Thoughts for Food:

Sustainable Agriculture and its Technological and Social Opportunities

Conference 9 October 2016

Anaerobic Digestion of Agricultural Wastes:

Review of Recent Technological Developments

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Deutsches
Wissenschaftszentrum Kairo

Deutschland
Land der Ideen

المركز العلمى الألمانى
بالقاهـــــرة

ألمانيا بلد الأفكار

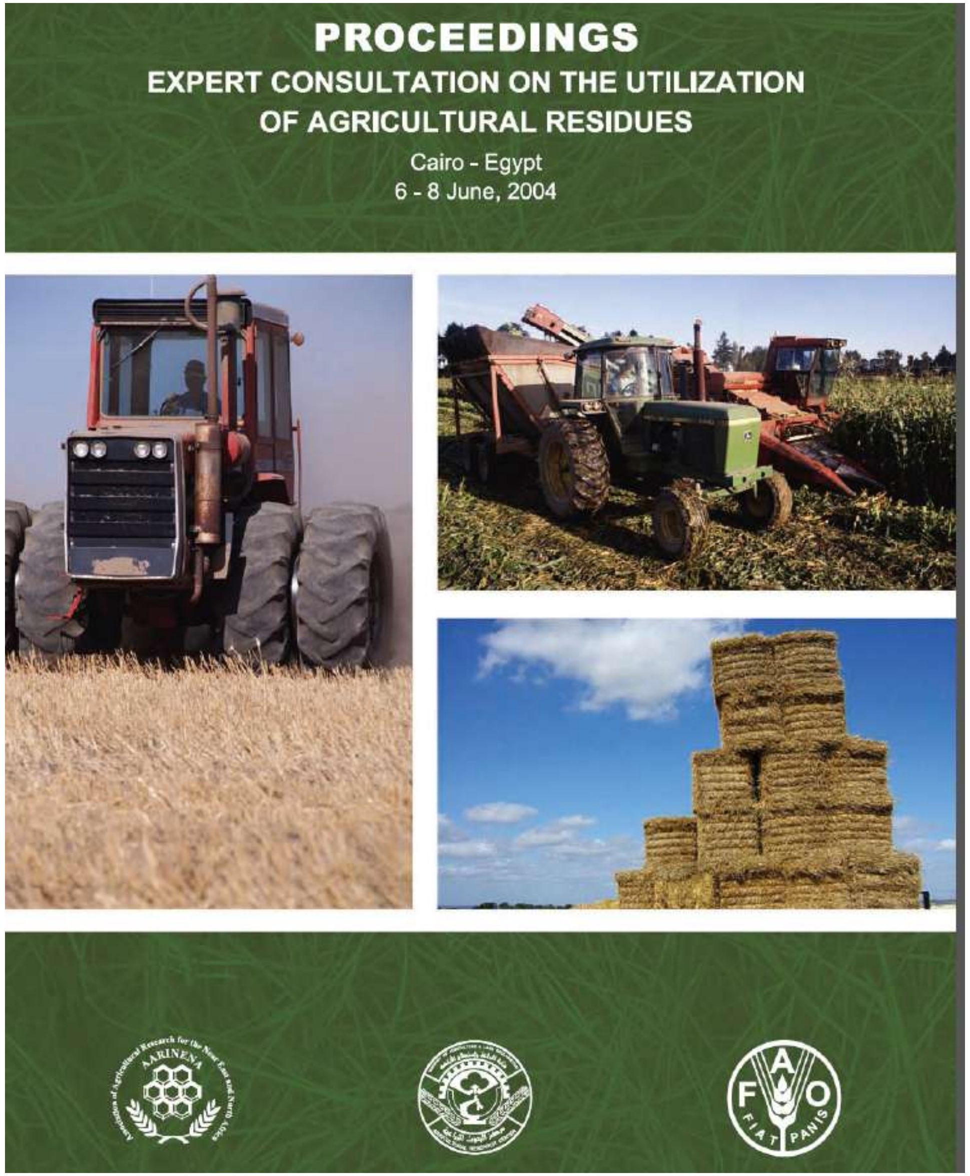
Outline

1. Egypt’s biomass resources
2. Utilization of biomass resources in Egypt
3. Utilization of biomass resources in developed countries
4. Our research interest in biomass utilization
5. Anaerobic digestion recent developments
6. Conclusions

1. Egypt's Biomass Resources

Main Biomass Types	Estimated production, 1000 ton/year	Comments
Agriculture residues[1] (wheat, rice, maize, sorghum, barley, cotton, sugar cane residues)	27,400	much higher estimates have been presented in other reports
Animal manure[1]	13,600	much higher estimates have been reported
Agro-industry waste	partially available	bagasse:2.8 m, tons/year, filter mud:360.000 tons/year
Sludge from WWTP's	1,500	this estimate is based on the production rate from existing WWTPs
Faecal sludge, FS (dilute suspension)	100,000	rough estimate based on population 30 millions @ 10 liters/day FS production rate (80 gm dry basis)
Organic fraction from MSW	11,000	based on an estimate of the current collection rate

(1) Source: Said,N. et al, Quantitative appraisal of biomass resources and their energy potential in Egypt, Renewable and Sustainable Energy Reviews, 24 (2013)



PROCEEDINGS

EXPERT CONSULTATION ON THE UTILIZATION OF AGRICULTURAL RESIDUES

Cairo - Egypt
6 - 8 June, 2004

This project is financed by the European Commission (SMAP II), executed by the World Bank (METAP) and hosted at ANGED

Technical/Policy Note on Agricultural Waste Management in Egypt

Draft Final Report

PREPARED BY
GTZ INTERNATIONAL SERVICES

20 May 2006

2. Current utilization of biomass resources in Egypt

Main Biomass Types	Estimated production, 1000 ton/year	Estimated utilization rate, %	Comments
Agriculture residues[1] (wheat, rice, maize, sorghum, barley, cotton, sugar cane residues)	27,400	80[1]	Estimated amount utilized 5-6 million tons/year, mostly rice straw and cotton stalks.
Animal manure[1]	13,600	80[1]	Farm-level biogas units have been introduced and
Agro-industry waste	not available	not available	bagasse has used as source of heat energy in sugar factories other initiatives for utilizing agro-industry waste exist
Sludge from WWTP's	1,500	10	Gabal el Asfar WWTP AD->biogas->electricity, PPP projects are underway in Kafr el Sheikh, Cement industry in Beni Suif
Faecal sludge	100,000	0	new rural sanitation strategy addressing the issue
Organic fraction from MSW	11,000	10	Egypt experience in composting plants

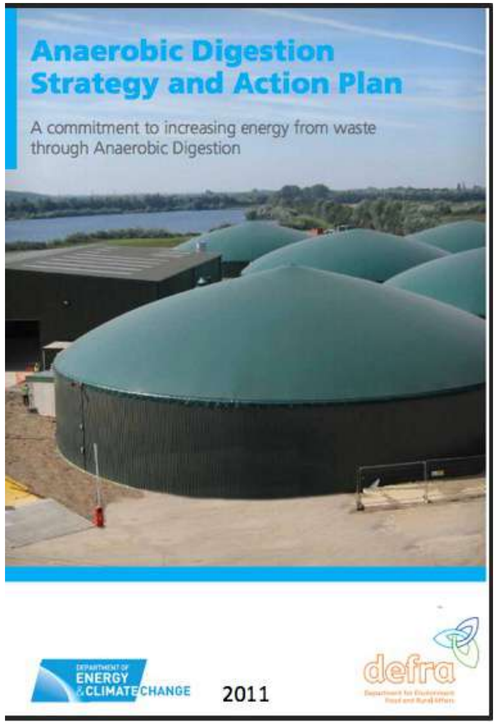
Low level of biomass utilization, National Strategy does not exist

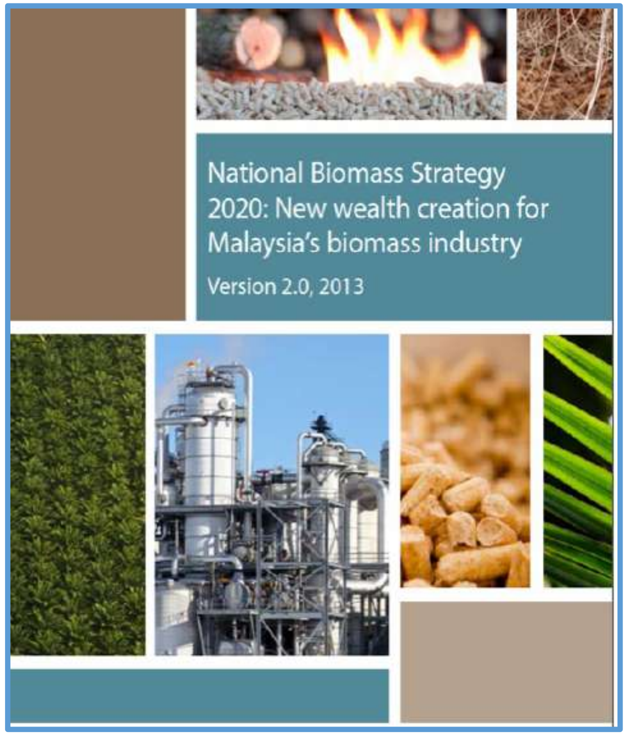
3. Biomass utilization in developed countries

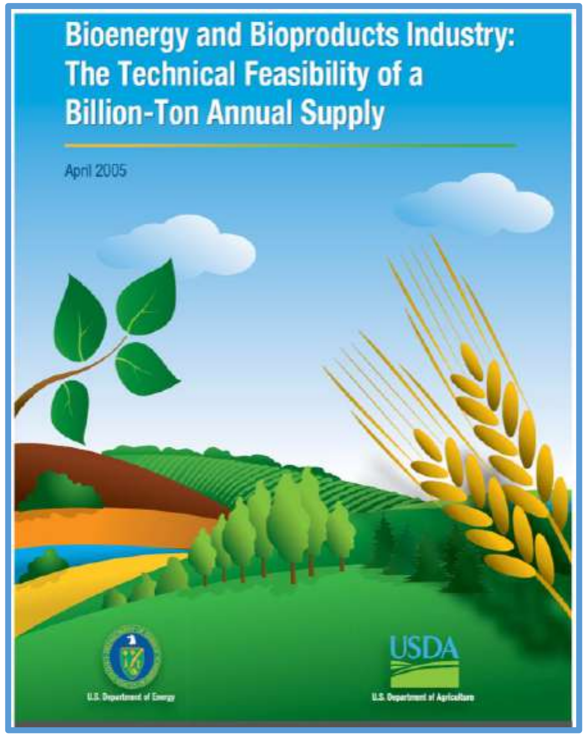
- The European energy production from biogas reached 6 million of oil equivalent (Mtoe) in 2007 with yearly increase of 20%.
- Germany has become the largest biogas producing country in the world. Number of biogas production units in operation is 7700 (2016) producing more than 8 billion cu m of biomethane as well as roughly the samr amount of "green" carbon dioxide per year (www.euroobserv-er.org).

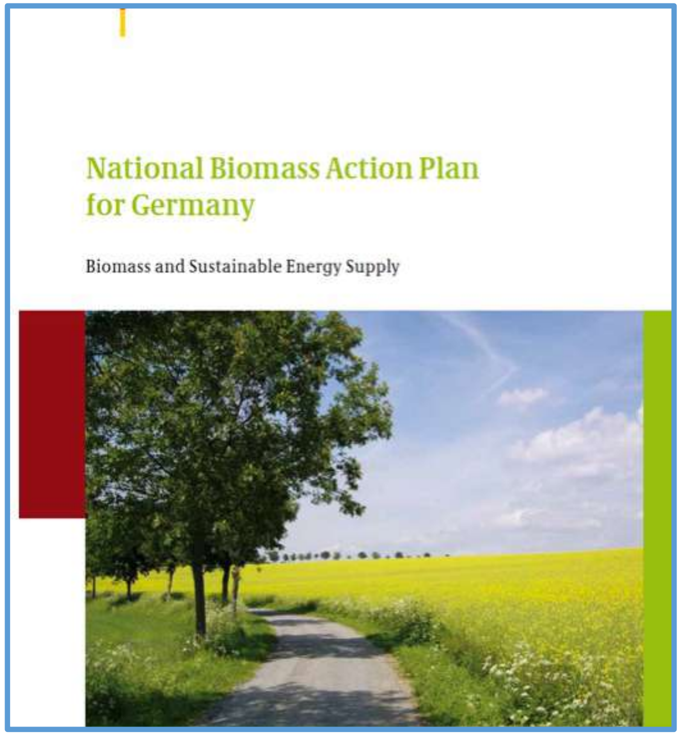
National Biomass Strategies and Action Plans, four examples:

- **UK**
- **Germany**
- **Malaysia**
- **USA a billion ton annual supply target**









Example of resourceful publications

Table 2. Technology Evaluation Tools and Studies

Resource	Description	URL
Thermo-chemical conversion of biomass	This page contains a description and videos of the thermo-chemical conversion processes.	http://www.nrel.gov/biomass/thermochemical_conversion.html
Bio-chemical conversions of biomass	This page contains a description and video of the bio-chemical conversion processes.	http://www.nrel.gov/biomass/biochemical_conversion.html

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

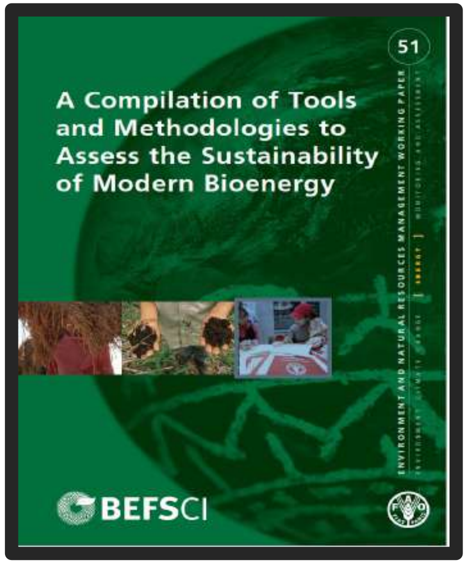
Bioenergy Assessment Toolkit

Anelia Milbrandt and Caroline Uriarte

Produced under direction of the United States Agency for International Development by the National Renewable Energy Laboratory (NREL) under Interagency Agreement AEG-P-00-00003-00; Work for Others Agreement number 3010543; Task Numbers WFE2.1012, WFE2.1013, and WFE2.1014.

Examples		
U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry	This report is an economic assessment of the current and potential biomass resources in the United States that includes projections by 2030 and a spatial county-by-county inventory of primary feedstocks. It also contains prices and available quantities (e.g., supply curves) for the individual feedstocks such as crop residues, forest residues, primary mill residues, urban wood waste, and dedicated energy crops.	http://www1.eere.energy.gov/biomass/pdfs/billion_ton_update.pdf

Biomass Socio-Economic Multiplier Model (BIOSEM)	BIOSEM facilitates existing data so that the employment and income benefits from bioenergy development and deployment in rural areas can be measured. The model simulates the interaction between agricultural crops, biomass production, energy production, and other sectors of the economy.	http://ec.europa.eu/research/agro/fair/en/uk1389.html



11.2 Biomass Socio-economic Multiplier[108] (BIOSEM)

Author	FAIR Programme, European Commission
Year	1997
Type	Planning
Application level/scale	Regional; National; Local; Farm
Primary users	Governments; Operators
Availability	Free
www.task29.net/assets/files/reports/Madlener_Myles.pdf	

Recycling of Agricultural, Municipal and Industrial Residues in Agriculture Network (RAMIRAN)

The "Recycling of Agricultural, Municipal and Industrial Residues in Agriculture Network (RAMIRAN)" is a research and expertise network dealing with environmental issues relating to the use of livestock manure and other organic residues in agriculture. RAMIRAN evolved in 1996 from the much smaller FAO Animal Waste Network, that had been active since 1978, and the scope was expanded to include other organic residues (industrial and municipal) which are used on land as organic manures and soil amendments. It is in principal a European network, but it is also open to interested experts from other parts of the world.

The network provides an invaluable means of exchanging ideas, information and experiences on topics that are becoming increasingly important at a national and international level. The main objectives of the network are to:

- Promote the exchange of methodologies, materials and processes;
- Progress knowledge on the environmental assessment of organic residues recycling in agriculture;
- Identify research priorities and initiate innovative collaborative activities that make use of the synergies resulting from the international network.

4. Our interest in biomass utilization

Chemonics Egypt consulting has established the Eco-Industrial Department (EID) in 2014, which collaborates with international consulting firms and local research institutions in implementing projects in two broad areas:

- Energy from biomass resources
- Biomass business opportunities for entrepreneurs and start-ups

Follows are three examples of EID projects:

4.1 Chemonics Egypt Eco-Industrial Unit:

Identification of business opportunities for high socio-economic impact

- Utilization of biomass as feedstock to small industrial establishments in upper Egypt

Business Opportunities	Supply/Demand					Economic		Barriers to Entry				Social		
Highly favorable / Favorable / Moderate / Least favorable	Availability of Supply	Existence of Demand	Supply Chain Simplicity	Growth Potential	Market Saturation	Capital Intensity	Profit Margin	Simplicity of Tech.	Clarity & simplicity of regulations	Access to Knowledge	Existing Competition	Number of Jobs / capital	Job Favors unemployed	Job Favors Women
1- Agriwaste / Compost	Highly favorable	Highly favorable	Favorable	Favorable	Highly favorable	Highly favorable	Favorable	Highly favorable	Highly favorable	Highly favorable	Favorable	Highly favorable	Highly favorable	Highly favorable
2- Bagasse / energy	Favorable	Highly favorable	Highly favorable	Favorable	Moderate	Favorable	Highly favorable	Highly favorable	Favorable	Highly favorable	Highly favorable	Favorable	Highly favorable	Least favorable
3- Palm trees / wood	Highly favorable	Highly favorable	Highly favorable	Highly favorable	Highly favorable	Favorable	Favorable	Favorable	Highly favorable	Highly favorable	Highly favorable	Highly favorable	Highly favorable	Moderate
4- Agriwaste / animal feed	Highly favorable	Highly favorable	Favorable	Highly favorable	Highly favorable	Highly favorable	Favorable	Highly favorable	Highly favorable	Highly favorable	Favorable	Highly favorable	Highly favorable	Highly favorable
5- Tomato / food & pharm	Favorable	Favorable	Favorable	Highly favorable	Highly favorable	Favorable	Favorable	Favorable	Highly favorable	Highly favorable	Highly favorable	Highly favorable	Highly favorable	Favorable
6- Date / dips food	Highly favorable	Favorable	Favorable	Highly favorable	Highly favorable	Favorable	Favorable	Favorable	Highly favorable	Highly favorable	Highly favorable	Highly favorable	Highly favorable	Favorable
7- Animal waste / biogas	Highly favorable	Moderate	Highly favorable	Highly favorable	Highly favorable	Highly favorable	Moderate	Favorable	Favorable	Favorable	Highly favorable	Moderate	Highly favorable	Moderate

Typical project ideas

filter-mud produced from sugar factories

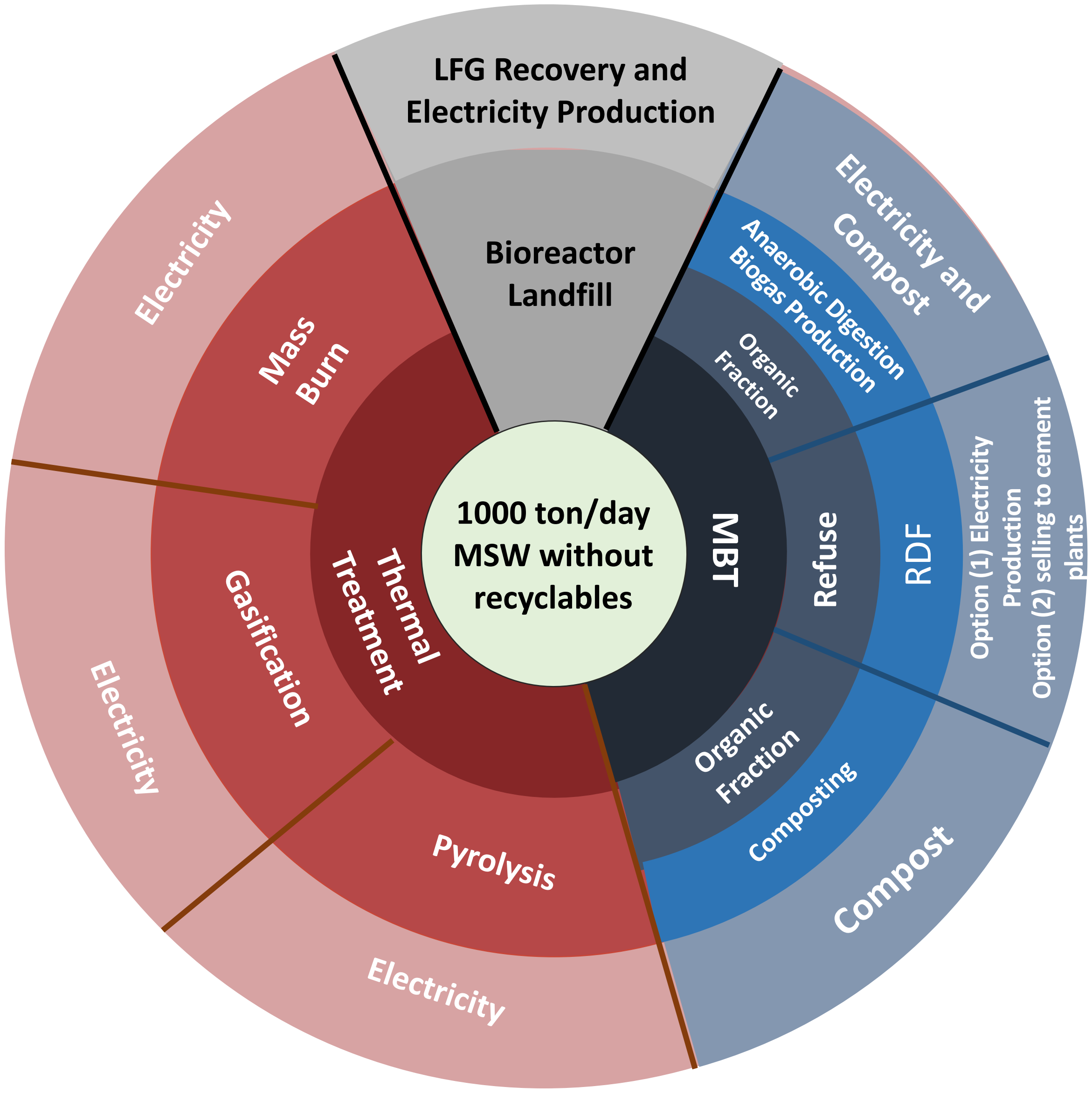
PV pumping and biogas at a rural farm in Altoud - Luxor

The role of innovation in waste management businesses

Reject dates

Reject tomatoes

4.2 W2E study which has considered the option of AD of the OFMSW as a viable option to produce electricity and organic fertilizer from biomass.



Capital Investment, Million EGP

Operation and Maintenance Cost, Million EGY/year

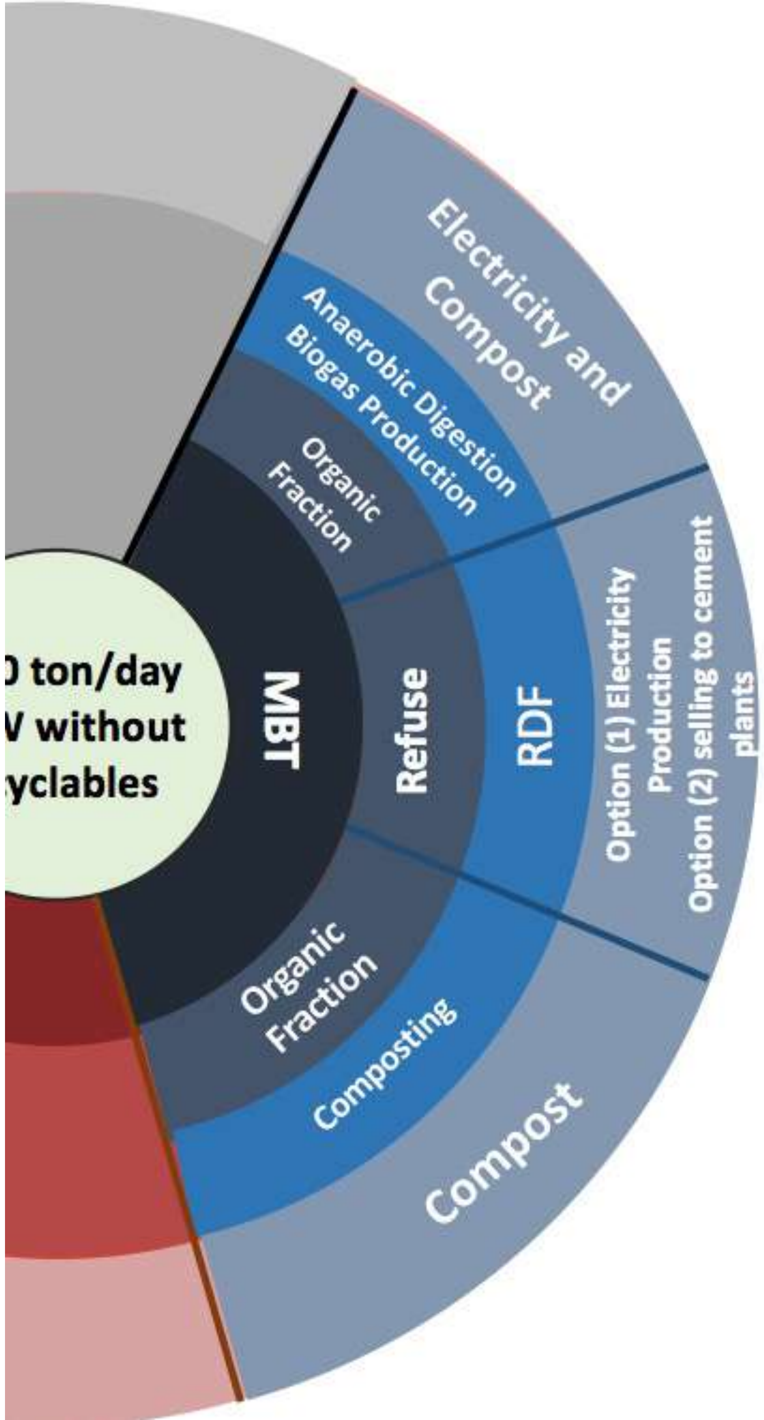
Land Area, Acres

Products, MW or ton

MSW: Municipal Solid Waste
MBT: Mechanical Biological Treatment
RDF: Refuse-Drived Fuel
LFG: landfill Gas

Mechanical Biological Treatment of MSW has been studies in full detail with two treatment routs:

1. Aerobic composting of the OFMSW to produce compost
2. Anaerobic digestion of the OFMSW to produce biogas which is then utilized in electricity generation, and digestate which is processed to produce bio-fertilizer



Capital Investment, Million EGP

Operation and Maintenance Cost, Million EGY/year

Land Area, Acres

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MSW: Municipal Solid Waste
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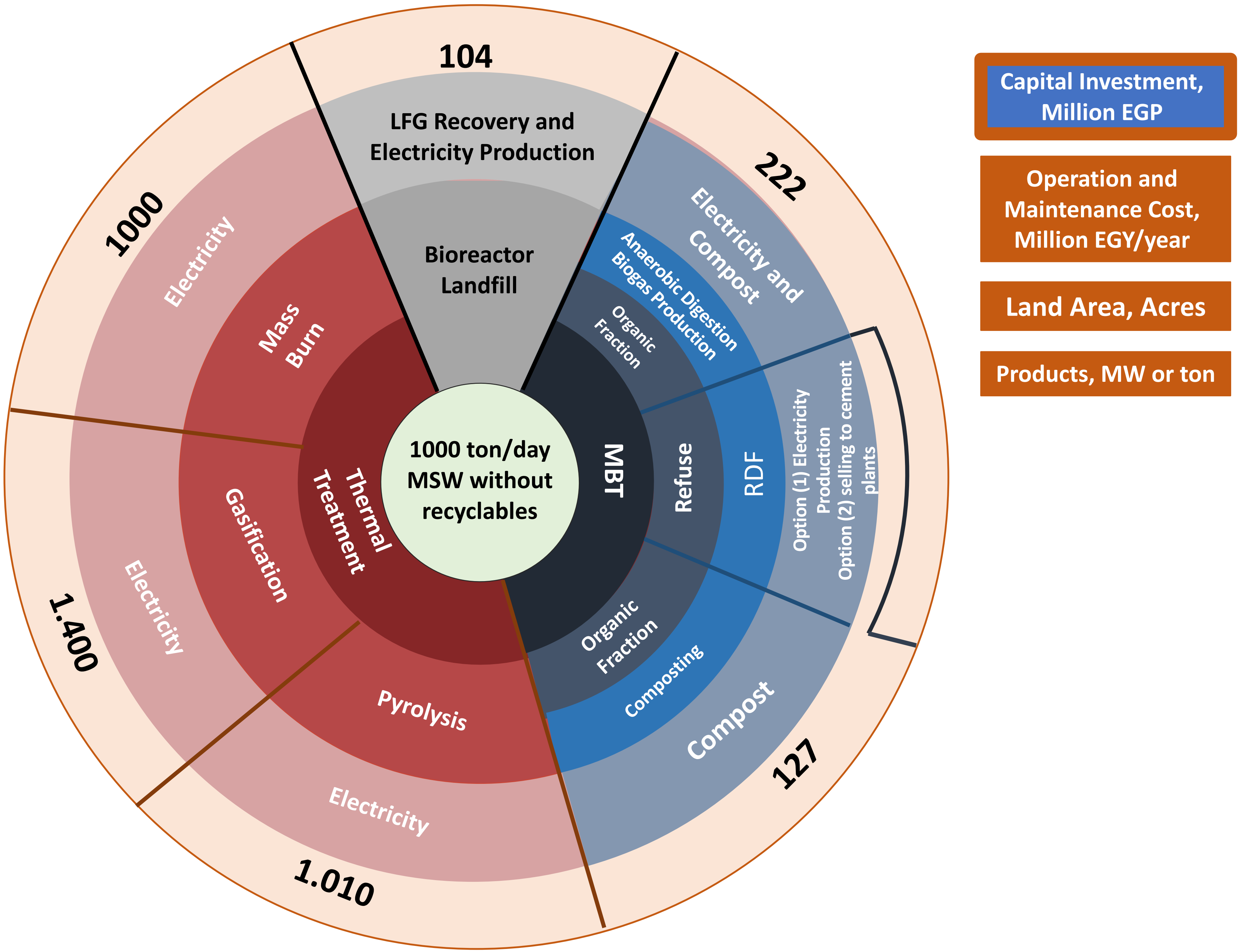
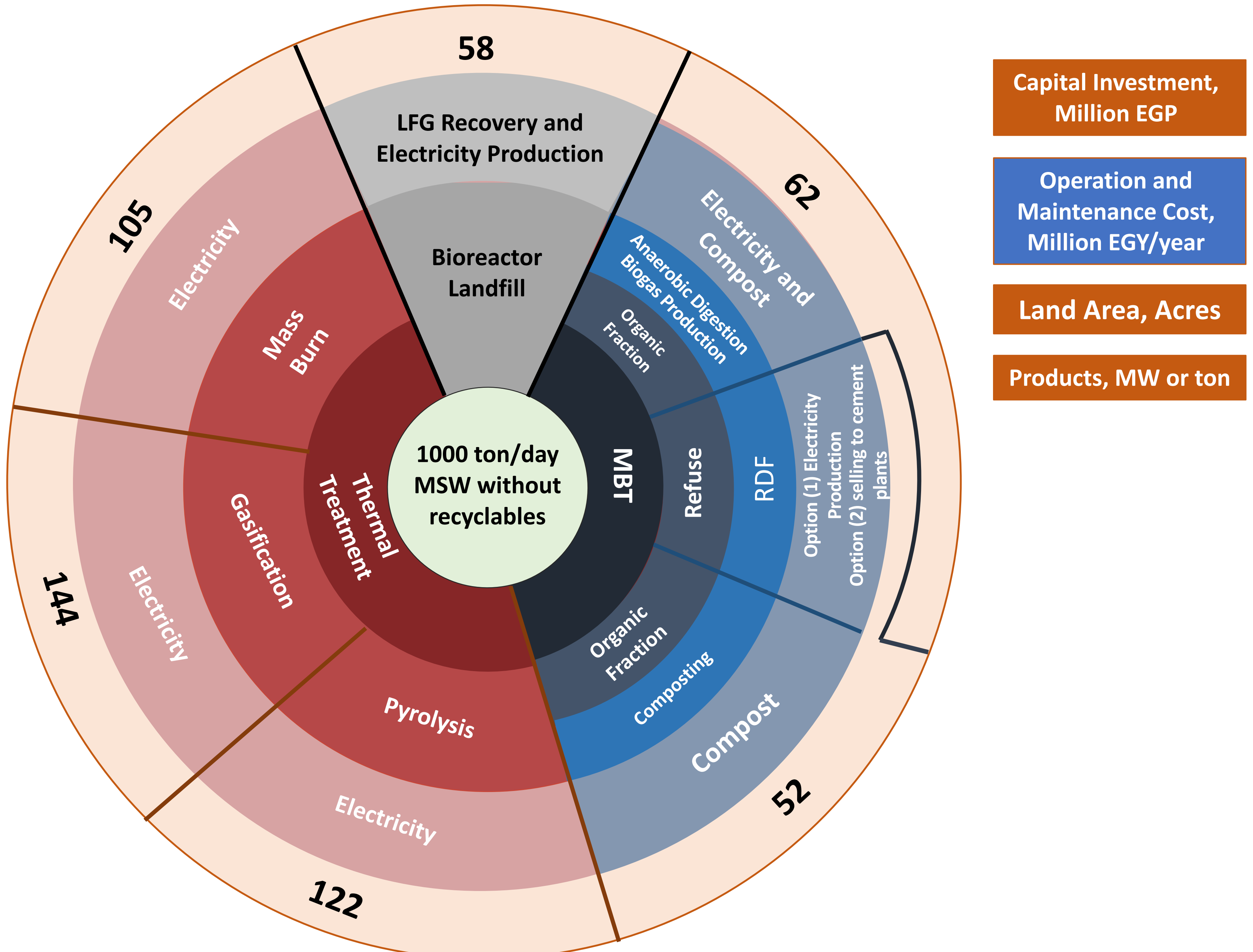
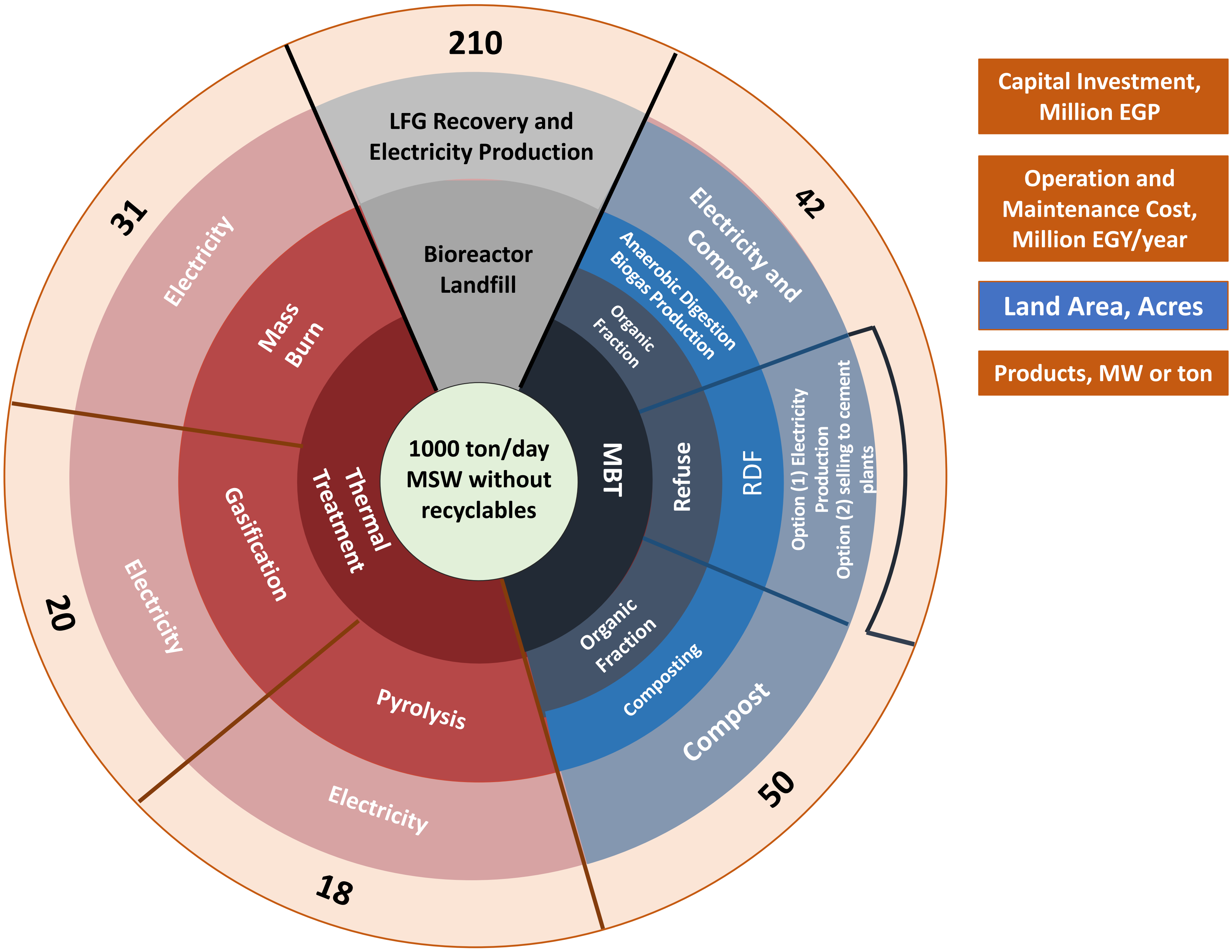
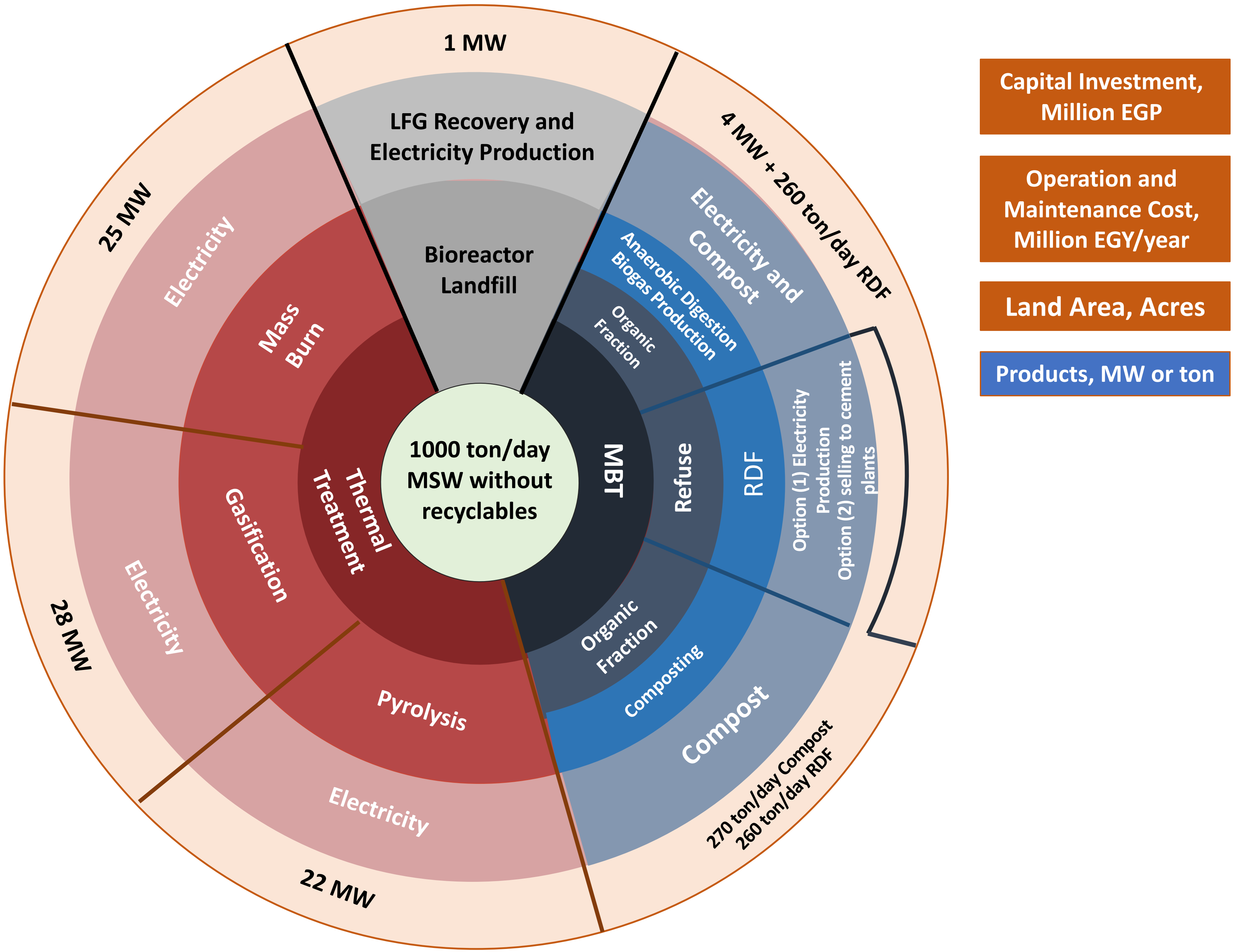

1000 ton/day MSW without recyclables
Thermal Treatment
Mass Burn
Gasification
Pyrolysis
Electricity
Electricity
Electricity
1000
1.400
1.010
Bioreactor Landfill
LFG Recovery and Electricity Production
104
MBT
Organic Fraction
Anaerobic Digestion Biogas Production
Electricity and Compost
222
Refuse
RDF
Option (1) Electricity Production
Option (2) selling to cement plants
Organic Fraction
Composting
Compost
127
Capital Investment, Million EGP
Operation and Maintenance Cost, Million EGY/year
Land Area, Acres
Products, MW or ton

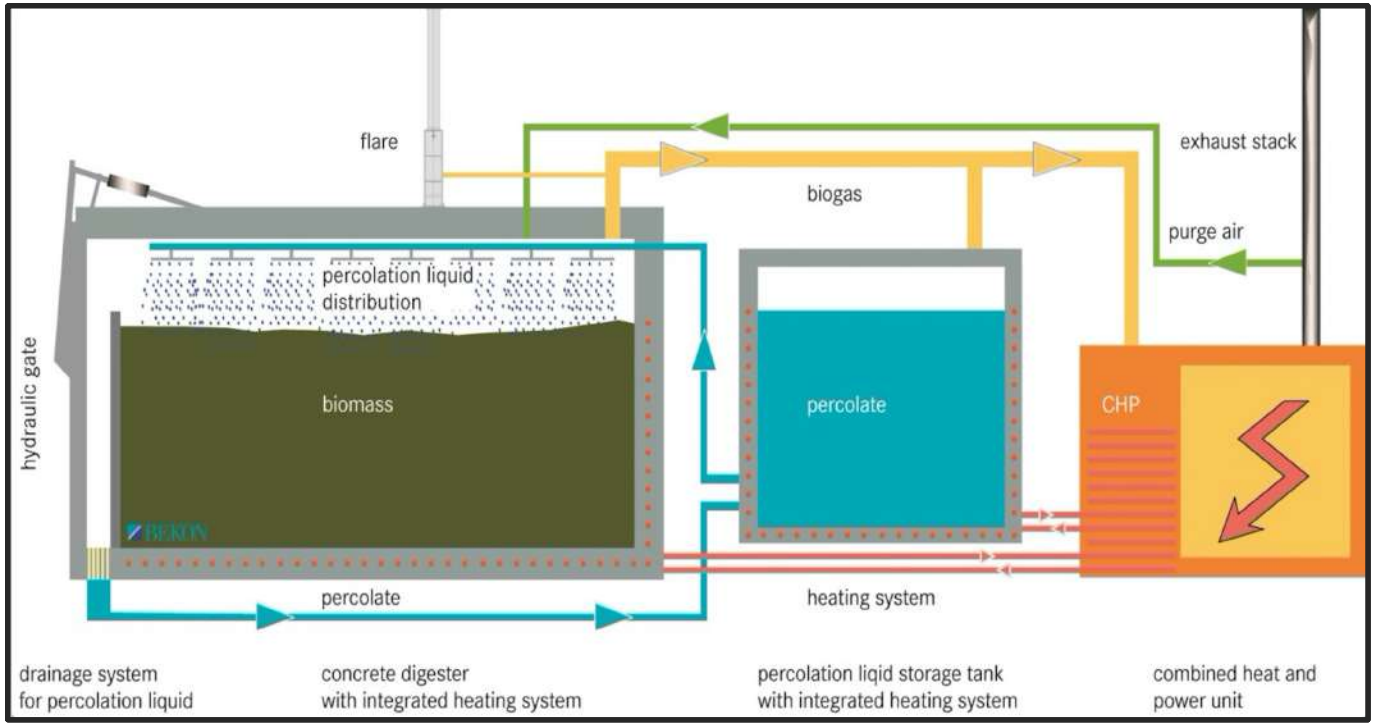

1000 ton/day MSW without recyclables
Thermal Treatment
Mass Burn
Electricity
105
Gasification
Electricity
144
Pyrolysis
Electricity
122
Bioreactor Landfill
LFG Recovery and Electricity Production
58
MBT
Organic Fraction
Anaerobic Digestion Biogas Production
Electricity and Compost
62
Refuse
RDF
Option (1) Electricity Production
Option (2) selling to cement plants
Organic Fraction
Composting
Compost
52
Capital Investment, Million EGP
Operation and Maintenance Cost, Million EGY/year
Land Area, Acres
Products, MW or ton



Capital Investment, Million EGP
Operation and Maintenance Cost, Million EGY/year
Land Area, Acres
Products, MW or ton
1000 ton/day MSW without recyclables
210
LFG Recovery and Electricity Production
Bioreactor Landfill
42
Electricity and Compost
Anaerobic Digestion Biogas Production
Organic Fraction
MBT
Refuse
RDF
Option (1) Electricity Production
Option (2) selling to cement plants
Organic Fraction
Composting
Compost
50
18
Electricity
Pyrolysis
20
Electricity
Gasification
Thermal Treatment
31
Electricity
Mass Burn


1000 ton/day MSW without recyclables
LFG Recovery and Electricity Production
Bioreactor Landfill
1 MW
Thermal Treatment
Mass Burn
Electricity
25 MW
Gasification
Electricity
28 MW
Pyrolysis
Electricity
22 MW
MBT
Organic Fraction
Anaerobic Digestion Biogas Production
Electricity and Compost
4 MW + 260 ton/day RDF
Refuse
RDF
Option (1) Electricity Production
Option (2) selling to cement plants
Organic Fraction
Composting
Compost
270 ton/day Compost
260 ton/day RDF
Capital Investment, Million EGP
Operation and Maintenance Cost, Million EGY/year
Land Area, Acres
Products, MW or ton

4.3 Technology assessment project: dry fermenters



Industrial scale “dry” fermentation systems known as solid-state anaerobic digesters are designed to handle feedstocks with total solids higher than 15%. Several designs exist. There are no moving parts. Systems installed in Europe accepts MSW, biowaste as feedstock.

We have conducted technology assessment of dry fermentation technology to assess its transferability to Egypt, its flexibility and profitability.

5. Anaerobic digestion recent developments

AD specific characteristics

- Anaerobic digestion (AD) converts biomass feedstocks with a relatively high moisture content into a biogas.
- AD is most commonly operated as a continuous process and thus needs a steady supply of feedstock.
- The feedstock needs to be strictly checked and usually needs some form of pre-treatment to maximize methane production and minimize the possibility of killing the natural digestion process.

- Co-digestion of multiple feedstocks is most commonly practiced to achieve the best balance of biogas yield and process stability.
- The two main products of AD are biogas and a residue digestate, which, after appropriate treatment, can be used as a bio-fertilizer.
- Biogas is primarily a mixture of methane (CH_4) and carbon dioxide (CO_2), as well as some other minor constituents including nitrogen, ammonia (NH_3), sulfur dioxide (SO_2), hydrogen sulfide (H_2S) and hydrogen.
- Biogas is readily used as a fuel in power or combined heat and power units and has the potential to be used as a substitute for natural gas after appropriate cleaning and upgrading.

IRENA, Biomass for power generation, 2012

Industry and research focus on biomass power generation critical components:

1. Biomass feedstocks: It come in a variety of forms and have different properties that impact their use for power generation.
2. Biomass conversion: This is the process by which biomass feedstocks are transformed into the energy form that will be used to generate heat and/or electricity.
3. Power generation technologies: There is a wide range of commercially proven power generation technologies that can use biomass as a fuel input.

IRENA, Biomass for power generation, 2012

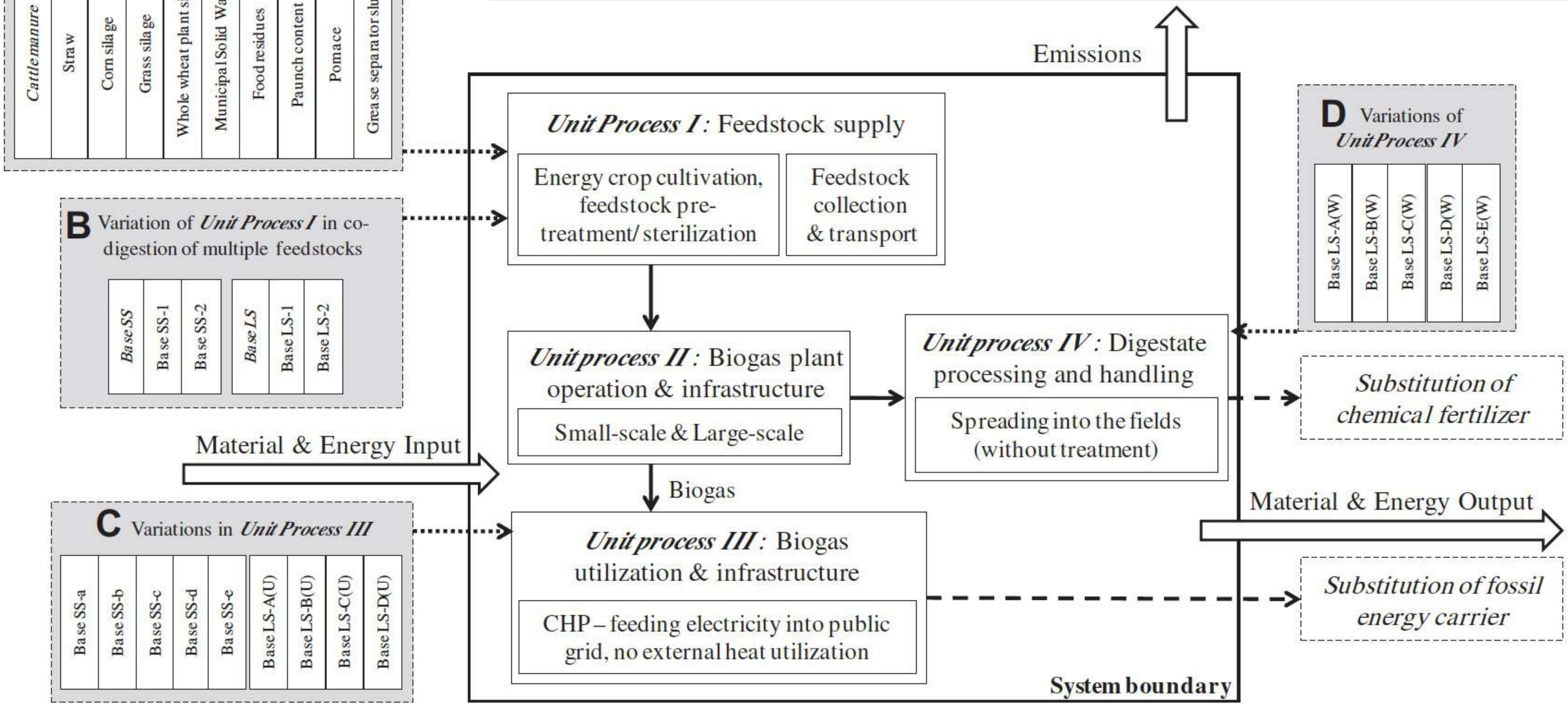
Appropriate anaerobic digesters by waste or crop stream

Type of Waste	Liquid Waste	Slurry Waste	Semi-solid Waste
Appropriate digester	Covered lagoon digester/ Upflow anaerobic sludge blanket/Fixed Film	Complete mix digester	Plug flow digester
Description	Covered lagoon or sludge blanket-type digesters are used with wastes discharged into water. The decomposition of waste in water creates a naturally anaerobic environment.	Complete mix digesters work best with slurry manure or wastes that are semi-liquid (generally, when the waste's solids composition is less than 10%). These wastes are deposited in a heated tank and periodically mixed. Biogas that is produced remains in the tank until use or flaring	Plug flow digesters are used for solid manure or waste (generally when the waste's solids composition is 11% or greater). Wastes are deposited in a long, heated tank that is typically situated below ground. Biogas remains in the tank until use or flaring.

SOURCE: CENTRE FOR CLIMATE AND ENERGY SOLUTIONS, 2012.

IRENA, Biomass for power generation, 2012

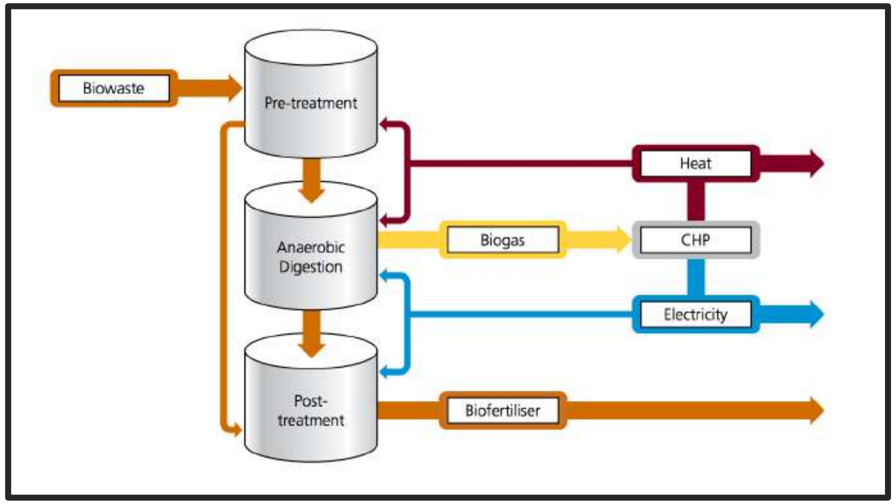
Variations in biogas production and utilization pathways considering; (A) single feedstock digestion and (B) co-digestion of multiple feedstock, (C) biogas utilization, and (D) digestate processing and handling.



Poeschl,M., et al, Environmental impacts of biogas deployment Part II: life cycle assessment of multiple production and utilization pathways, Journal of Cleaner Production, 24 (2012)

Anaerobic digestion research topics

- Feedstock supply chain optimization
- Pre-treatment of feed substrate
- Optimization of feedstock composition (co-digestion)
- Reactor design and configurations
- Processes to enhance biogas production
- Biogas utilization
- Digestate utilization



Defra, Anaerobic digestion strategy and action plan (UK), 2011

Potential process innovations in biogas relevant industrial symbiosis

COG-AD process

A process for biomethanation by the injection of coke oven gas (COG)to an AD reactor enabled to achieve 98–99% CH_4 in the obtained biogas. The employment hydrogen from COG to reduce CO_2 content in biogas is a very good example of synergy between the unsustainable coke industry and bio-based AD technology. This is an excellent example of using AD for handling gaseous emissions from conventional industries, an example that can be adopted widely in other industries with unwanted gaseous emissions.

Cement-AD process

The main claimed benefits of this symbiosis is the utilization of excess thermal energy from a cement plant to heat AD digesters and the direct utilization of in-situ generated biogas as CO_2-neutral fuel for high temperature processes of the cement plant. Moreover, the biogas generation costs are reduced and for the integrated AD/cement plant with biogas production larger than $90 m^3/h$ are claimed to be below the natural gas market price. The major advantage of this concept is enhanced energy utilization since biogas fuel is fully utilized in the cement plant while heat from the cement plant is utilized in the biogas plant.

Source: Budzianowski, W., A review of potential innovations for production, conditioning and utilization of biogas with multiple-criteria assessment, Renewable and Sustainable Energy Reviews, 54, 2016

Potential innovations in coupling AD with other processes

A. Coupling AD with pyrolysis process

This process innovation combines anaerobic digestion and pyrolysis processes in order to increase the energy recovery from agricultural residues.

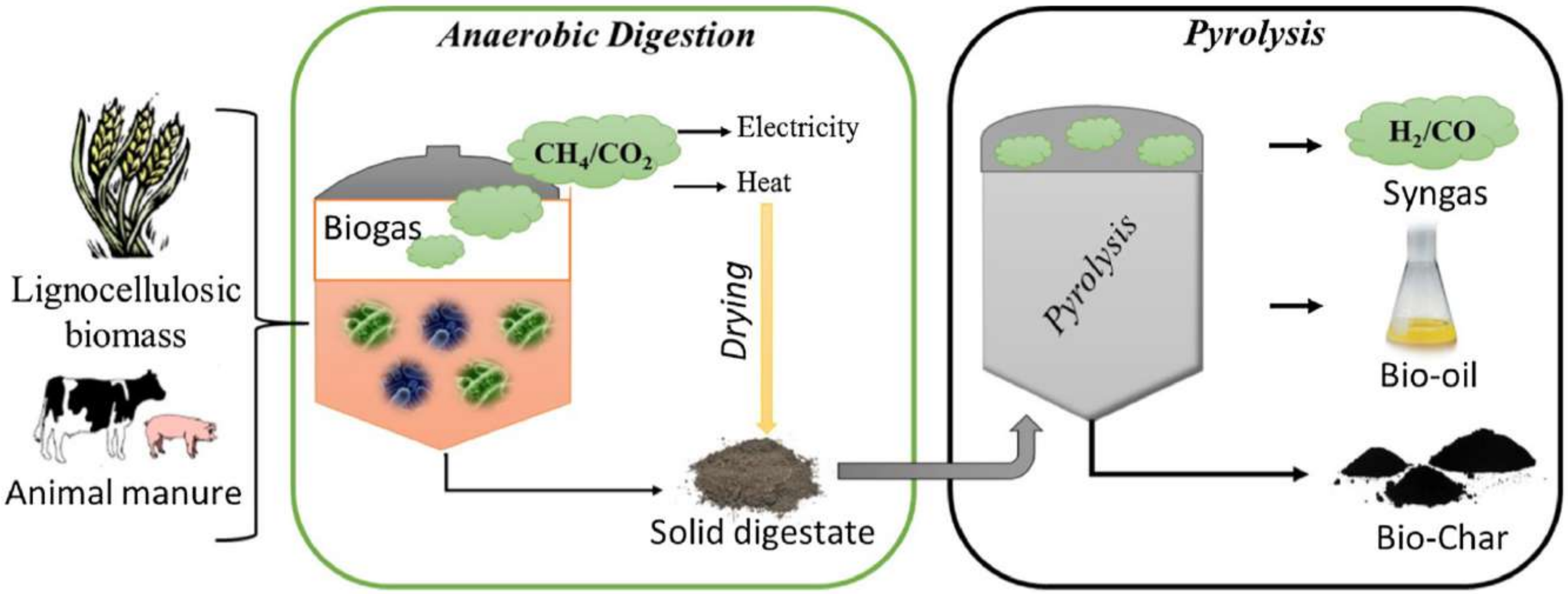


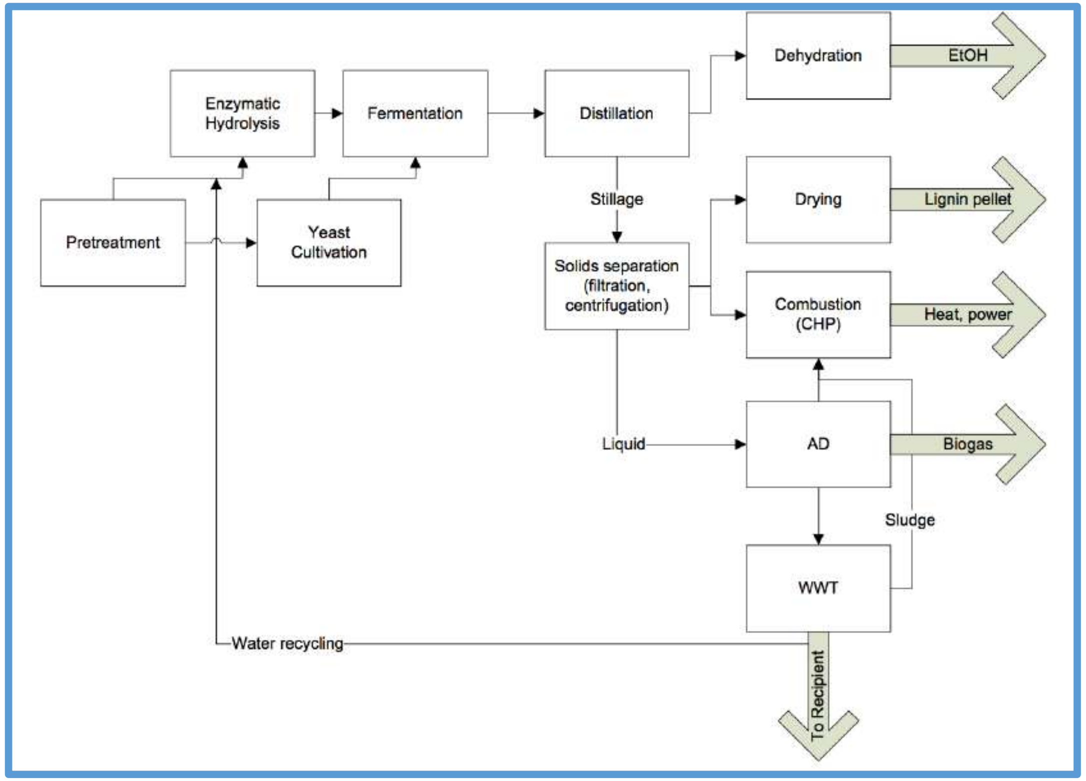
Fig. 1. Sustainable energy recovery from agricultural residues by coupling anaerobic digestion and pyrolysis process.

Source: Monlau, F. et al, A new concept for enhancing energy recovery from agricultural residues by coupling AD and pyrolysis process, Applied Energy, 148, 2015

Potential innovations in coupling AD with other processes

B. Combined biogas and bioethanol production

The integration of both fermentation and anaerobic digestion, in a biorefinery concept, would allow the production of ethanol along with biogas, which can be used to produce heat and electricity, thus improving the overall energy balance.



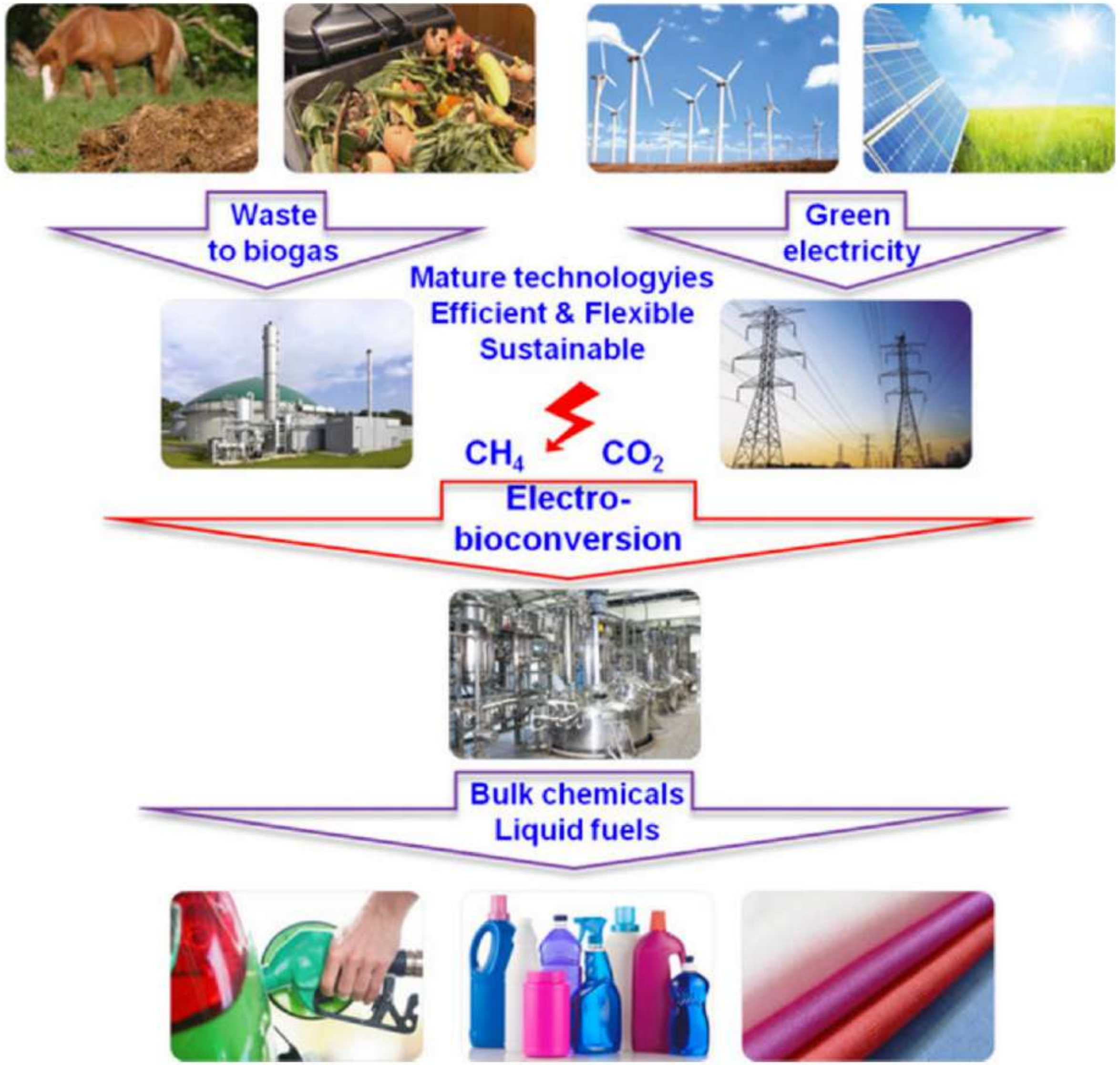
Sources: Cesaro, A et al, combined biogas and bioethanol production: opportunities and challenges for industrial applicaions, Energies, 8, 2015
Davidsson,A, Thesis, Lund University, combined biogas and bio-ethanol production for optimal energy utilization, 2013

C. Coupling AD with green electricity Innovation: $E\&G^2C$ concept

The central idea of the concept is the conversion of organic wastes into a widely usable product—biogas (CO2 +CH4)—which is then used as a clean and uniform substrate for the synthesis of bulk-chemicals and/or fuels, especially by using green electricity from wind and solar. The concept is believed to have the potential to overcome major limitations of known bioproduction systems. Biogas as a substrate of biosynthesis has many unique advantages, including sustainability, efficiency, and flexibility. The use of electricity for biosynthesis with biogas represents an ideal system for efficient bioelectrochemical conversion. The realization of the concept is discussed by looking at the possible conversion routes and key issues to be solved. The markets and perspectives provided by the concept E&G2C have been addressed. It has been argued that the concept E&G2C provides a unique and innovative path for the next move toward a real sustainable bioeconomy.

Source: Zeng,A. and Kaltschmitt,M., Green Electricity and biowaste via biogas to bulk-chemicals and fuels: the next move toward a sustainable bioeconmy, Eng. Life Sci. 16 (2016)

E&G^{2}C concept



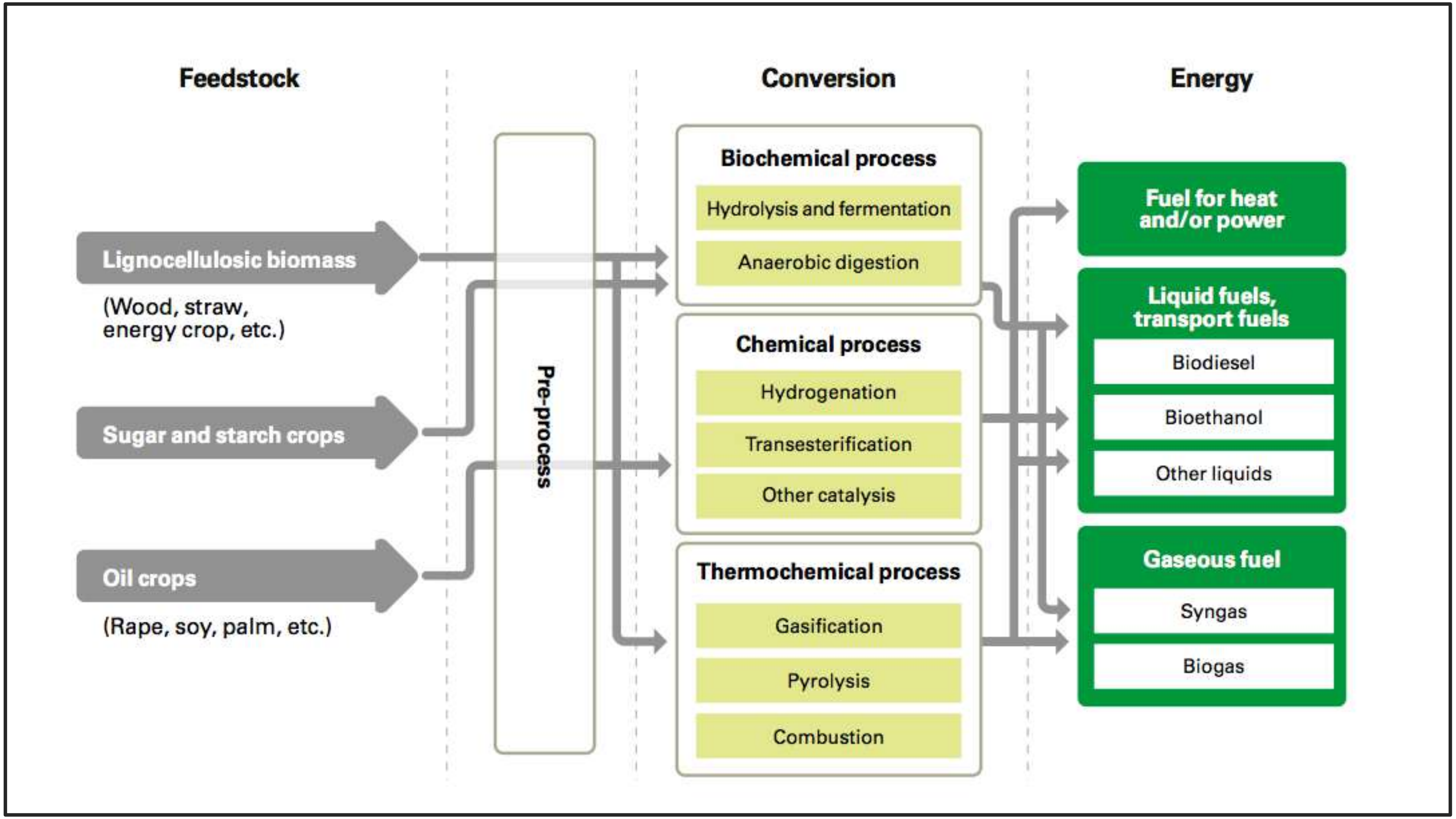
6. Conclusions

- Utilization rate of Egypt’s biomass resources is low. National strategy for biomass utilization shall be developed.
- Biogas is a multidisciplinary field of research, great effort is required to build research teams that can acquire and produce knowledge in close collaboration with local industry.
- Biogas production using anaerobic digestion of biomass resources in Egypt is expected to receive increasing interest by industry, research institutions and private sector. This will facilitate the provision of an alternative sustainable and viable energy supply.
- Waste processing clusters utilizing biomass and applying innovative conversion processes constitute great business opportunities for entrepreneurs and start-ups.

extra slides

Industry and research focus on biomass conversion processes

Schematic diagram of bioenergy production pathways. Feedstocks on the left of the diagram are converted via a range of processes to solid, liquid or gaseous fuels on the right



bp, Energy Biosciences Institute, Biomass in the energy industry, 2014

Biomass conversion technology status

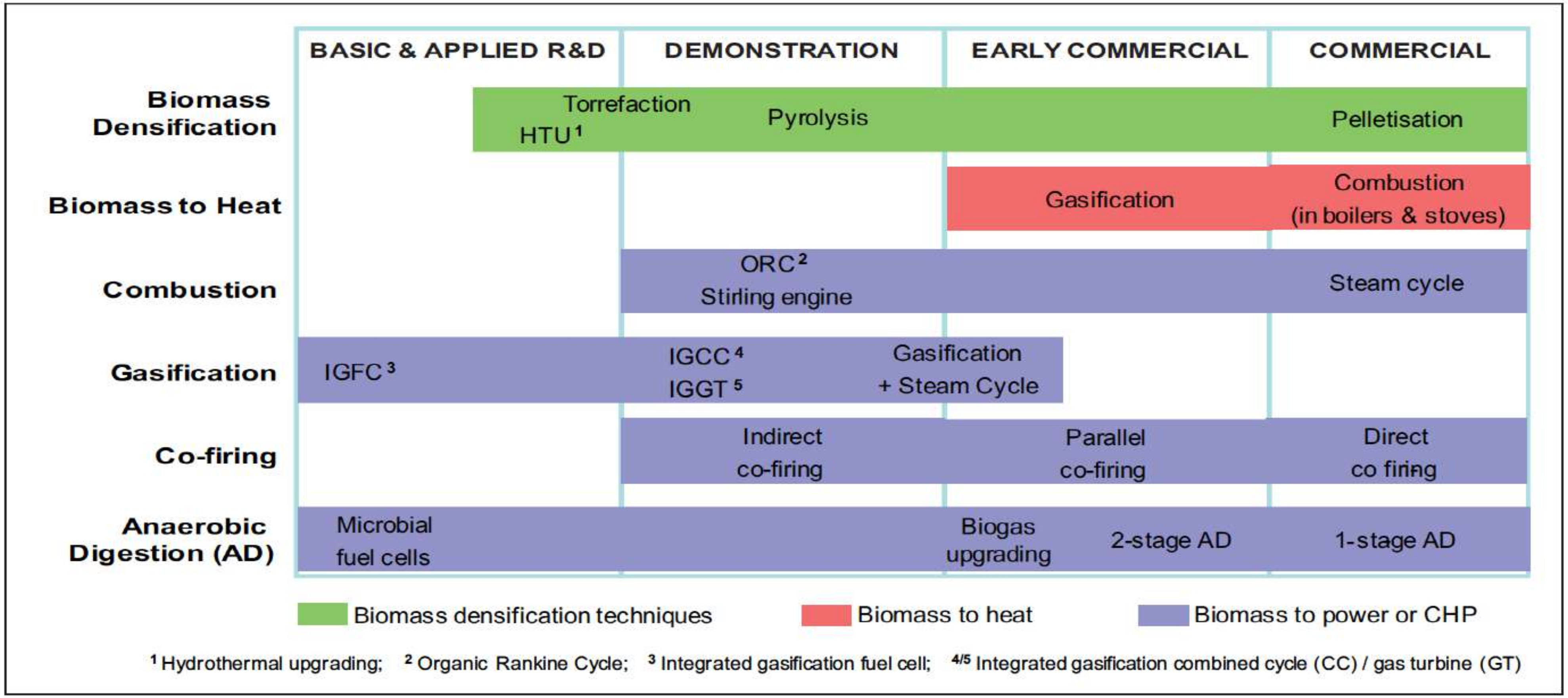


Figure 4. Development status of the main technologies to upgrade biomass and/or to convert it into heat and/or power. Source: E4tech, 2009.

Bioenergy-a sustainable and reliable energy source, IEA Bioenergy Report, 2009