Several legal actions have arisen and are ongoing in the courts. Both ABP regulations and uncertainty in the waste sector have hampered the AD industry in Ireland, where, despite the introduction of capital grants for AD plants and tariffs for energy from biogas, the industry has failed to get off the ground (Smyth et al., 2010a). The small size of the tariffs is also a contributory factor.

Changing policies in Denmark and New Zealand

Changing policies can also pose a barrier to development, as the introduction of sustainable technologies is often a long-term process that requires stability (Raven and Gregersen, 2007). The detrimental effect of policy transition can be seen in the AD sector in Denmark. Although the Danish AD sector is well established, with 20 CAD and over 35 farm-scale plants, there have been no new CAD plants constructed since 1998 (Raven and Gregersen, 2007). A change in government led to the withdrawal of many grants and support schemes, and a shift in policy direction. These changes, along with uncertainty over tariffs, deterred new operators from entering the market (Raven and Gregersen, 2007).

In New Zealand, changing policies resulted in the collapse of the NGV market (Yeh, 2007). Initially strongly supported by government through incentives and targets to promote the adoption of NGVs, the country had over 10 per cent penetration of NGVs by the mid-1980s. However, the withdrawal of incentives in 1985 resulted in a rapid decline in the number of NGVs and the failure of the NGV market (Yeh, 2007). There were only 200 NGVs in New Zealand in 2010 (NGV, 2011).

A stable and consistent policy framework is essential for the development of renewable energy technologies (Foxon et al., 2005).

Developing a policy roadmap for a biomethane industry

Roadmap

The main purpose of roadmaps, as discussed in a review by Amer and Daim (2010), is to forecast future market directions and developments in technology, and to assist in decision-making. Put simply, a roadmap is generally used to answer three basic questions: what is our current situation, where do we want to go, and how are we going to get there (Amer and Daim, 2010).

The roadmap in Figure 2.2 draws together knowledge gained from the case studies and the discussion of biomethane policy to present a strategy for the development of a bioCNG transport industry. The roadmap draws on other work in the literature, with particular reference to Thamsiriroj et al. (2011). The roadmap is based on a 15-year period, which is a typical time horizon for renewable energy roadmaps (Amer and Daim, 2010). The key points of the roadmap are outlined in the following paragraphs.

Identify stakeholders and get them on board

The first step in the development of a biomethane-for-transport industry is to identify the industry structure and stakeholders (Figure 2.1). The success of a bioCNG industry is based on numerous symbiotic relationships between these stakeholders (Thamsiriroj et al., 2011) and good communication between stakeholders during the development of new policies is important (van der Laak et al., 2007). Stakeholders should be brought on board in the early stages of industry development and involved in policy formation from the outset.

Align existing and develop new policies and targets to ensure a cohesive policy framework

Existing policies and targets

Many existing policies and targets already directly and indirectly support biomethane/bioCNG (e.g. renewable energy in the transport sector, the use of alternative fuels, energy crops, treatment of organic wastes, reducing pollution from agricultural wastes and improving urban air quality) and the ability of biomethane to contribute to these policies and targets is a benefit that should be highlighted to stakeholders. However, while existing policies and targets can lend support to a bioCNG industry, they can also pose barriers to the development of the industry. It is recommended that a government working group be set up to liaise between different government departments and stakeholders in order to align existing policies relating to biogas, biomethane and bioCNG, and to put in place new policies and targets to drive the development of the industry.

New policies and targets

A review of existing resources and resource potential should inform policy, and targets should take account of existing renewable energy and GHG emissions policies and targets as well as other related targets, such as those for local air quality and waste treatment. Ambitious targets are beneficial as they give a clear signal of intent from government and can provide the security needed for private sector firms to invest in the technology. It is important that targets are feasible and that there are policies in place to enable targets to be achieved.