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Biogas Talk - EMRC
24th June 2011

Biogas for EMRC

Dongke Zhang *FTSE*
Centre for Energy
The University of Western Australia

Centre for Energy
"energy for today and tomorrow"

Acknowledgement

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- Mr Steve Fitzpatrick and EMRC
- Colleagues, Postgraduates and Research Fellows
- Australian Research Council
- Industry Partners
  - BHP Billiton
  - Chevron
  - ANSAC
  - SCNRM
  - ENN
  - ……

The Australian Context……

The Australian Dollar in its 26 years history

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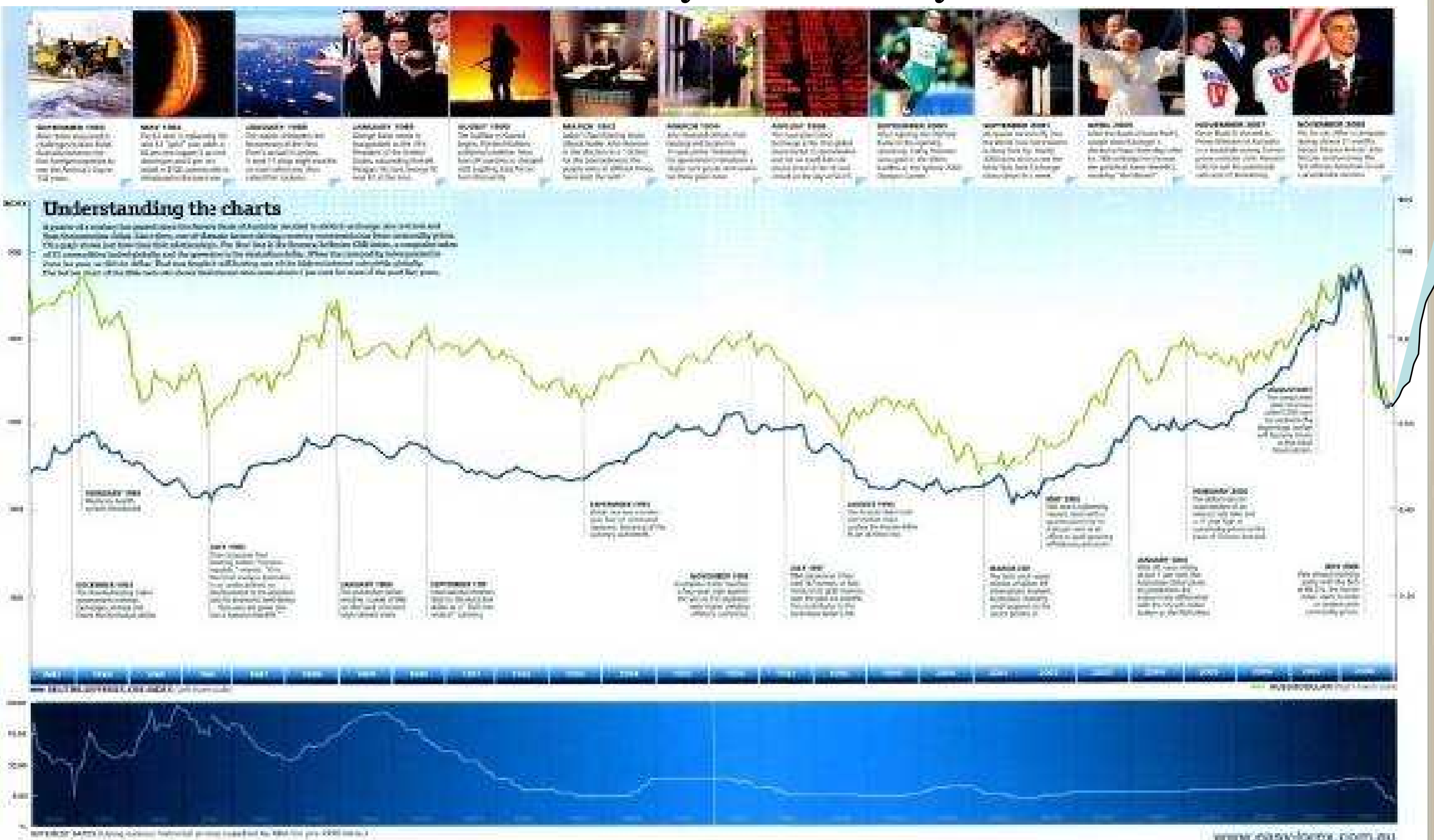

Centre for Energy

"energy for today and tomorrow"

Centre for Energy

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- Established 2008
- The only World-leading research facility of this kind in WA, providing scientific and technological support to the energy supply and use industries
- Expertise: Reaction Engineering, Coal and Gas Utilisation, Catalysis, Bioenergy and Biotechnology, Process Development and Modelling
- Ability to deliver innovative R&D outcomes with quality and scientific integrity
- Collaboration
- Education and research training

We Consider the Whole System

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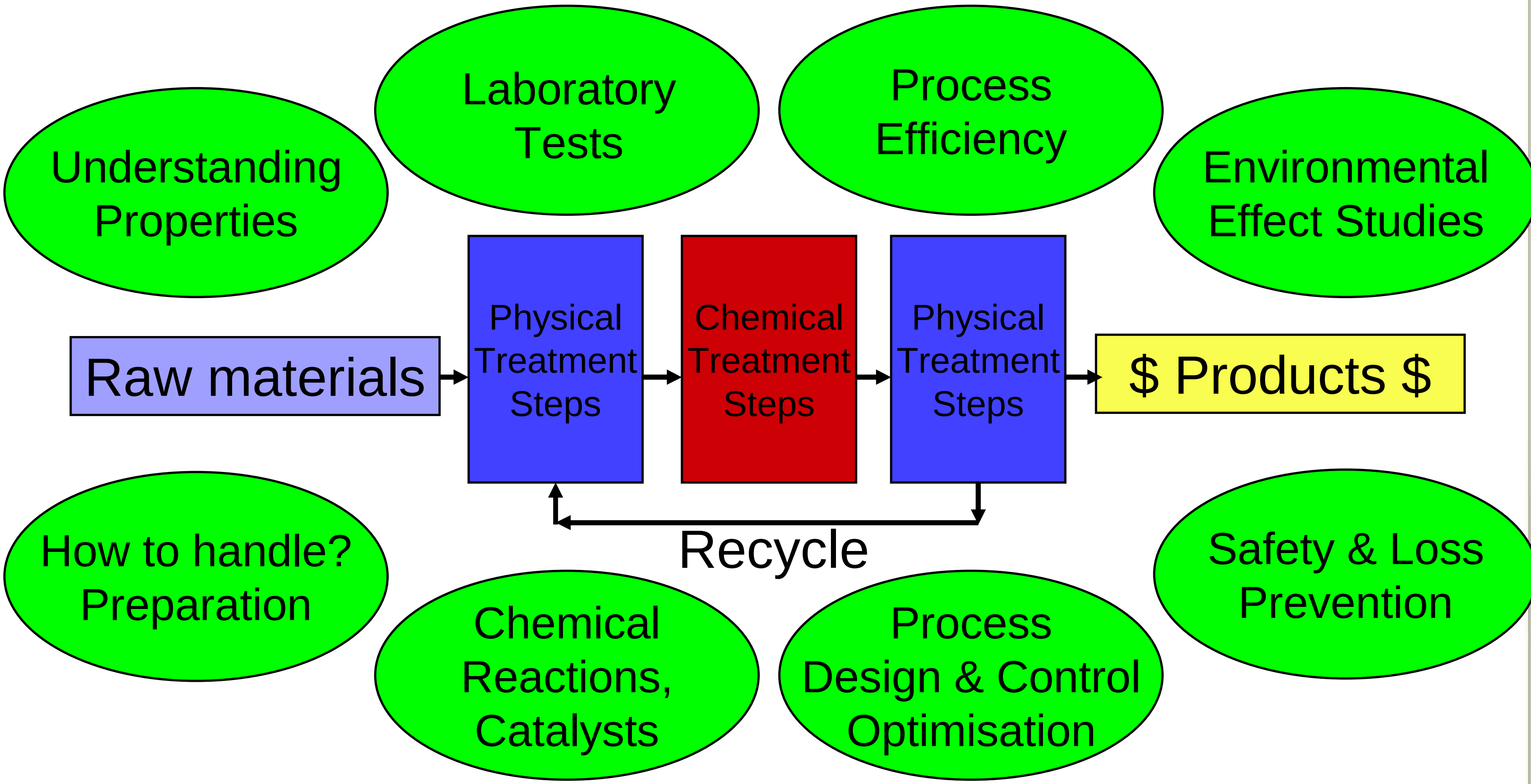

Laissez-Faire

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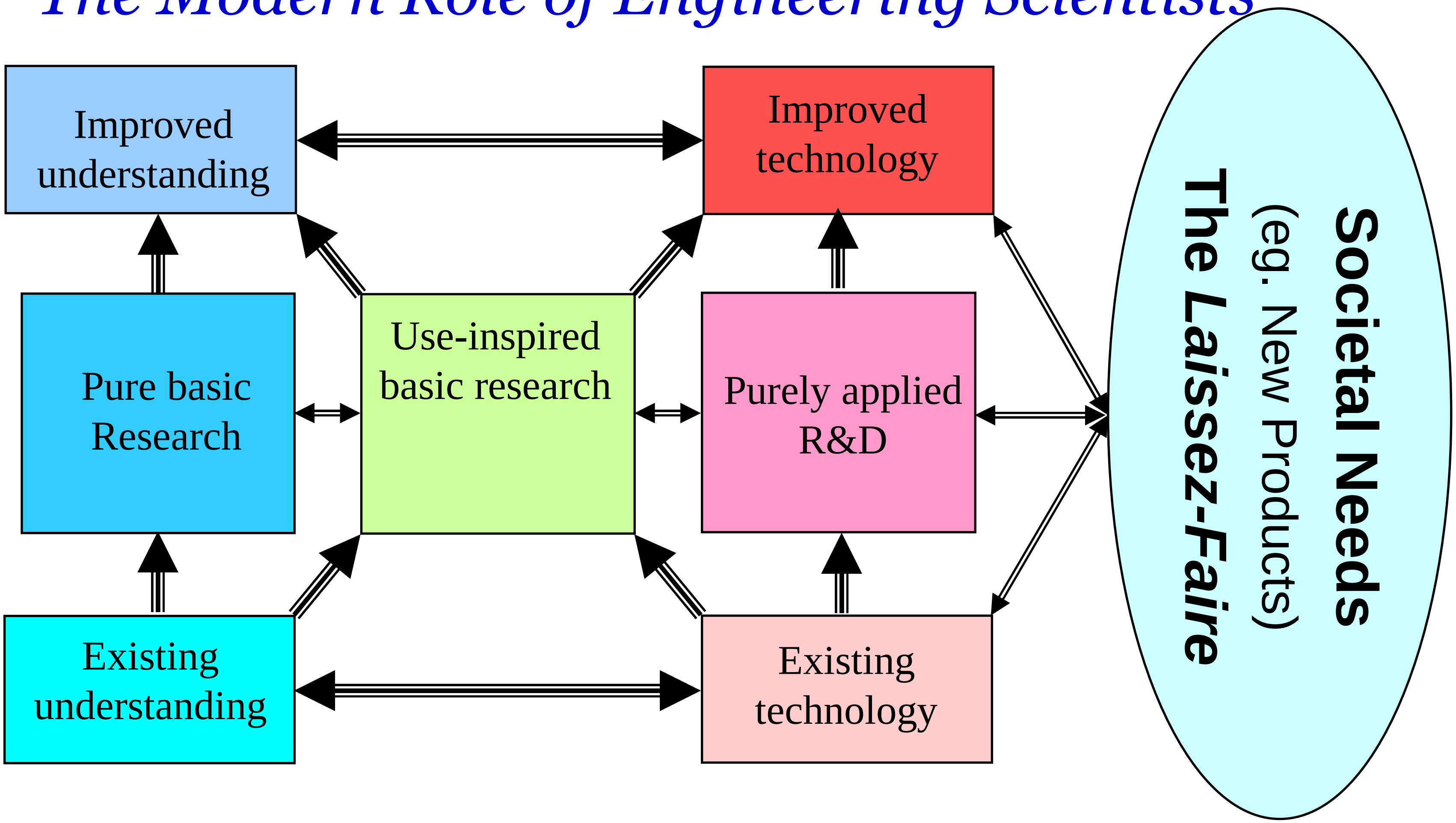
Laissez-Faire Drives New Technology and Science

The Modern Role of Engineering Scientists



Focus Area (6 themes)

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- Natural Gas (Winthrop Professor Eric May)
- Petroleum (Professor Jishan Liu)
- Coal and Biomass (Winthrop Professor Dongke Zhang)
- Geothermal energy and waste heat utilisation (Professor Hui Tong Chua)
- Energy Infrastructure: Marine and Subsea (Winthrop Professor Krish Thiagarajan)
- Future Energy (Winthrop Professor Dongke Zhang)
  - Including biogas from wastes

We have deep roots in industry

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Strong industry support through a range of partnerships

- BHP Billiton Ltd
- Chevron Texaco Ltd
- Woodside Energy Ltd
- Wesfarmers Ltd
- Griffin Coal Mining Group Pty Ltd
- Western Power Corporation
- Dyno Nobel Asian Pacific Ltd
- Rio Tinto Ltd
- Prica Mining Services Pty Ltd
- Chemeq Ltd
- Environmental Solution International Ltd
- Hydrogen Technology Ltd
- Hurricane Energy Ltd
- Loongana Lime Pty ltd
- ……

We also create industry

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- Chemeq Ltd
- Hydrogen Technology Ltd
- Hurricane Energy Ltd
- Spitfire Oil Ltd
- Ashking Pty Ltd
- 3D Reactions Pty Ltd

Energy and Civilisation

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	Daily per capita consumption (1000 kcal)				
Period	Food	H & C	I & A	Transportation	**Total**
Primitive	2				**2**
Hunting	3	2			**5**
Primitive Agricultural	4	4	4		**12**
Advanced Agricultural	6	12	7	1	**26**
Industrial	7	32	24	14	**77**
Technological	10	66	91	63	**230**

World Primary Energy Consumption by Fuel Type

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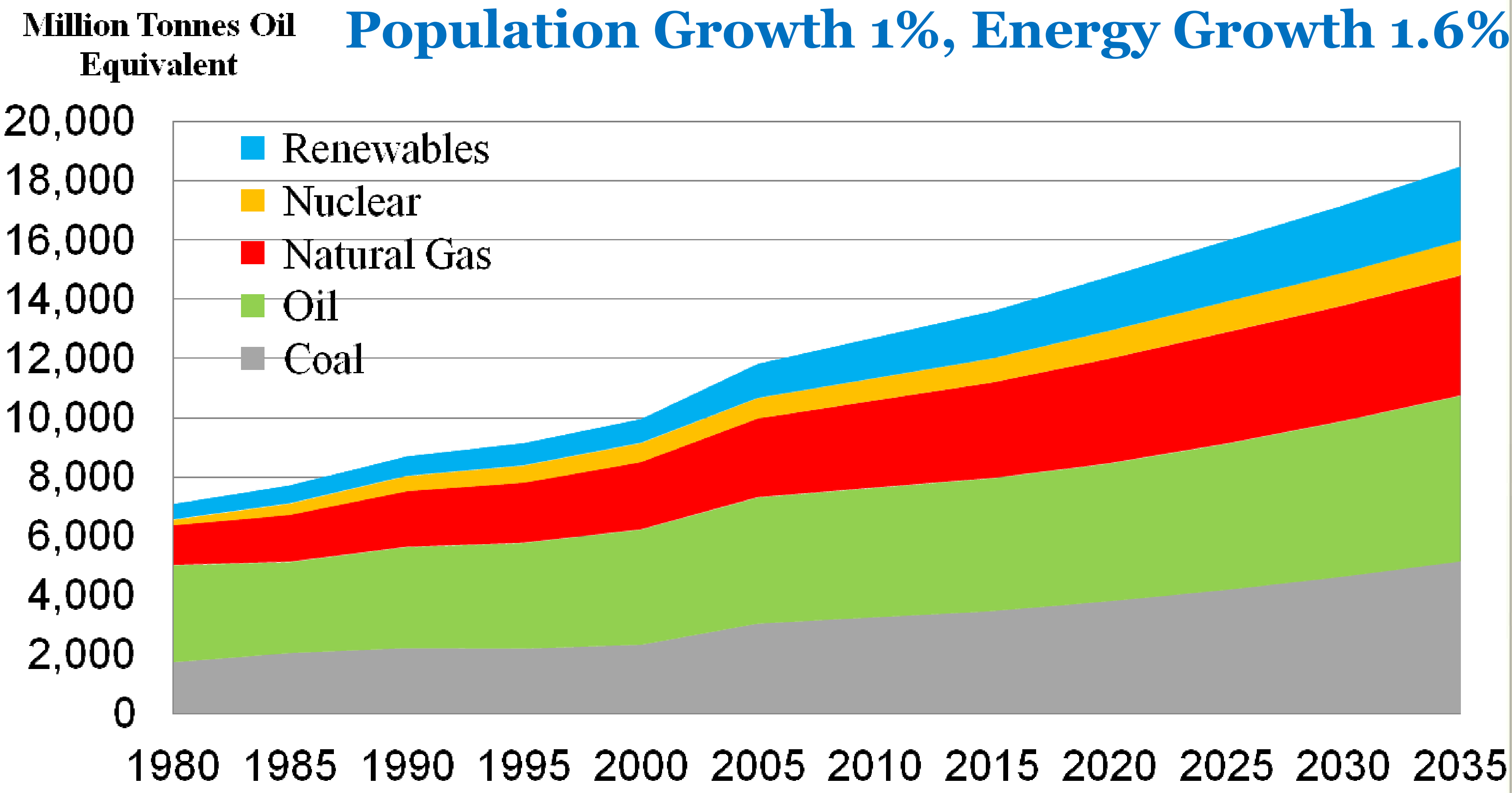
Population Growth 1%, Energy Growth 1.6%



Source: IEA

Zhang's
Four Imperatives of Energy

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Energy is a mass commodity and governed by **Four Imperatives**:

- **Power Density**
- **Energy Density**
- **Cost**
- **Scale**

Definitions: Power Density

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- **Power = Energy / time,**

  units: W (J/s), kW, MW, or horse power

- **Power Density** – the amount of power generated per unit of area of land occupied by the whole process of using a given primary energy source, from extraction to final waste disposal

Definitions: Energy Density

- **Do we have a definition of Energy? *No*!**

- **Energy Density – the amount of energy per unit of mass or volume of an *energy carrier***

  units: MJ/kg or MJ/m^3

Definitions: Cost

- **Both Capital Cost (or Capex) and Operating Cost (or Opex)**

  units: ¥, $, $/kW, etc

- **Nobody wants to pay more for the same goods and services**

Definitions: Scale

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- **Large or Small,**

  units: kW, MJ, GW, or TW, etc, or
  kg, tonnes, kt, Mt, etc, or
  m^3, Bcm, Tcf, barrel, ……

- **Consumers behaviour:** "I want what I want, as much as I want, when I want and want it cheaply!"

Climate Change

There is also a Climate Change issue

- **The 5th Imperative?**
- **I don't think so!**
  - Link of climate change to CO_2 yet to be proven
  - Capturing & storing CO_2 → >10% efficiency loss
  - Limiting China's economic development & growth
  - **Policy should focus on adaptation**
    - Infrastructure
    - Environmental protection
    - Education, health and age care

How much Energy Do we Need?

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Broadly, we need three forms of energy:

- Food
  - This has been largely ignored in most energy policy making
- Electricity
  - Converted from a primary energy source
- Transport Fuels
  - Liquid fuels, mostly from petroleum

What the World Eats

Japan: The Ukita family of Kodaira City

Food expenditure for one week: 37,699 Yen or $317.25
Favorite foods: sashimi, fruit, cake, potato chips

What the World Eats

Chad: The Aboubakar family of Breidjing Camp

Food expenditure for one week: 685 CFA Francs or $1.23
Favorite foods: soup with fresh sheep meat

Power Density

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Power density of common fuels	
Energy Sources	**Power Density**
Nuclear	**~57 W m^{-2}**
Coal	21 - 49 W m^{-2}
Crude Oil	~27 W m^{-2}
Natural Gas	**~53 W m^{-2}**
Solar PV	~6.7 W m^{-2}
Wind Turbines	~1.2 W m^{-2}
Hydroelectricity	**~0.02W m^{-2}**
Geothermal	**~0.01W m^{-2}**
Biomass-Fired Power Plant	**~0.4 W m^{-2}**
Corn Ethanol	**~0.05 W m^{-2}**
Algae (ex energy for processing)	**~1 W m^{-2}**

Energy Density

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Energy density of common materials		
Materials	**MJ kg^{-1}**	**MJ m^{-3}**
Natural uranium (99.3% U-238, 0.7% U-235) in fast breeder reactors	86,000,000	
Coal	32	42,000
Crude Oil	42	37,000
Natural Gas	54	38
Petrol	47	36,000
Diesel	45	37,000
Dry wood or sawmill scrap	12.5	10,000
Ethanol	28	22,000
Biodiesel	38	34,000
Carbohydrates	17	12,750
Proteins	17	11,500
Sugar	10	8,500
Fat	37	33,000

Power Cost

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Cost of kW sent out (without subsidies)	
Energy Sources	**Cost (A¢/kWh)**
Nuclear	**6 ~ 8**
Coal	2 ~ 4
Crude Oil	~
Natural Gas	**5 ~ 7**
Solar PV	> ~ 40
Wind Turbines	5 ~ 10
Hydroelectricity	**4 ~ 15**
Geothermal	**> ~ 18**
Biomass-Fired Power Plant	**> ~ 25**

Scale

Scale - Efficiency – Cost – Environmental Impact	
Energy Sources	
Nuclear	**50 MW - > 1 GW**
Coal	250 MW – 1 GW
Natural Gas	**50 to > 500 MW**
Solar PV	~ kW
Wind Turbines	0.1 – 10 MW
Hydroelectricity	**10 – 1000 MW**
Geothermal	**100 - 500 MW**
Biomass-Fired Power Plant	**10 – 100 MW**

The Australian Way

Land Area	7.6 Million km^2
Population	22 Million
Solar irradiance	2200 $kWh/m^2/year$
Power consumption	230 kWh/day/person
CO_2 from electricity	1.0 kg/kWh
CO_{2e}	21 tCO_{2e}/person/year

How do we consume Energy?

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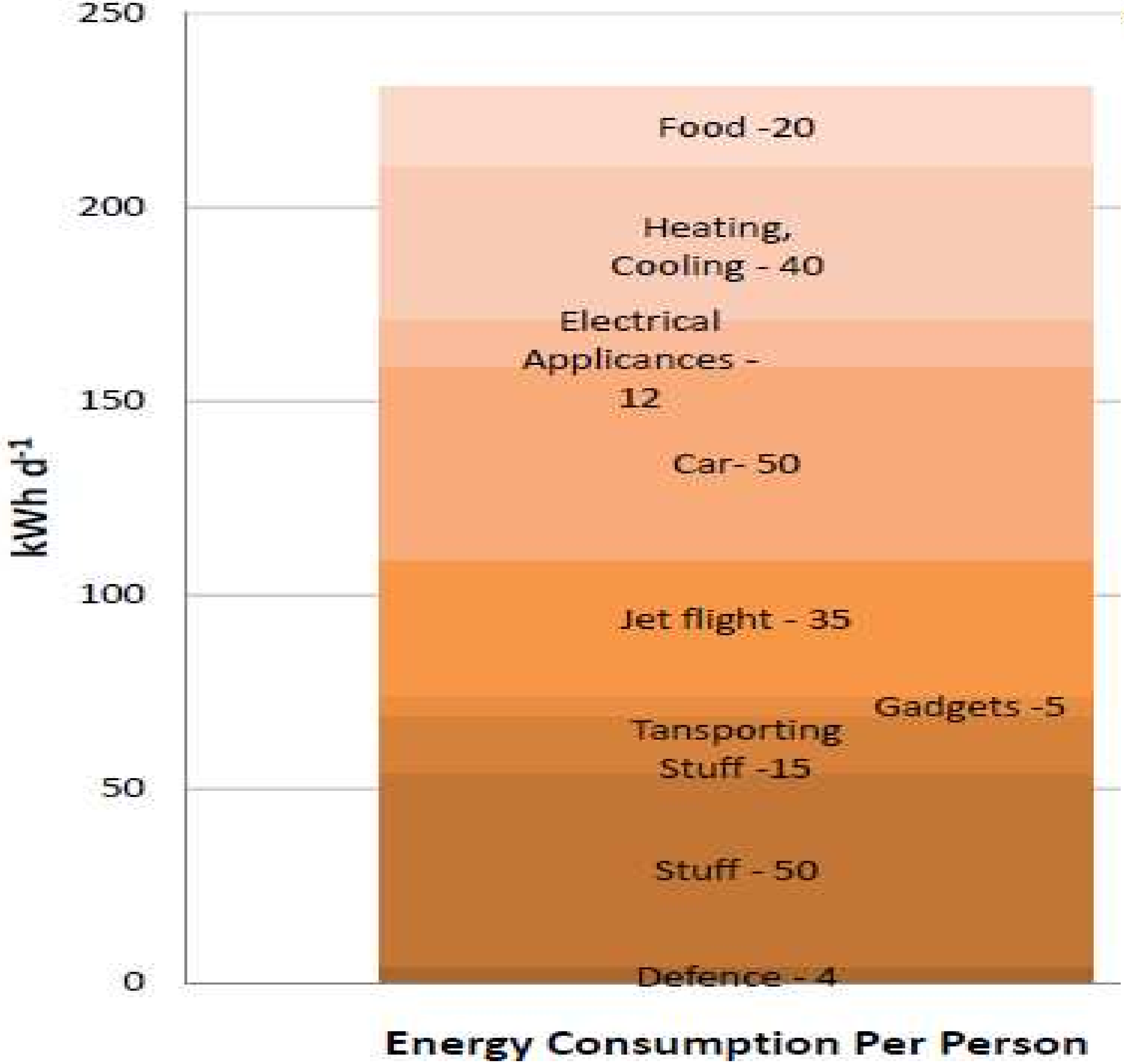

How do I consume Energy?

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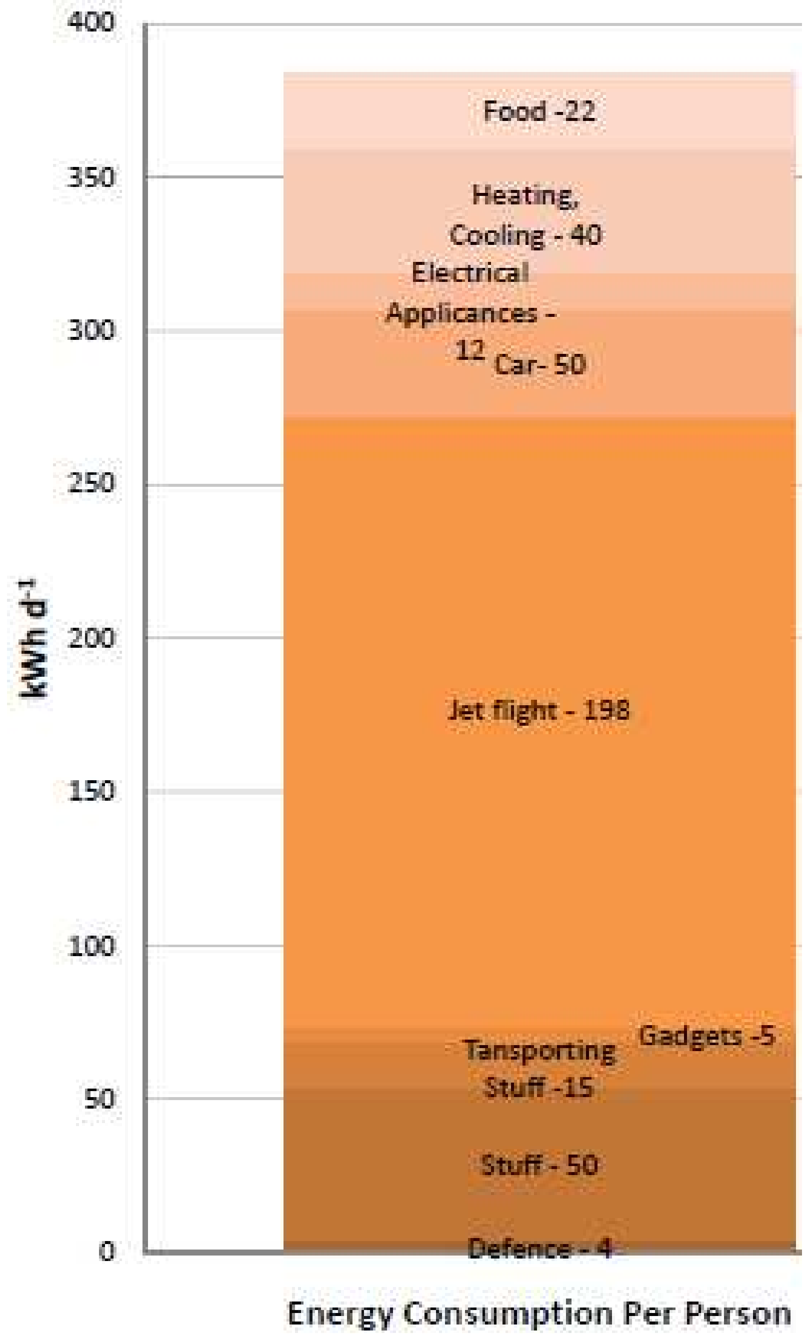

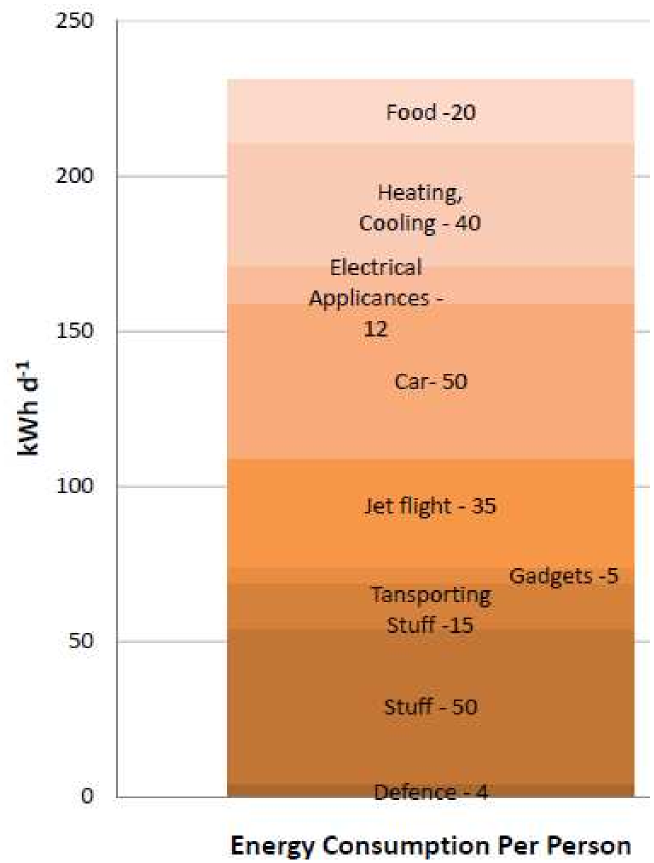

How much renewable is available?

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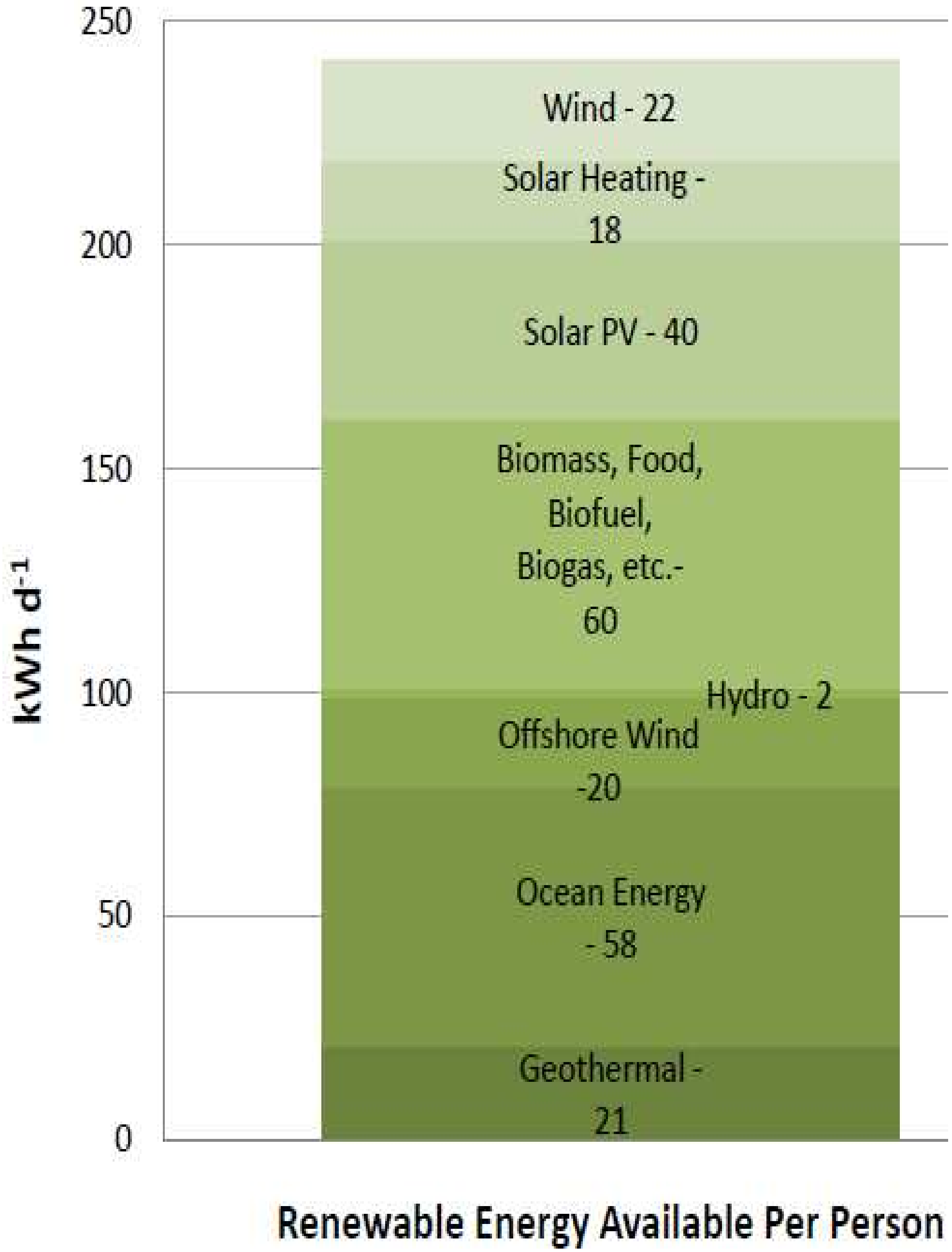

Consumption vs Availability

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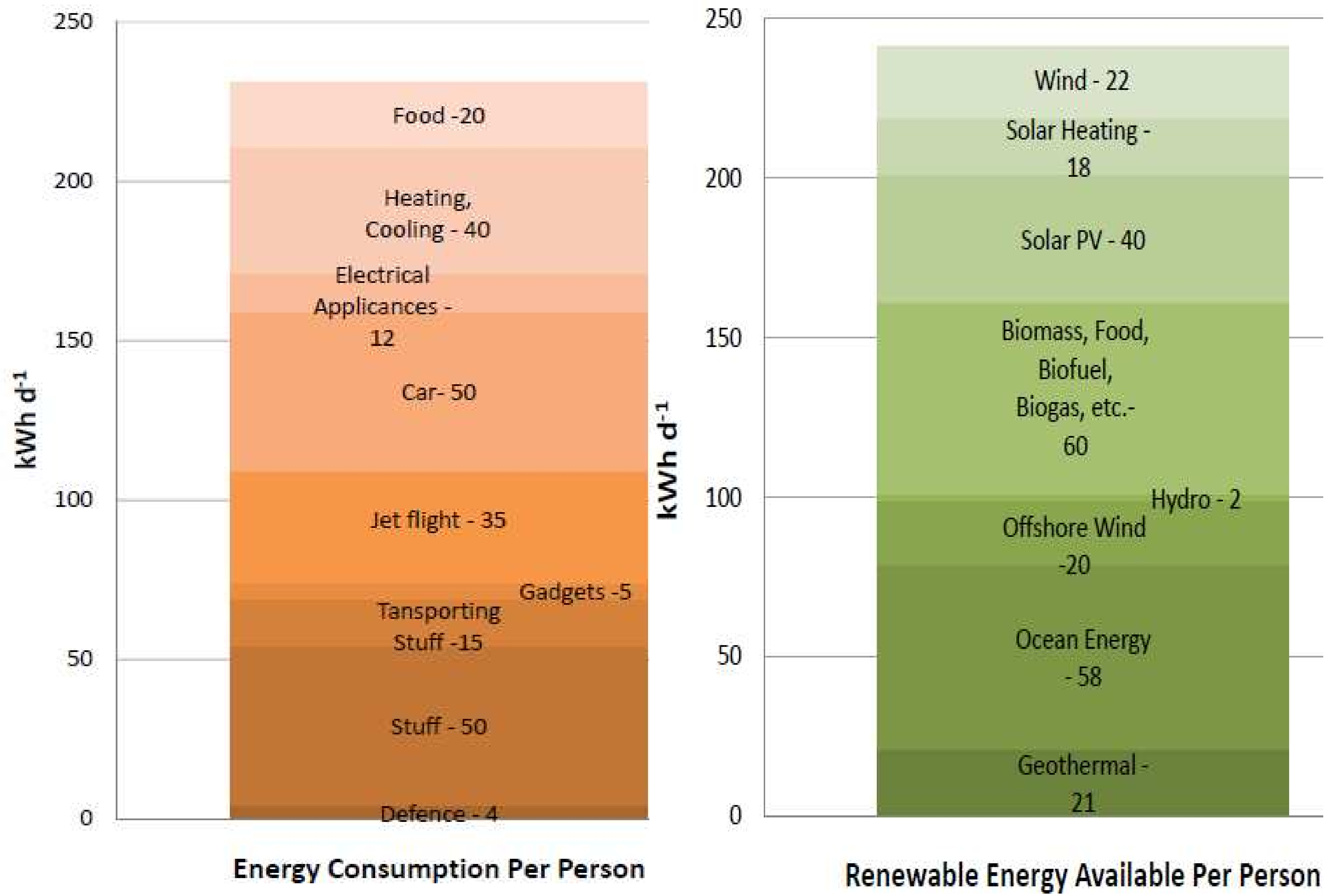

Principles of Anaerobic Digestion

Biogas and Anaerobic Digestion

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Anaerobic digestion (AD) –is biological processes to break down biodegradable material by microorganisms in the absence of oxygen. It has been used one of the most efficient methods to manage industrial or domestic waste and to extract energy in form of biogas.

Biogas – the gas produced from anaerobic digestion of organic wastes such as livestock manure, sewage, municipal waste, green water and plant material. The composition biogas usually is 60-80 percent **methane**, 20-40 percent **carbon dioxide**, and other trace gases such as **hydrogen sulfide**, **ammonia** and **hydrogen**.

Biogas

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The biométhanisation or **methane digestion** consists of **an anaerobic digestion** (in absence of air) of **residues** and various **organic matters** (bovines or porcine dung's, human faeces, etc). This fermentation leads to the formation of a gas rich in **methane** called **biogas**. This **source of energy** is directly usable for the apparatus supply such as gas refrigerators, lamps, burners or for the production of electricity by the means of a power-generating unit (diagram below).

This **bioconversion** is held in waterproof tanks called **digesters**.

Biogas

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- Methanogenic bacteria strains:
  - psychrophilic,
  - mesophilic and
  - Thermophilic
- Both mesophilic and thermophilic strains are used for biogas generation.
- Thermophilic digesters - highly sensitive to changes in feed materials and temperature
- The optimum range
  - mesophilic strains: 30 to 35 ^{o}C,
  - thermophilic strains: 50 to 60 ^{o}C.

An integration of AD of Resource Recovery and Renewable Energy Production eg-1

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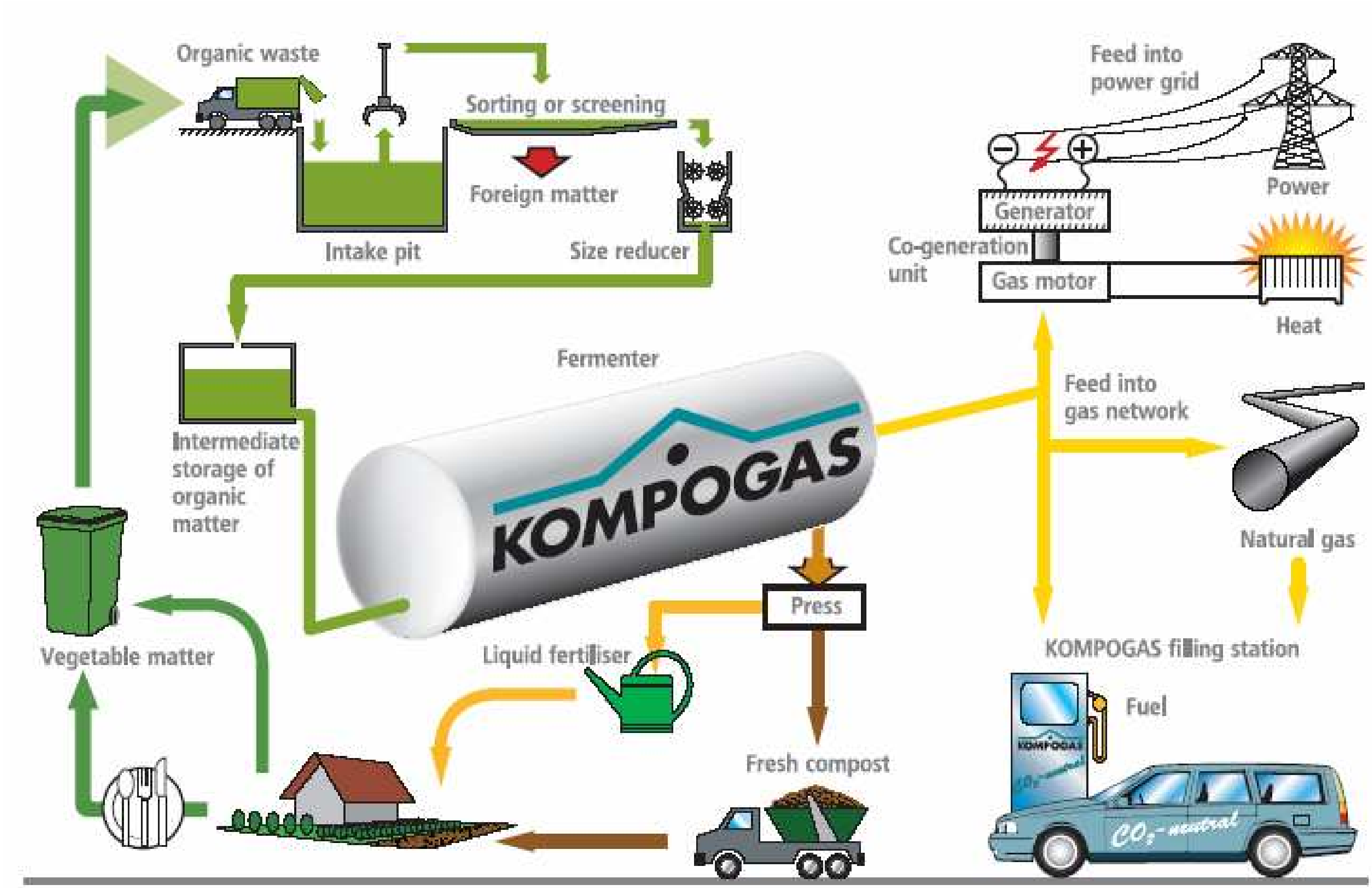

Evergreen Energy Corporation Pty Ltd has exclusive rights for the Australian license for the KOMPOGAS Process; the process was developed by W. Schmid of Glattbrugg, Switzerland in the 1980's.

An integration of AD of Resource Recovery and Renewable Energy Production eg-2

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http://test.1010global.org/sites/default/files/uploads/ckfinder/images/english%20figure%20biogas.png

A integration of AD of Resource Recovery and Renewable Energy Production eg-3

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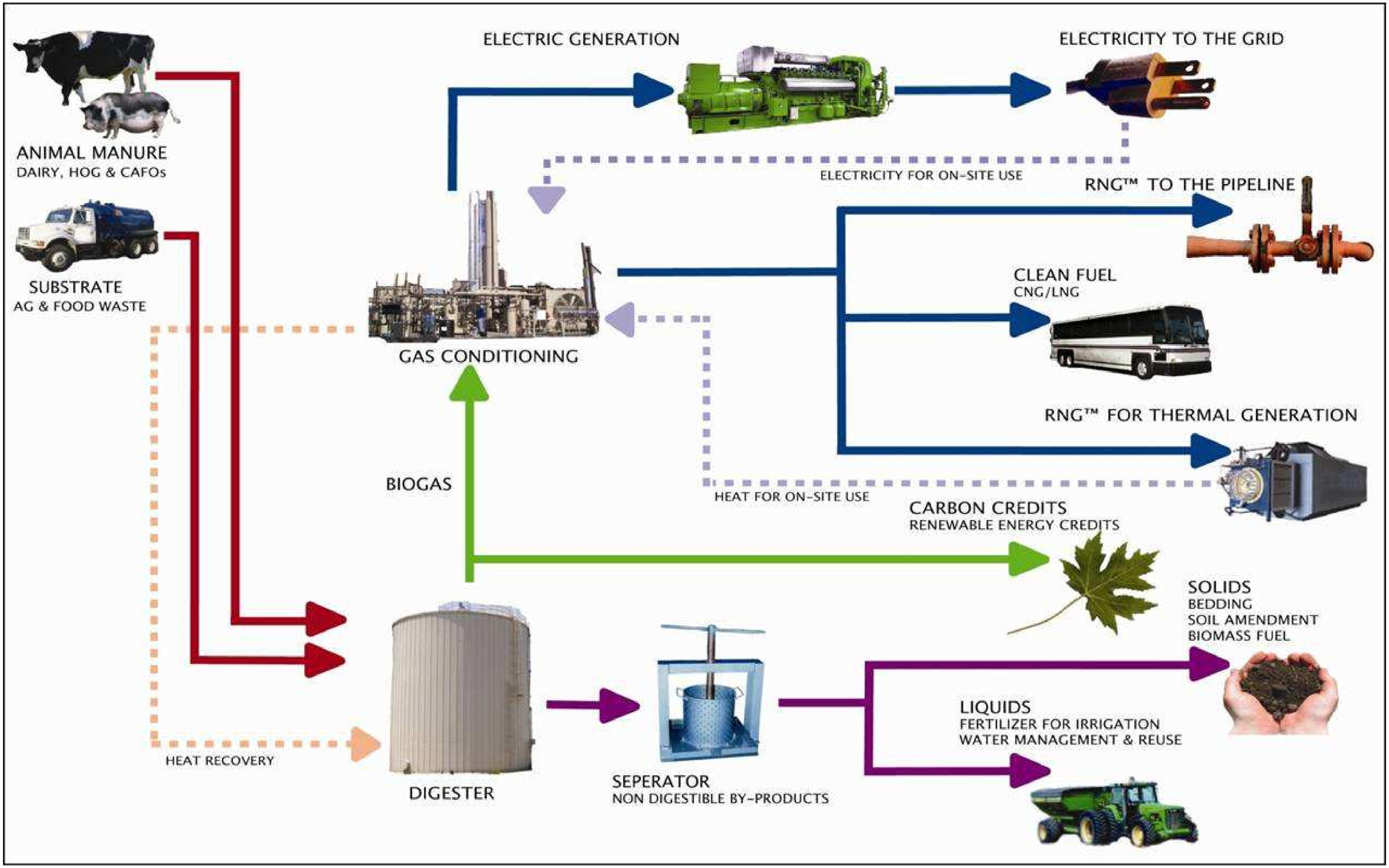

http://www.starenergyservices.net/Biogas_Process.jpg

History of AD for Biogase

- Biogas is one of the oldest forms of renewable Energy.
- 1859: First digestion plant was built in in Bombay.
- 1895: biogas used to power street lamps in Exeter, England.
- AD for Biogas has been attracted more attention recently.

Types of AD

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Based on feedstock

Dry (> 25% dry matter, municipal solid waste(MSW))

Wet (waste water, farm animal dropping, ect.)

Mono digestion (signal feedstock)

Co-digestion (several feedstocks)

Based on Temperature

Psychrophilic (5 -15°C)

Mesophilic (38 – 42 °C)

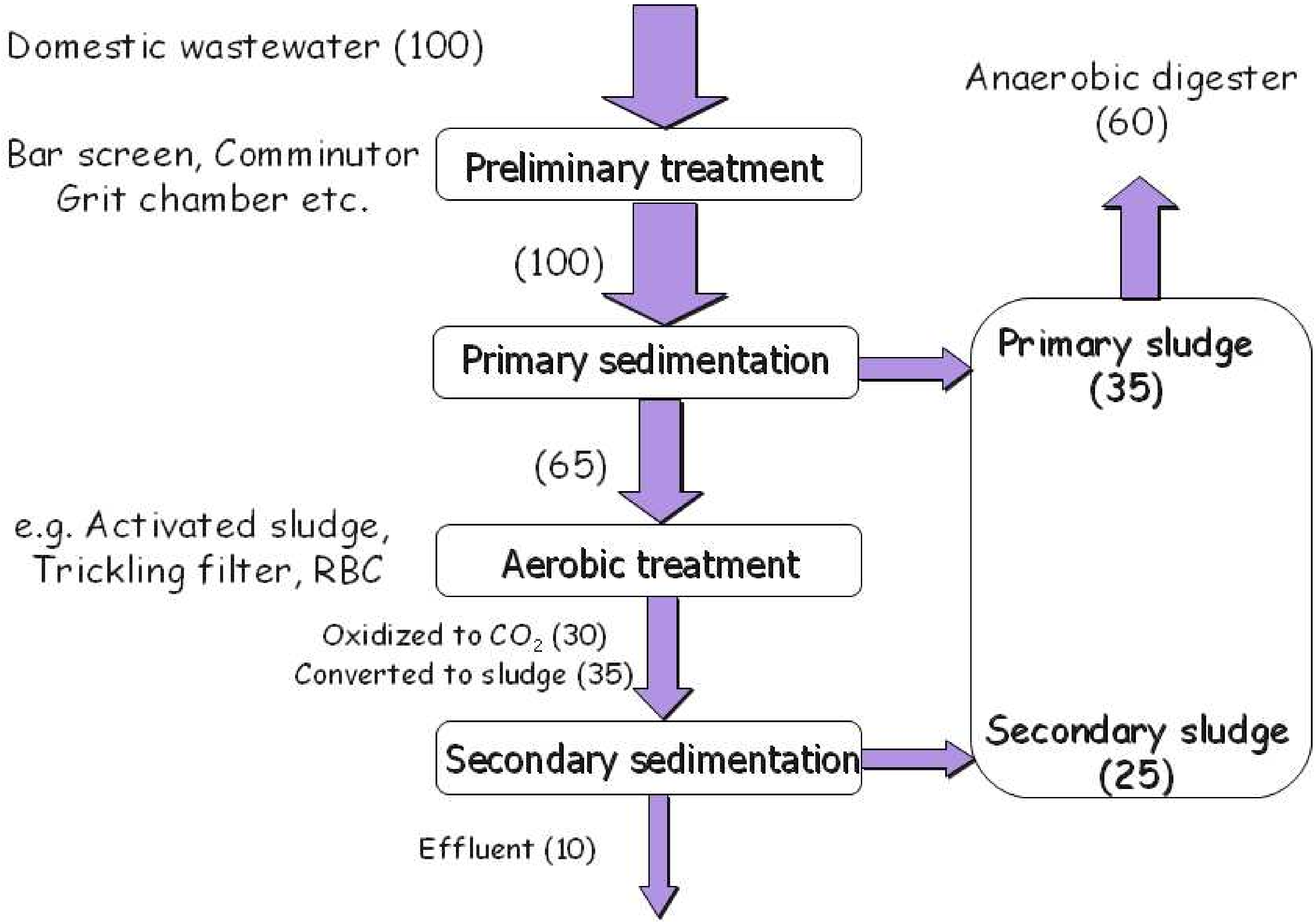
Thermophilic (55 – 65 °C)

Based on feeding system

Batch system (MSW)

Continuous system (requires mixing, pumping)

AD has been wildly used as an important part for wastewater treatment



AD of solid

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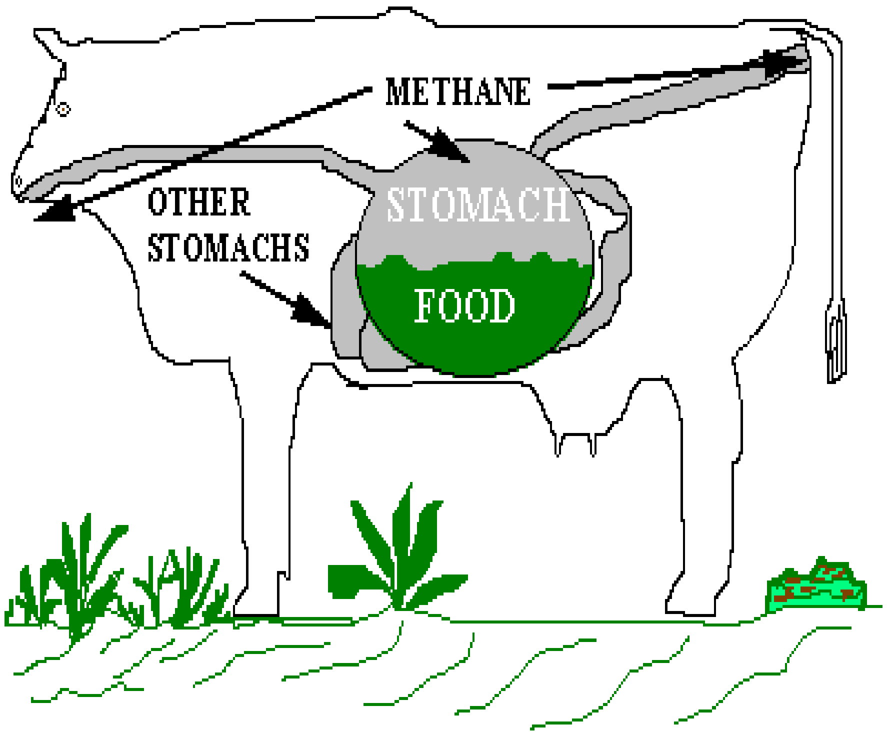
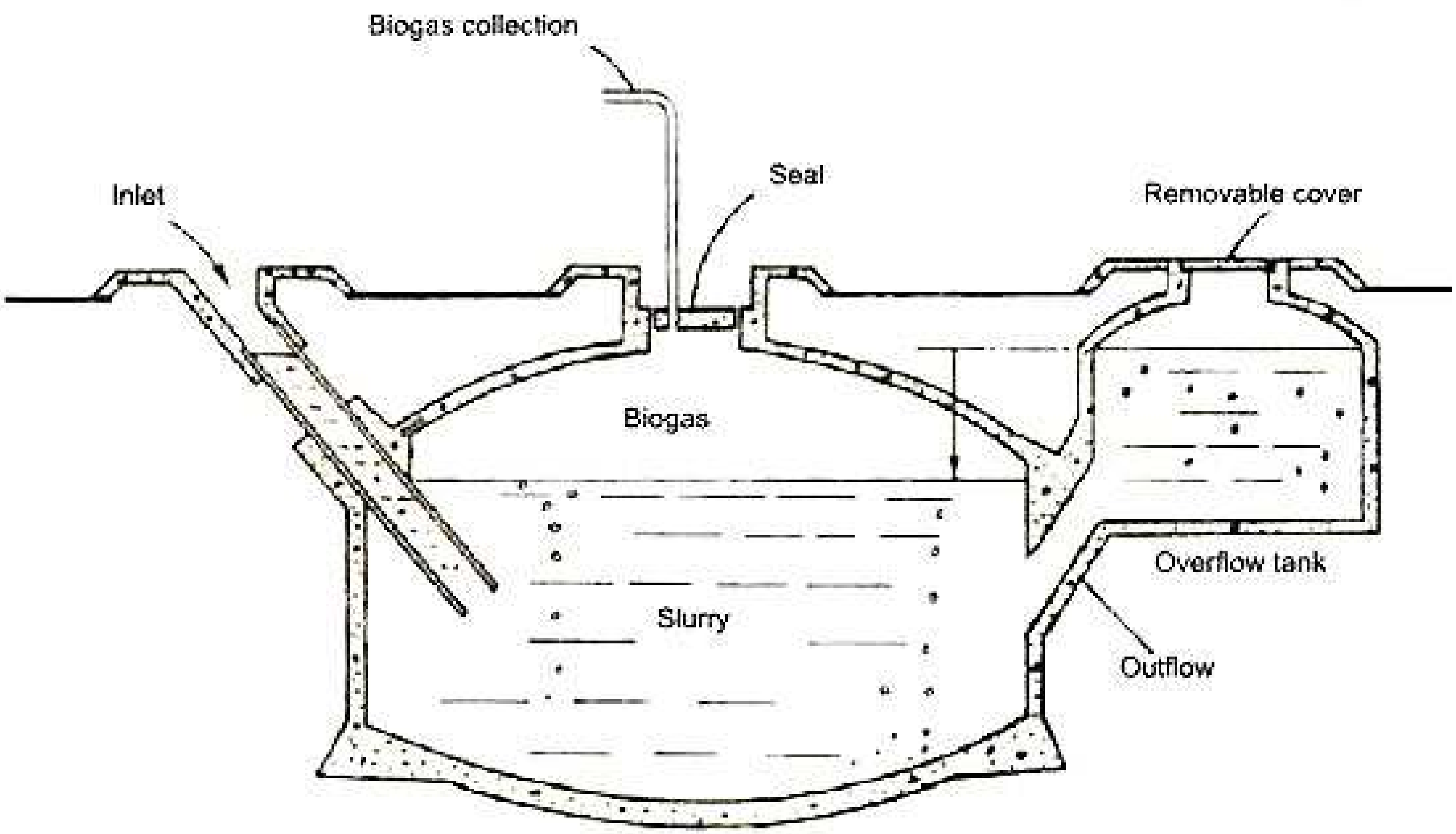
- AD are used of high solids such as animal manure, biological sludge, MSW, etc.
- AD for solid is usually a continuous flow stirred tank reactor (CFSTR) for which HRT (Hydraulic retention time)~ SRT (Solid Retention time) = 1.
- The Wet AD for solids is more similar to water treatment AD.

The examples of biogas and anaerobic digester :



Biogas

Anaerobic Digestion System



Biogas

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A good, clean energy source in rural areas

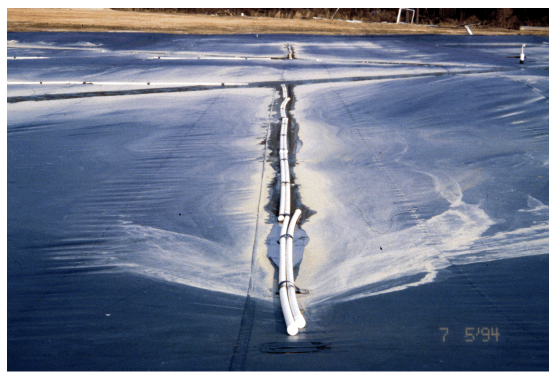
Biogas

In wastewater works

Home made

DiCOM for *MSW* (thermophilic)

Plug flow



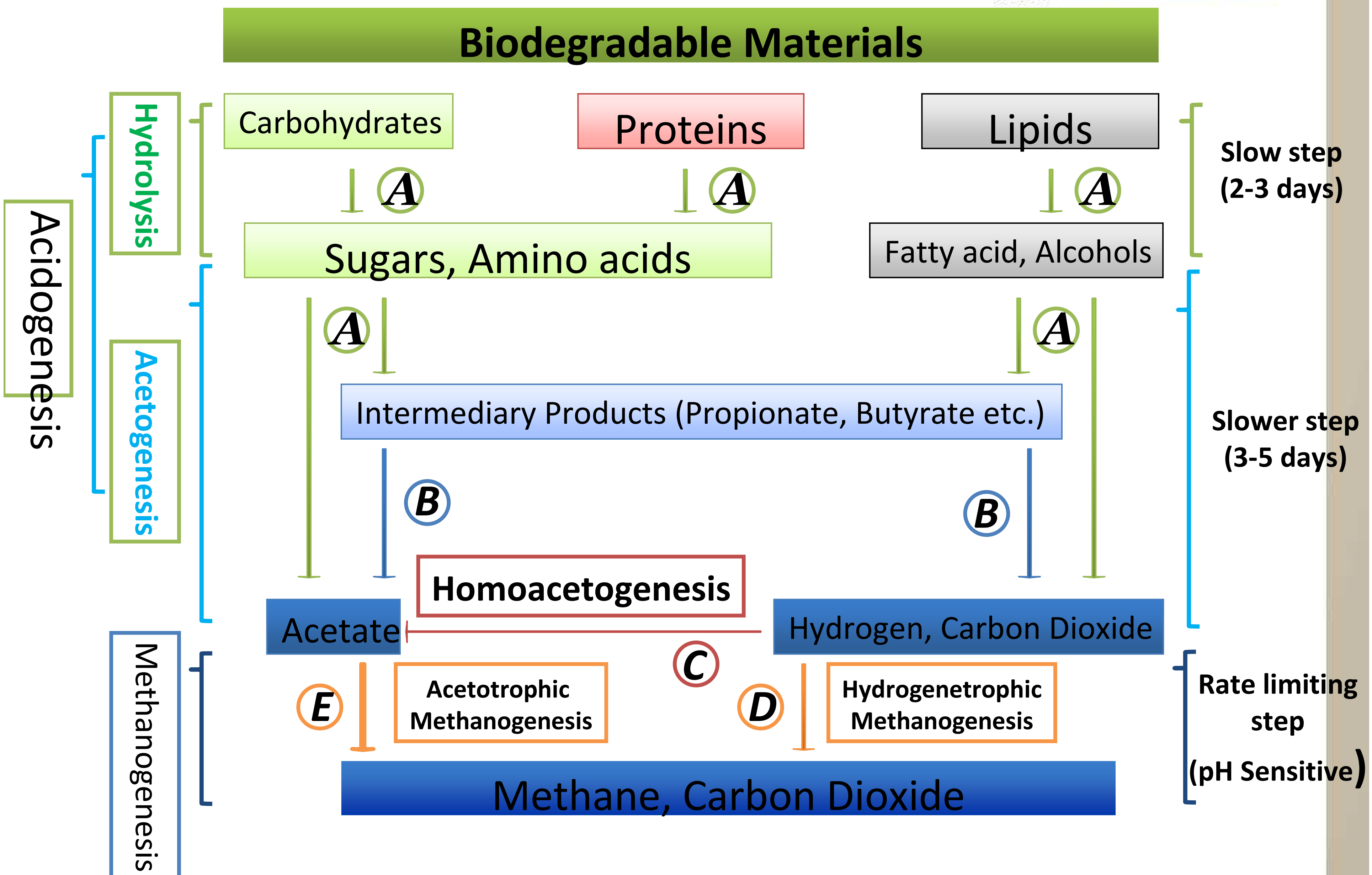
Covered Lagoon

Fixed film AD

Complete mixed digester: (Cooperstown, NY: mesophilic or Thermopilic, manure 3 to 10 % Total solid)

Bacteria that do the work

Principles of Anaerobic Digestion



The microbial groups for AD

Fermentative bacteria (*A*)

1.Responsible for the first stage of anaerobic digestion - hydrolysis and acidogenesis.

2.They are either facultative or strict anaerobes.

3.Most of them belong to the family of Streptococcaceae and Enterobacteriaceae. The genera of *Bacteroides*, *Clostridium, Butyrivibrio*, *Eubacterium*, *Bifidobacterium* and *Lactobacillus* are most common.

The microbial groups for AD

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Hydrogen Producing Acetogenic Bacteria (*B*)

1.Convert organic acids (C>2), alcohols and some aromatic acid to acetic acid (C=2) and CO_2.

$$CH_3CH_2COO^- + 2H_2O \rightarrow CH_3COO^- + CO_2 + 3H_2$$

2.Their activity is inhibited by Hydrogen.

3.The hydrogen concentration should below 200ppm

The microbial groups for AD

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Homoacetogenes: Hydrogen consuming acetogenic bacteria (C)

1.The bacteria utilize H_2 and CO_2 to give Acetic acid.

$$2CO_2 + 4H_2 \rightarrow CH_3COOH + 2H_2O$$

2.The bacteria have a high thermodynamic efficiency, to keep Hydrogen and Carbon dioxide at lower concentration.

3.Clostridium aceticum and *Acetobacterium woodii* are the two homoacetogenic bacteria isolated from the sewage sludge.

The microbial groups for AD

Methanogens (*D* and *E*)

1.Methanogens are *Archeae,* use acetate to generate Methane.

Hydrogenetrophic Methanogenesis (*D*)

$CO_2 + 4H_2 \rightarrow 2H_2O + CH_4$

Acetotrophic Methanogenesis (*E*)

$CH_3COOH \rightarrow CO_2 + CH_4$

2.Methanogens are obligate anaerobes and considered as a rate-limiting species in anaerobic treatment of AD

3.Two classes of methanogens that metabolize acetate to methane are: *Methanosaeta* (old name *Methanothrix*): Rod shape, low Ks, high affinity*Methanosarcina* (also known as *M. mazei*): Spherical shape, high Ks.

Economy: Energy out put of AD

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All AD performance can be measured in the term of COD removed. **COD (chemical oxygen demand)**: a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant.
COD expresses generally as :

$$C_nH_aO_bN_c + \left(n + \frac{a}{4} - \frac{b}{2} - \frac{3}{4}c\right) O_2 \rightarrow nCO_2 + \left(\frac{a}{2} - \frac{3}{2}c\right) H_2O + cNH_3$$

*Correction should add:

$$NH_3 + 2O_2 \rightarrow NO_3^- + H_3O^+$$

Energy out put of AD in form of CH_4

Assuming all removed COD converted to CH_4.
Given equation of when CH_4 consumed:

$$\mathbf{CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O}$$

1 mole CH_4 = 22.4 litre CH_4 needs 2 mole O_2 = 64 g O_2 , which equals 64 g of COD.

Therefore 1 kg of removed COD should generate 0.35 m^3 CH_4 = 13.9MJ energy

<u>1kg COD = 13.9MJ</u>

Energy balance of AD

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- No aeration and Less energy input:

  0.5-0.75 kWh for 1kg COD removal.

- Output energy in the form of methane:

  1.5 kWh produced for 1kg COD (40% conversion of methane to electricity).

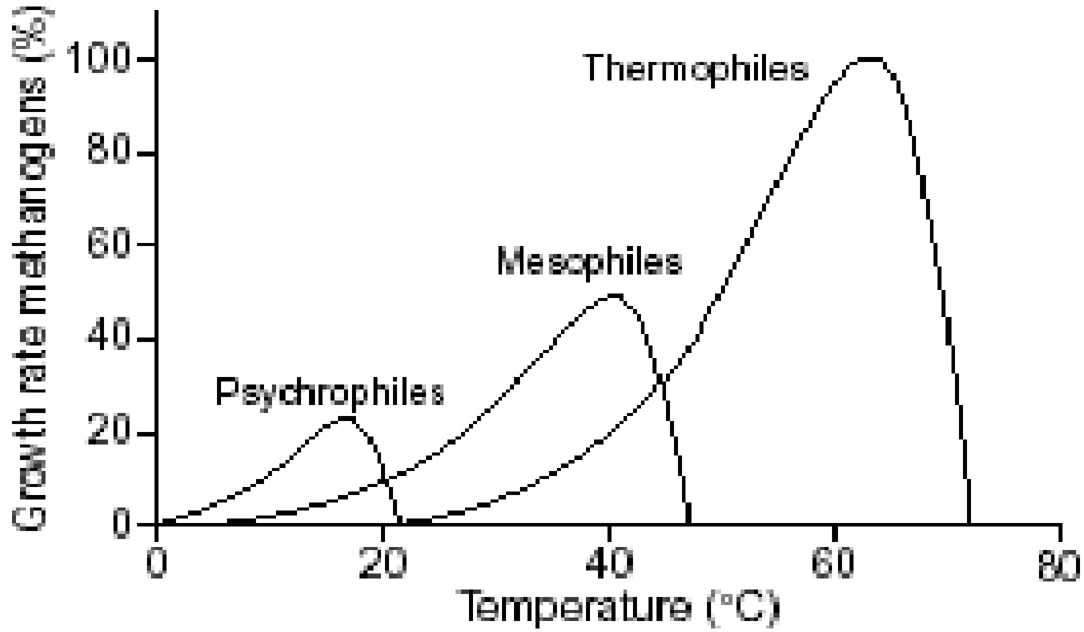
Parameters influence the AD

- Feedstock: source? Energy (Carbon) contents?
- Microbiology: Inoculation (type and size)
- Water requirement: wet AD need more water to make slurry.
- Temperature
- pH value
- Reaction time (HRT/SRT)

New directions of technology development and their challenges

Current of AD for MSW

- AD was widely used throughout the world.
- The majority of plants are large scale with complex design. (2,500 tonnes of waste per day).
- Much of the technology is based in Europe.
- Multi-stage processes are often used. particular digestion stage can be optimised increase the reaction rate and amount of gas produced.
- Use thermophilic system to increase the gas production rate.
- Most of the larger scale, industrial systems process MSW alone, however the simpler, smaller scale systems are more successful when co-digestion with animal manure is used. The animal manure improves the C/N ratio of the feedstock and aids the anaerobic digestion process, allowing a more simple process to be used.



Rate of a reaction doubles for every 10 ^{o}C rise in temperature up to an optimum and then declines rapidly

Recycling of Organic waste

- Composting: Major player in Perth.
- AD: some examples
- Gasification ??
- Pyrolysis??
- Combustion??
- Plasma??

Composting V.S. AD

1. Aerobic (with air) v.s. is anaerobic (without air).
2. Large v.s. small (digester, 'tank')
3. Compost v.s. compost+gas+processing water
4. Energy negative v.s. energy positive (renewable energy)

Combined Biogas, Power and Heat

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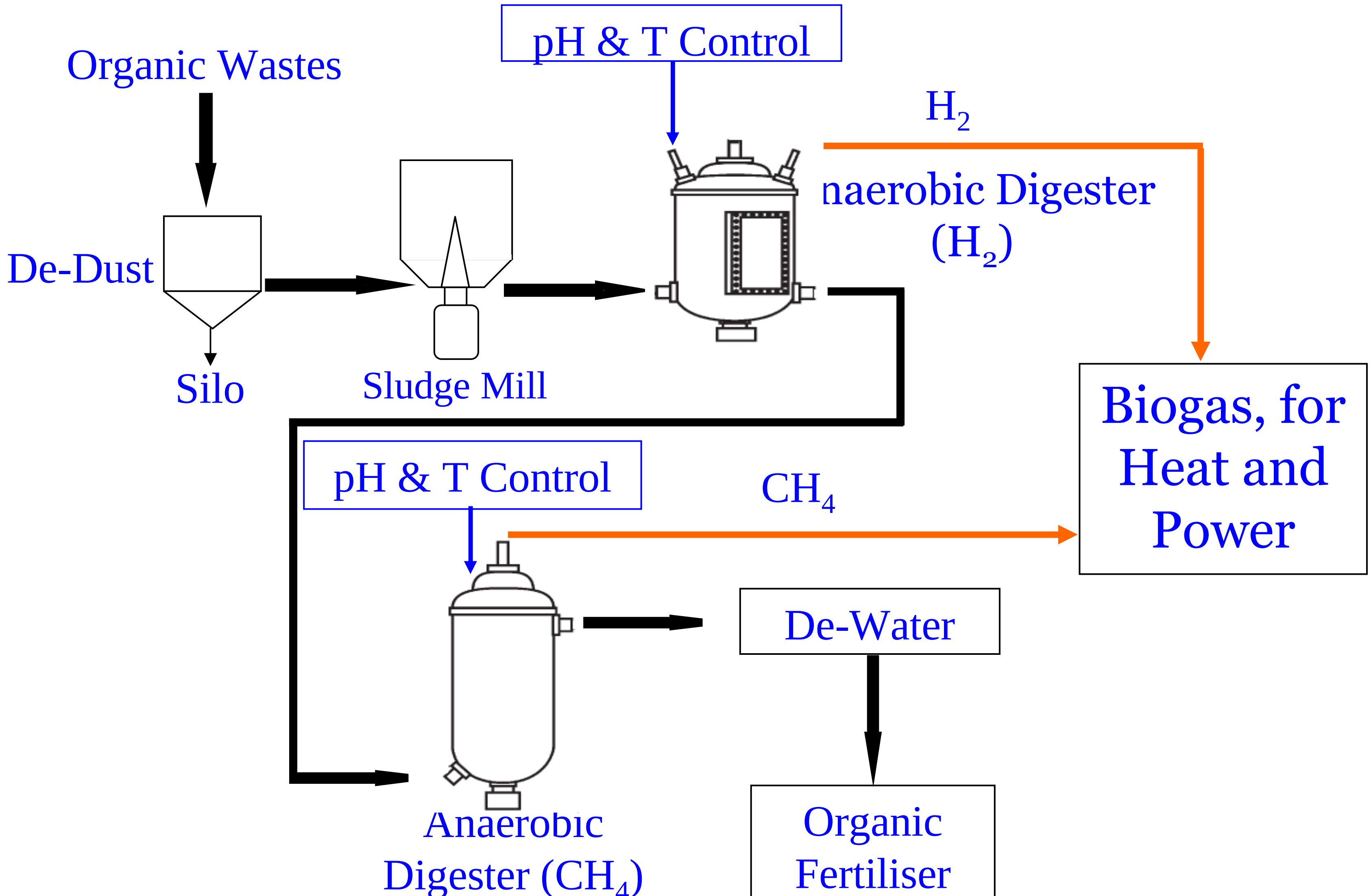

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Pilot Plant in Japan and China

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two-stage processing: solubilisation-hydrogen fermentation and methane fermentation

reduction of overall processing time from 25days to 15days，energy recovery increased from 40~46% to 55%

World First Biogas Plant to Recover Hydrogen and Methane Quickly from Kitchen Waste（2004）


When fossil fuels finally run out……
Thank you!