MEMANEN ENERGI SURYA SEBAGAI SUMBER ENERGI BERKELANJUTAN BAGI KEHIDUPAN:

Peran Air dalam Konversi Termo-kimia, Bio-kimia dan Elektro-kimia

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Tim Perumus : Strategi Induk Pembangunan Pertanian 2015-2045, Kementerian Pertanian 2011-2014

Pertemuan Forum Guru Besar ITB

ITB untuk Bangsa: Air sebagai Bahan Bakar. Mungkinkah ?

Bandung, 25 Mei 2022

ISI PAPARAN

I. Pendahuluan
II. Memanen Energi Surya dan Simbiosis Industrial: Peran Air dalam Konversi Bio-kimia.
III. Penelitian dan Pengembangan Konversi (Gasifikasi) Biomasa: Peran Air dalam Konversi Termo-kimia.
IV. Penelitian dan Pengembangan Lanjut Konversi Termo-kimia dan Bio-kimia Biomasa.
V. Peran Air dalam Konversi Termo-kimia dan Elektro-kimia.
VI. Rangkuman.

I. PENDAHULUAN

"Life must be regarded, at the deepest level,
as a matter as much of energy transformation
as of genetic replication"

(Wicken 1987)

The trouble with simple things is
that one must understand them very well.

(ANONYMOUS)

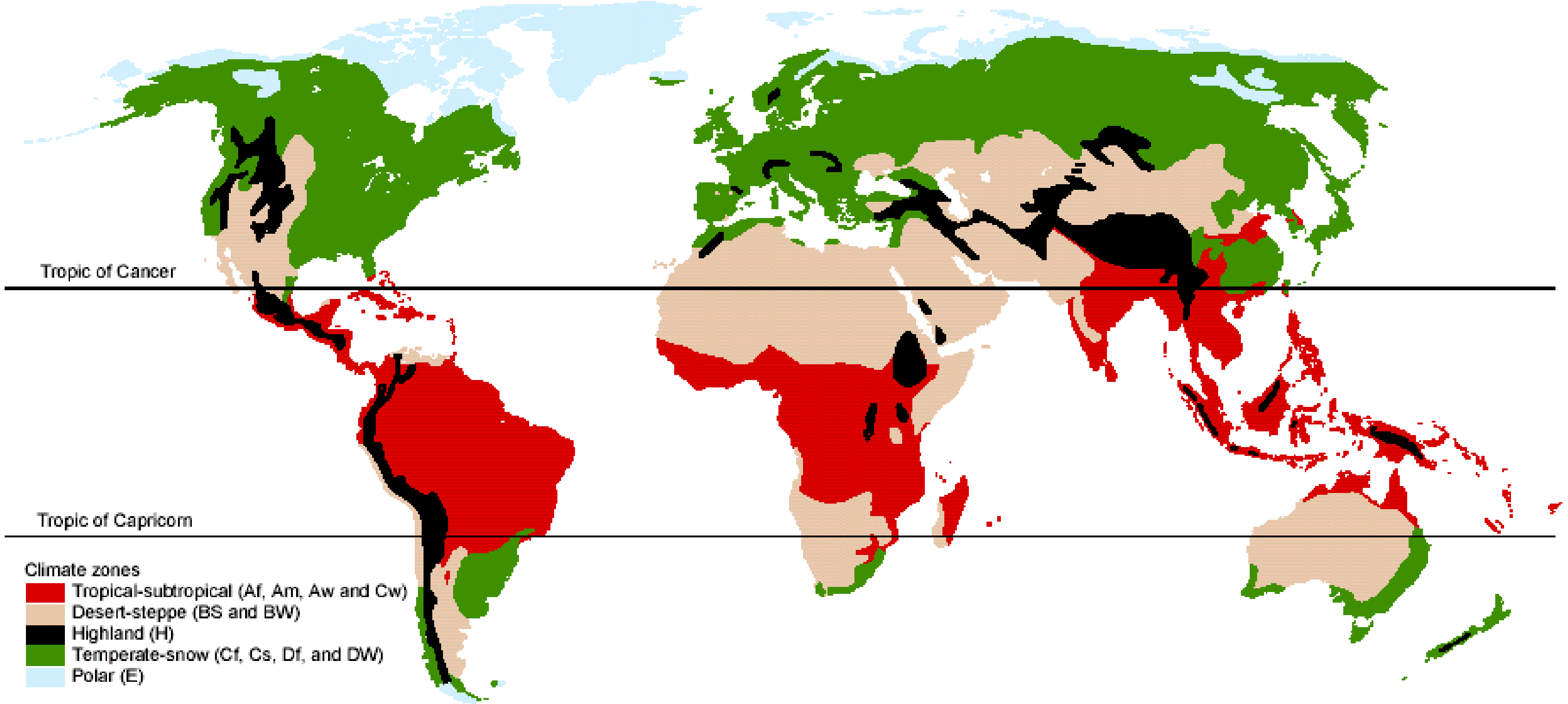
Energy Expenditure During Different Types of Activity for a 70 kg Man*

Form of activity	Energy expenditure (kcal/hr)
Sleep	65
Awake, lying still	77
Sitting at rest	100
Standing relaxed	105
Dressing or undressing	118
Typewriting rapidly	140
Walking slowly (2.6 mph)	200
Swimming	500
Running (5.3 mph)	570
Walking very fast (5.3 mph)	650
Walking up stairs	1100

*Table adapted from Guyton AC and Hall JE, *Textbook of Medical Physiology*. Philadelphia: Saunders, 2000.

Tantangan dan Kesempatan pada Pengembangan Sistem Pertanian- Bioindustri Berkelanjutan :

Wilayah Indonesia berlokasi pada Sabuk Tropis Dunia dan memiliki Keragaman Hayati terkaya kedua di Dunia



- Tropical areas are the most challenging to agriculture -

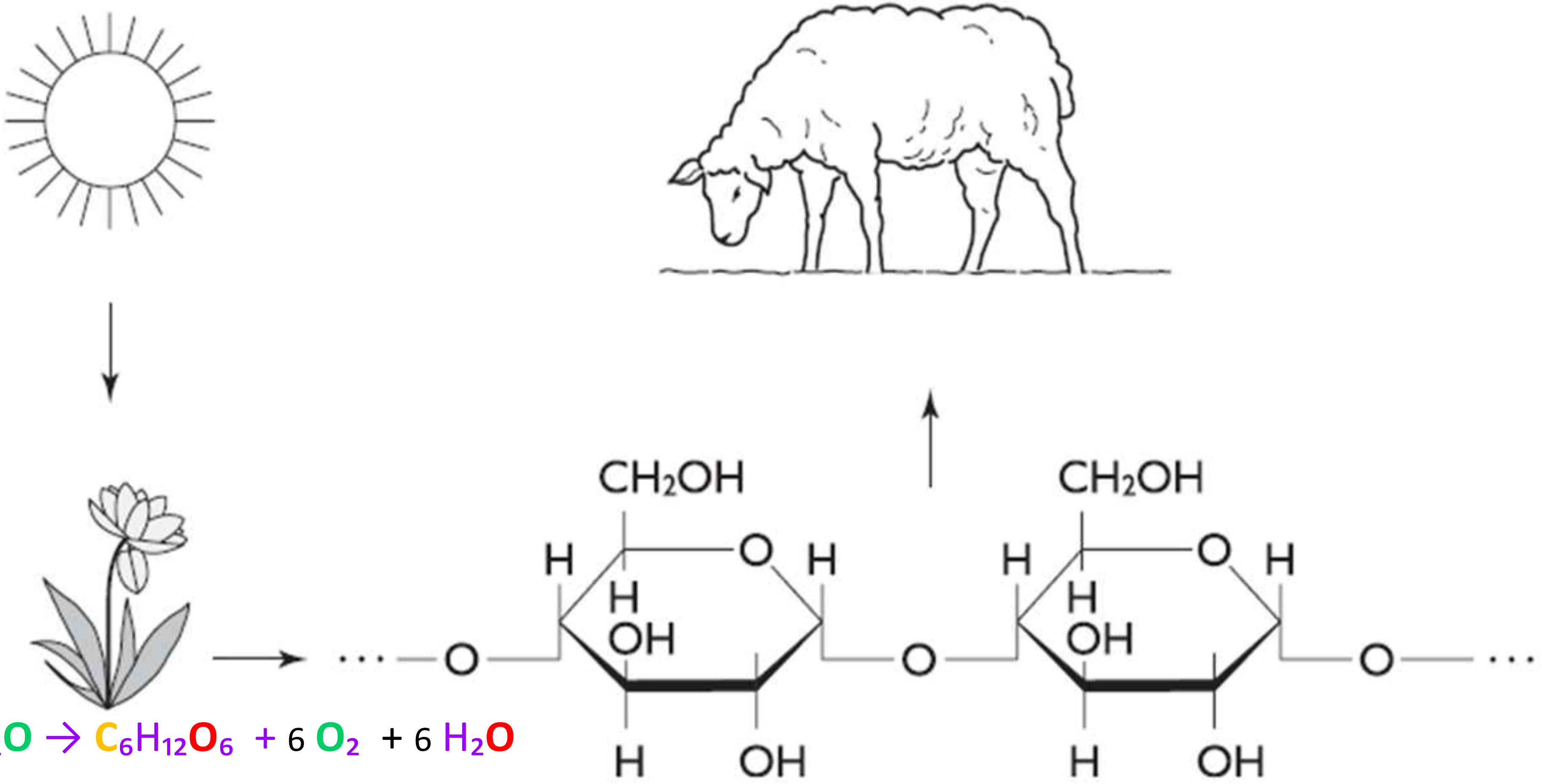
Intense biotic (pests) and abiotic (drought, soil acidity, low nutrients, etc) stresses.
All these challenges will be intensified with the global climatic changes.

II. MEMANEN ENERGI SURYA DAN SIMBIOSIS INDUSTRIAL

PERAN AIR DALAM KONVERSI BIO-KIMIA

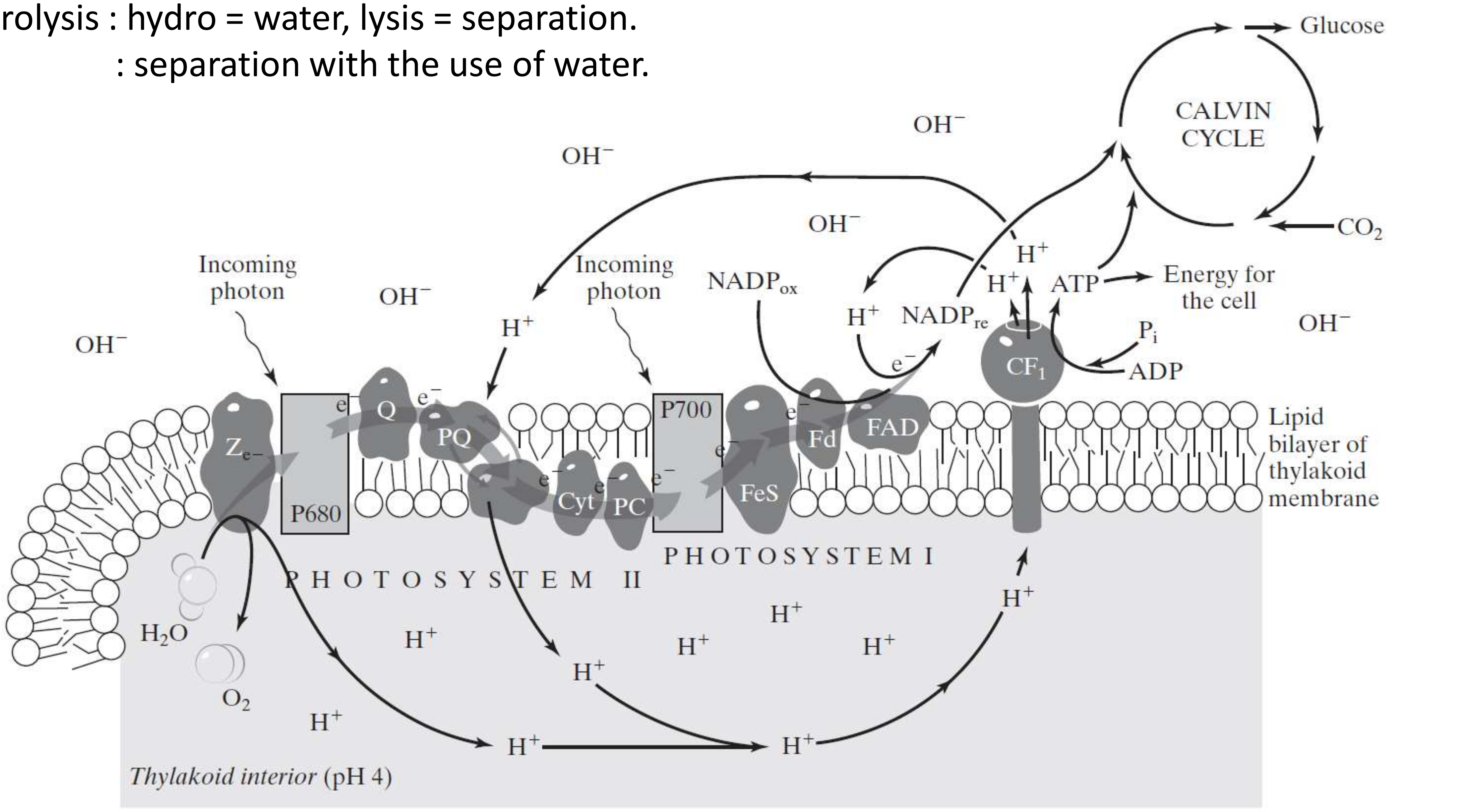
Pertanian-Perkebunan: transformasi energi elektromagnetik sinar matahari mejadi energi kimiawi pada tanaman.

$$C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O \rightarrow 6\ CO_2 + 12\ H_2O$$



$$6\ CO_2 + 12\ H_2O \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

Hydrolysis : hydro = water, lysis = separation.
: separation with the use of water.



Photosynthesis with light and dark reactions. (Source: Keeton WT and Gould JL, Biological Science, 4th ed. New York: WW Norton, 1986.)

Table 4.4. *Values of $\Delta G^{\circ\prime}$ for some important biochemical reactions*

Reaction	$\Delta G^{\circ\prime}$ (kcal mol^{-1})
HYDROLYSIS	
Acid anhydrides:	
Acetic anhydride + H_2O → 2 acetate	−21.8
$PP_i + H_2O \rightarrow 2P_i$	−8.0
$ATP + H_2O \rightarrow ADP + 2P_i$	−7.3
Esters:	
Ethylacetate + H_2O → ethanol + acetate	−4.7
Glucose-6-phosphate + H_2O → glucose + P_i	−3.3
Amides:	
Glutamine + H_2O → glutamate + NH_4^+	−3.4
Glycylglycine + H_2O → 2 glycine (a peptide bond)	−2.2
Glycosides:	
Sucrose + H_2O → glucose + fructose	−7.0
Maltose + H_2O → 2 glucose	−4.0
ESTERIFICATION	
Glucose + P_i → glucose-6-phosphate + H_2O	+3.3
REARRANGEMENT	
Glucose-1-phosphate → glucose-6-phosphate	−1.7
Fructose-6-phosphate → glucose-6-phosphate	−0.4
Glyceraldehyde-3-phosphate → dihydroxyacetone phosphate	−1.8
ELIMINATION	
Malate → fumarate + H_2O	+0.75
OXIDATION	
Glucose + $6O_2 \rightarrow 6CO_2 + 6H_2O$	−686
Palmitic acid + $23O_2 \rightarrow 16CO_2 + 16H_2O$	−2338
PHOTOSYNTHESIS	
$6CO_2 + 6H_2O$ → six-carbon sugars + $6O_2$	+686

The data are from p. 397 of Lehninger, A.L. (1975) *Biochemistry*, 2nd edn. New York: Worth.

Memanen Energi Surya Menggunakan Singkong ?

- Produktivitas karbohidrat (pati) singkong : 20 - 40 Ton/ha/tahun
  Produktivitas karbohidrat (beras) padi : 5 - 7 Ton/ha/tahun (2xpanen)
- Produktivitas lipida (Kelapa Sawit) : 4 - 6 Ton CPO/ha/tahun
- Tanaman singkong merupakan (salah satu) tanaman yang **paling efisien memanen Energi Surya**.
- Efisiensi Pemanenan Energi Surya, **singkong : sawit: beras**

  = 540 : 190 : 108 MJ/ha/th

  = 15 : 5 : 3

Nilai Kalor Pati : 4400 kkal/kg (18 MJ/Ton)
Nilai Kalor Lipida: 9200 kkal/kg (38 MJ/Ton)

Memanen Energy Surya di Gurun Pasir Sudan dengan Tanaman Singkong

Produktivitas: 15 kg/pohon, 10.000 pohon/ha

Pertanaman Campuran (*Polyculture*)

Cassava

Mega Flora Tree

A two-month old tree

One-year old trees

Flowers are an excellent nectar source

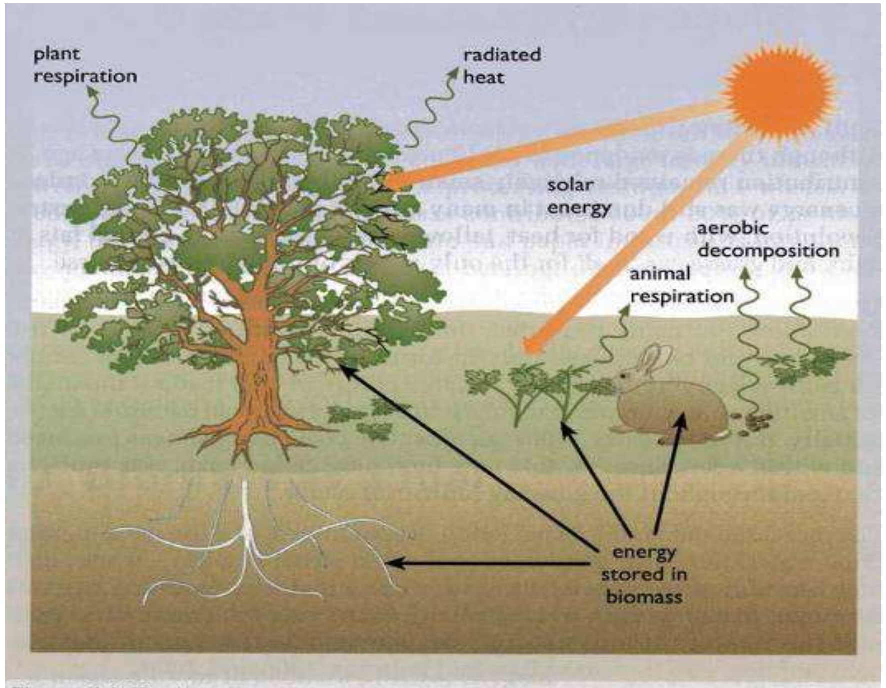


Figure 4.1 The bioenergy cycle on the local scale

Energy and Mass Flow through Ecosystems.

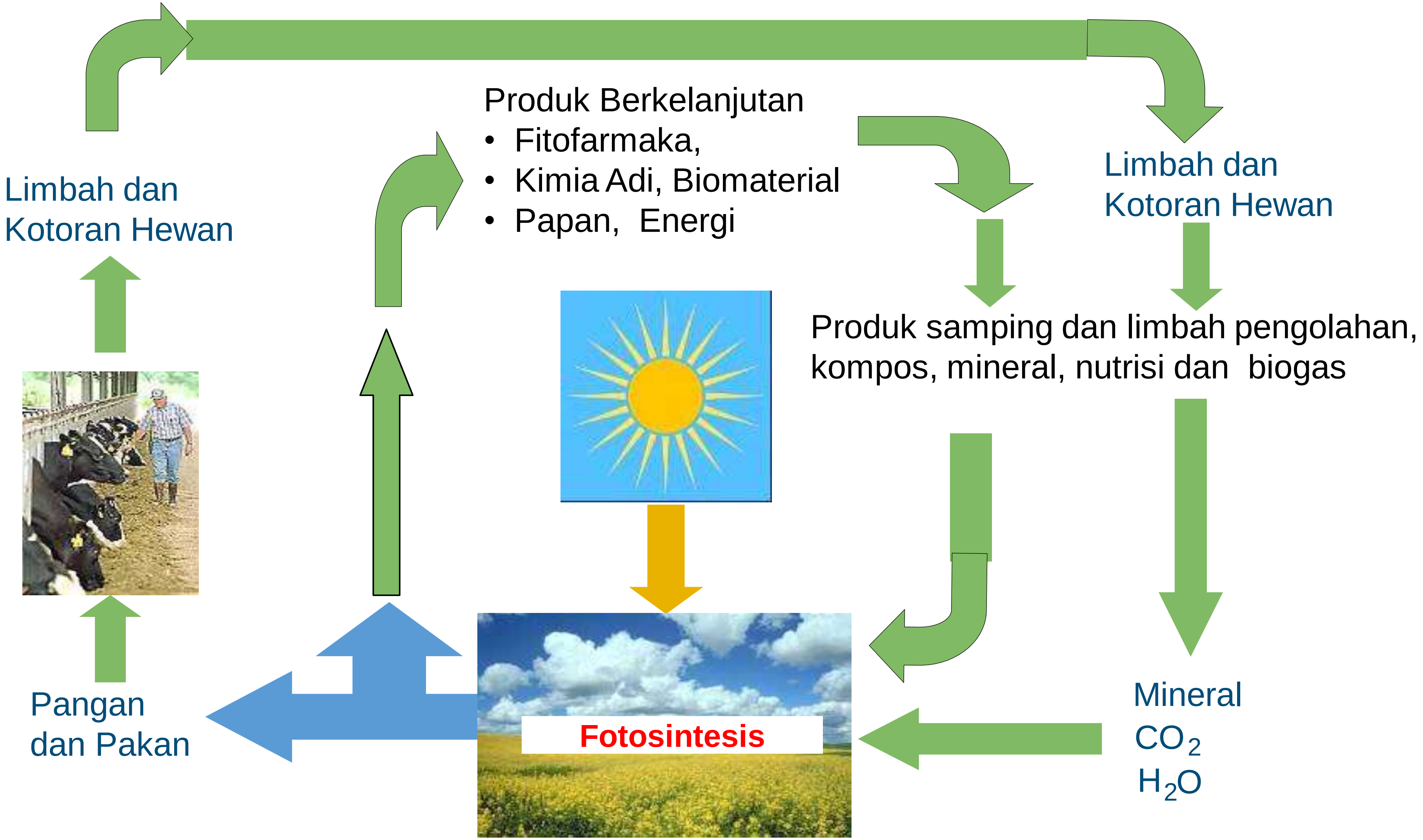
The Earth is bio-regenerative:

plants, animals and especially microorganisms regenerate, recycle, and control life's necessities.

— Eugene Odum, *Ecology and Our Endangered Life Support System.*

Ciri utama suatu ekosistem yang harmonis adalah kehadiran komunitas hayati (**produser, konsumer dan dekomposer**) yang beragam dan seimbang, dan hidup **secara bersama,** serta **saling terhubungkan** dan **saling bergantung** satu sama lain dalam suatu **pola interaksi simbiosis** sehingga dimungkinkan terjadi daur ulang zat saat (aliran) **transformasi energi** berlangsung di luasan lingkungan alam suatu ekosistem.

Valorisasi Biomassa Sumber Daya Hayati dengan Penerapan **Simbiosis Industrial** dan Strategi ***Biocascading***



IV. PENELITIAN DAN PENGEMBANGAN KONVERSI (GASIFIKASI) BIOMASSA

Bioenergy Technologies

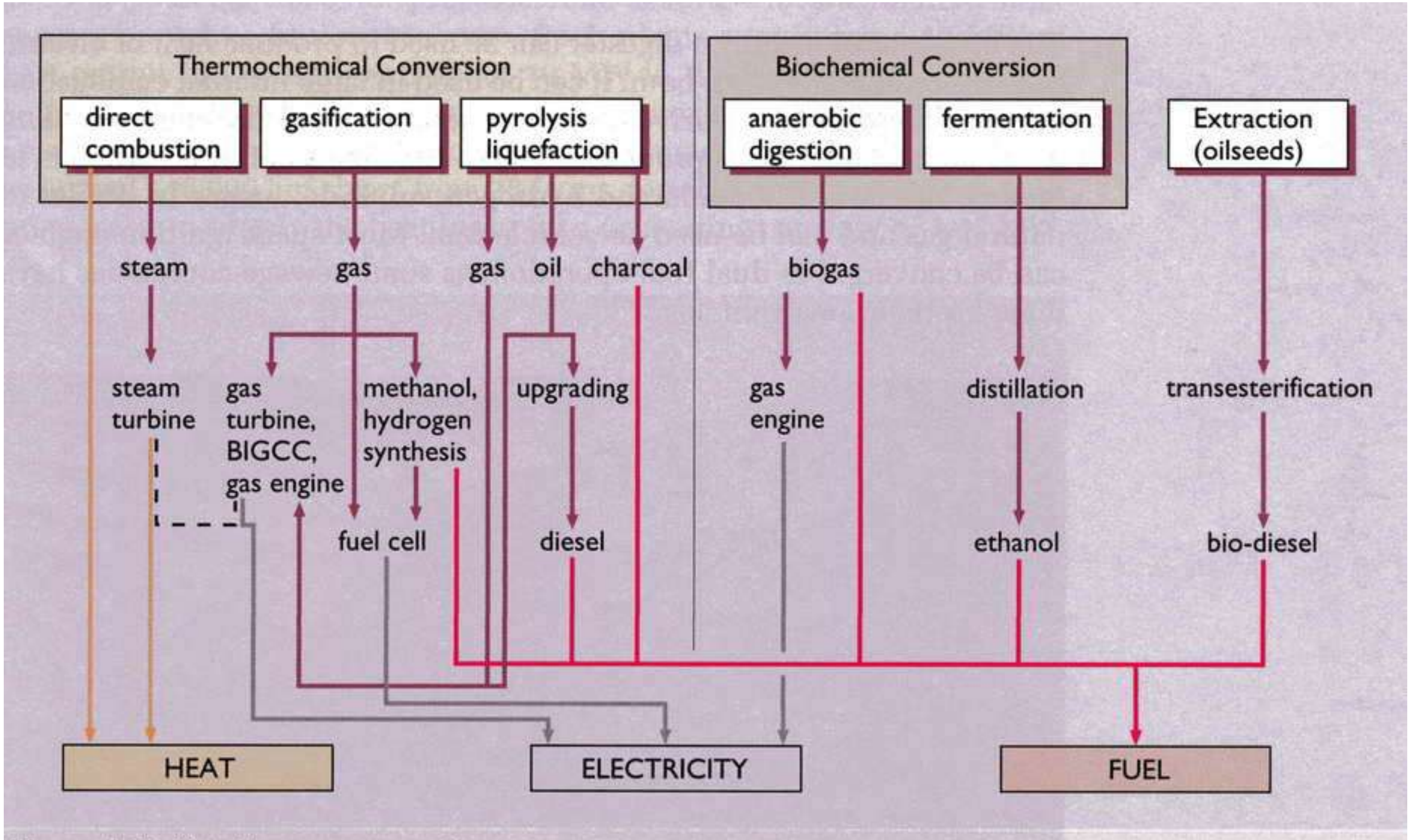
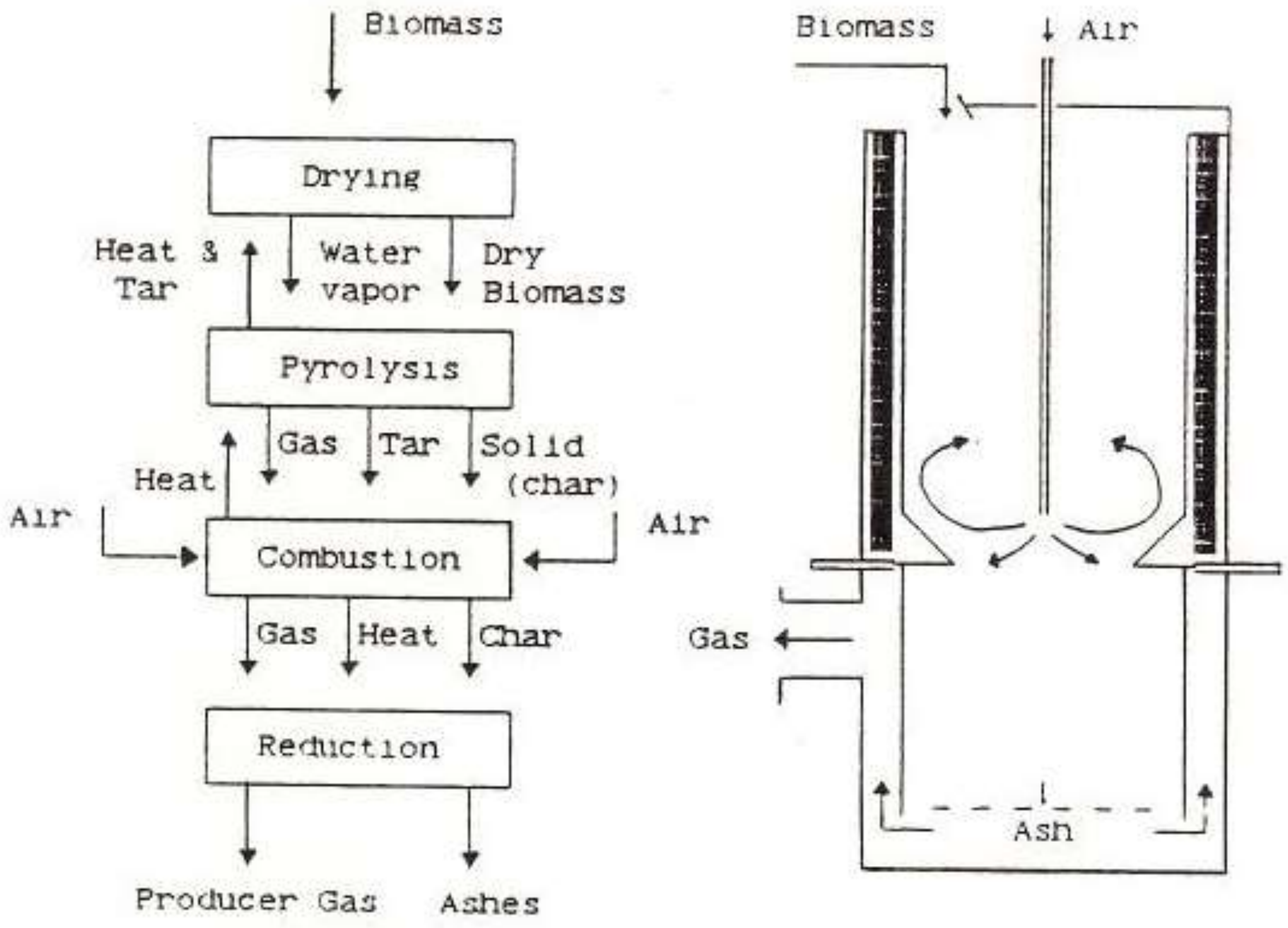


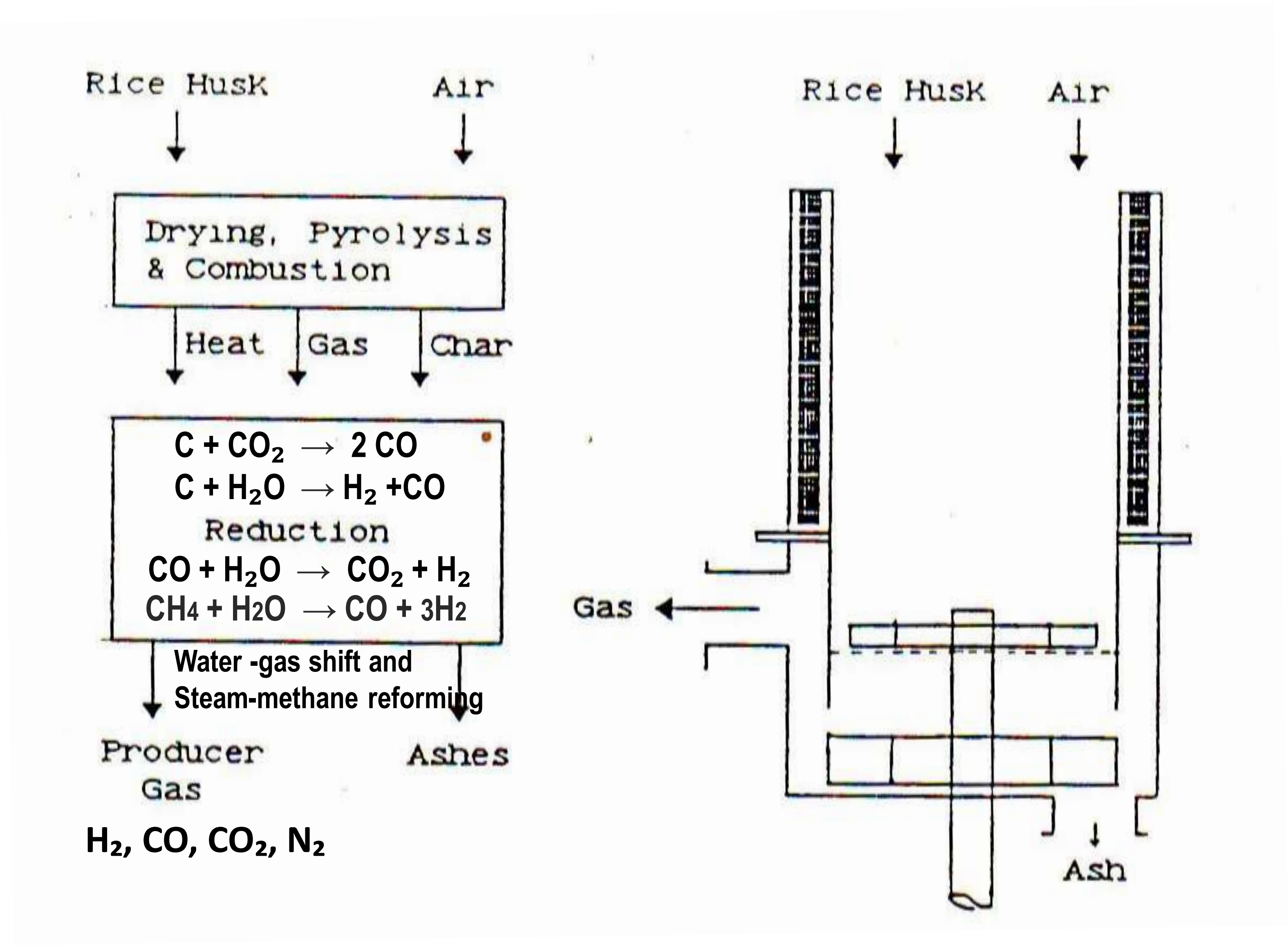
Figure 4.13 Main bioenergy conversion routes

Boyle, *Renewable Energy,* Oxford University Press (2004)

Scheme of conventional downdraft gasification process



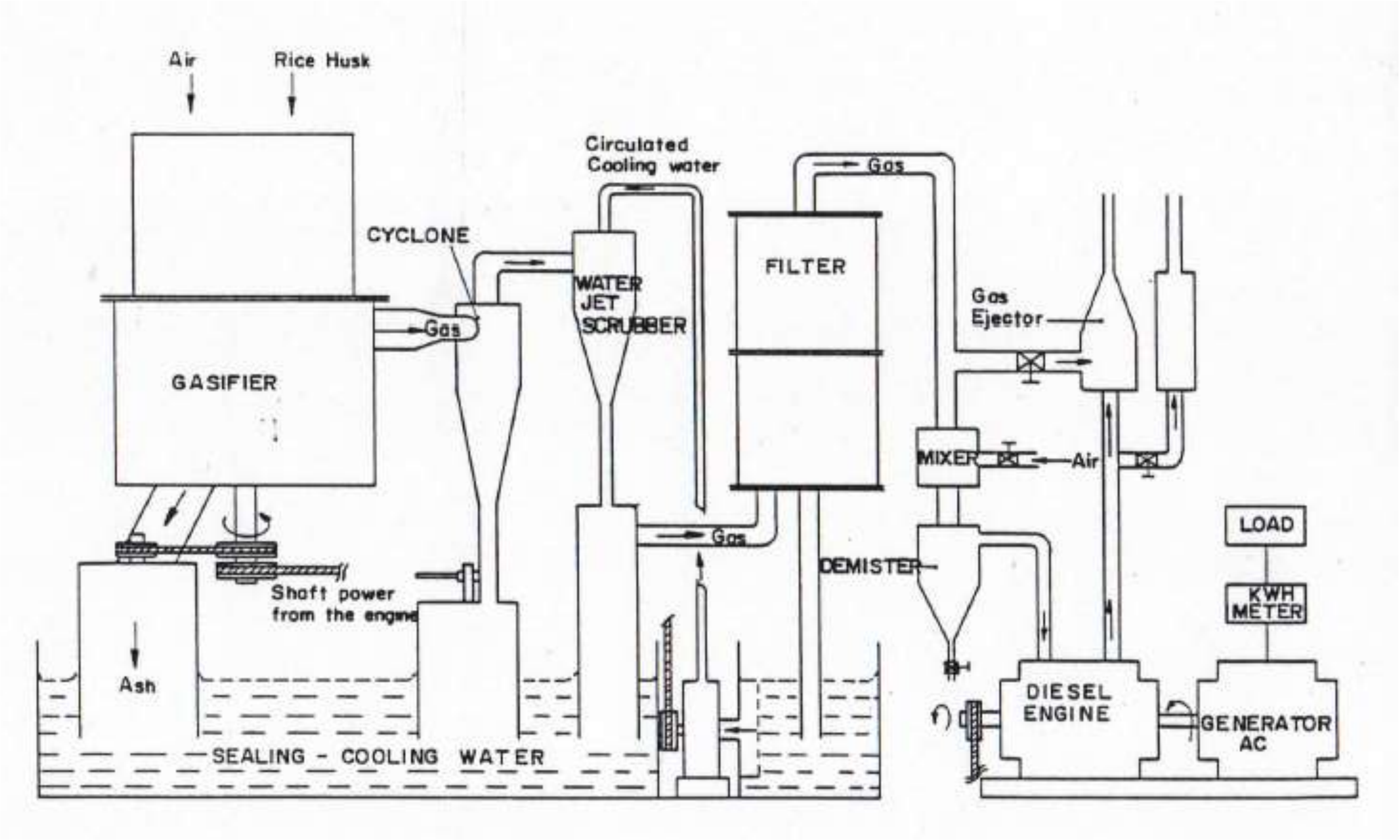
Scheme of novel downdraft rice husk gasifier



Unit Gasifikasi Sekam Padi.
Teknik Kimia ITB, 1984

Presiden Suharto Mengunjungi Prototipe Gasifikasi, 1985

Presiden Suharto Mengunjungi Unit Gasifikasi Bergerak (*mobile)*, 1985



Rancangan integrasi unit konversi sekam padi dengan “gen-set” untuk pembangkit energi listrik di desa Jayi, Kecamatan Sukahaji, Kabupaten Majalengka, yang diuji coba pada tahun 1985 hingga tahun 1990.

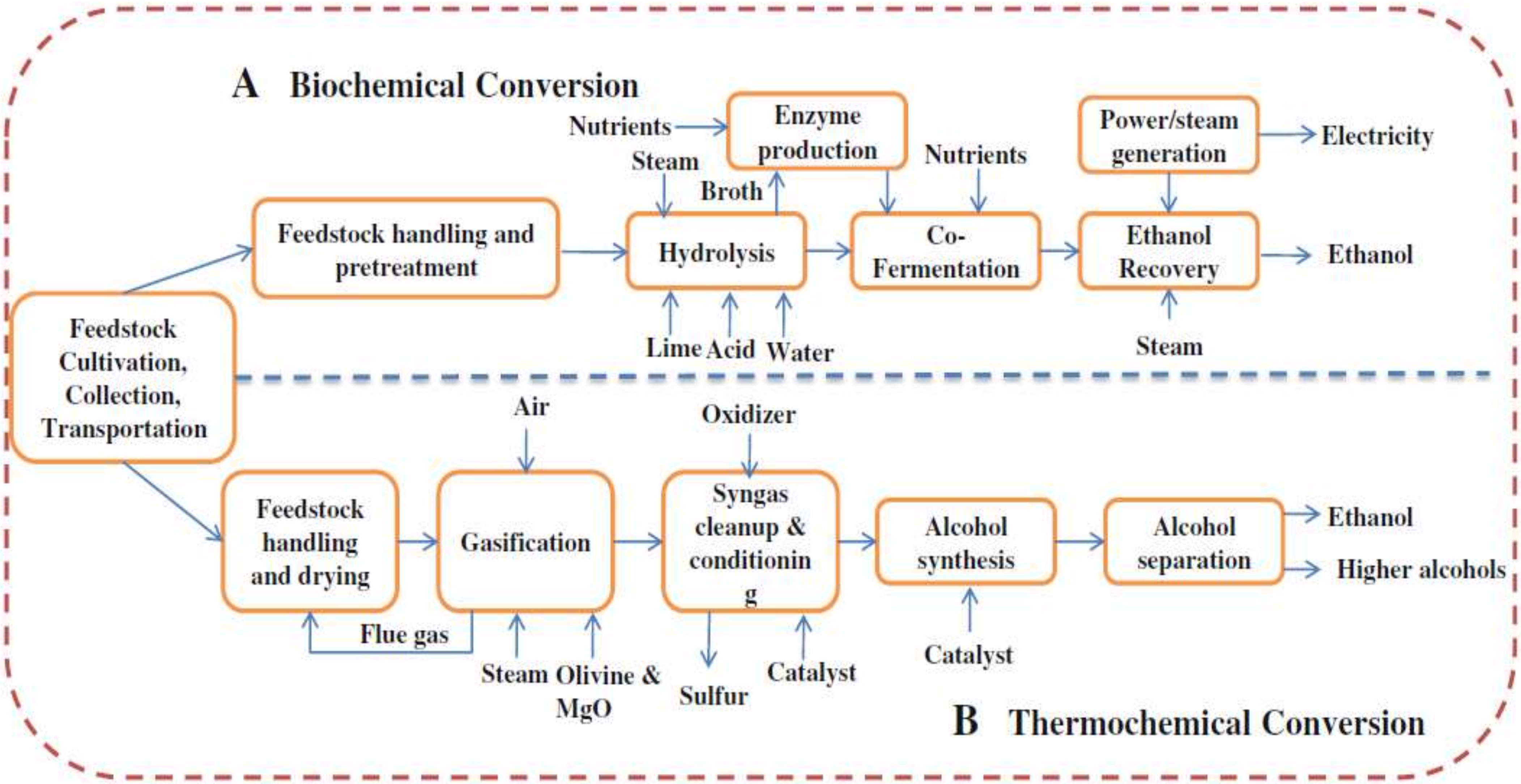
Prof Dr. Ton Beenackers (Promotor Doktor, Chemical Eng, RuG) mengunjungi Pabrik Karbon Aktif,1993

Rektor University of Groningen Prof. Fokert vd Woude, mengunjungi Pabrik Karbon Aktif (1995)

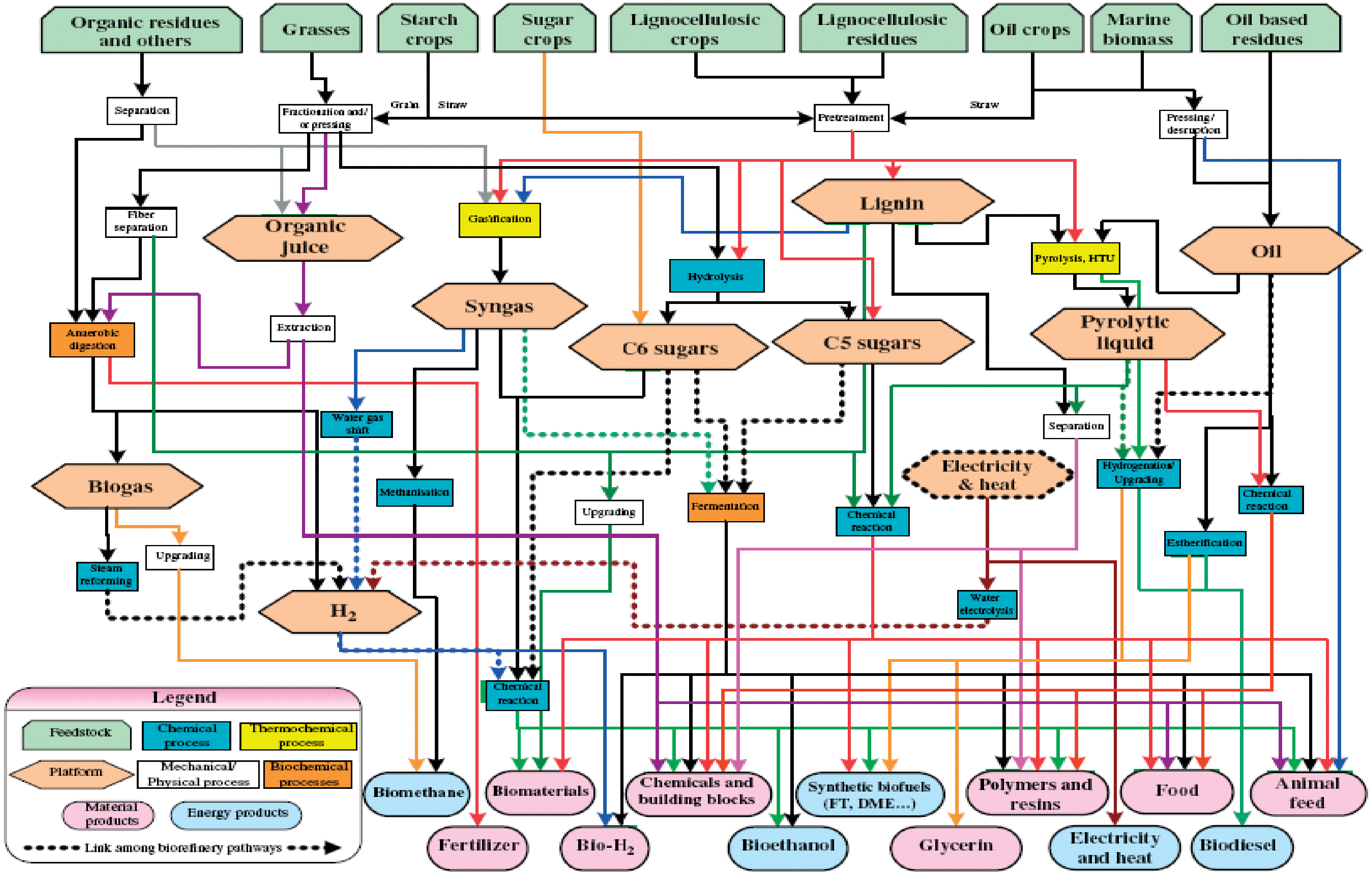
Rektor University of Groningen Prof. Fokert vd Woude, bersama Prof, Saswinadi Sasmojo (1995)

IV. PENELITIAN DAN PENGEMBANGAN LANJUT KONVERSI TERMO-KIMIA DAN BIO-KIMIA BIOMASA.

Diagram Skhema Konversi Biomasa (*Biomass Conversion*) : Thermokimiawi (*Thermochemical*) dan Konversi Biokimiawi (*Biochemical*)



Bioproduk dari Tanaman dan Limbah Biomasa :



The Top 12 Sugar-derived Building Blocks

Building Blocks	
C3	Glycerol
	3-hydroxypropionic acid
C4	1,4 di-acids (succinic, fumaric, and malic acid)
	Aspartic acid
	3-hydroxybutyrolactone
C5	Levulinic acid
	Glutamic acid
	Itaconic acid
	Xylitol/Arabinitol
C6	Sorbitol
	Glucaric acid
	2,5-furan-di-carboxylic acid

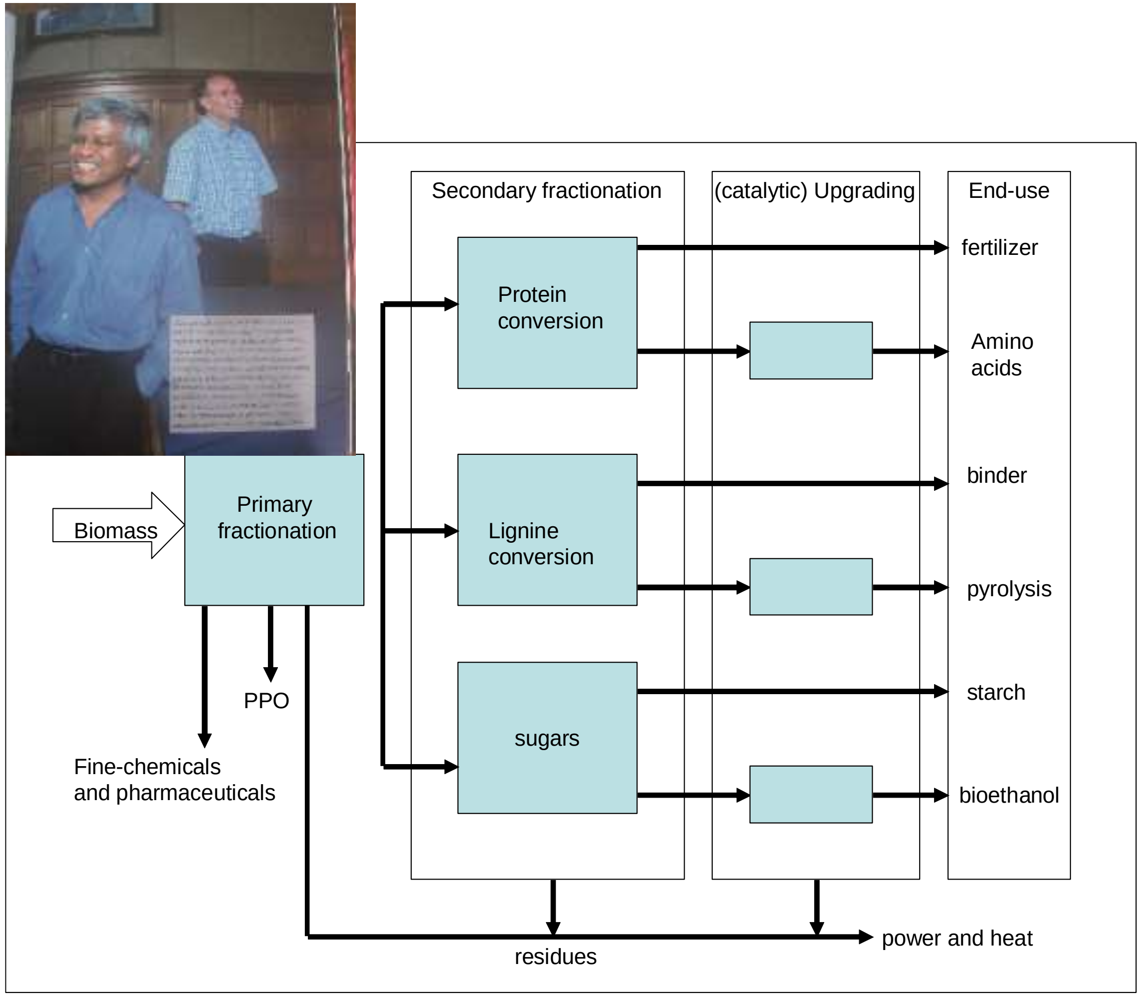
T. Werpy, G. Petersen, Top Value Added Chemicals from Biomass

- **Pati** (*starch*) merupakan sumber bahan baku utama yang sangat potensial dan menjanjikan untuk menghasilkan berbagai senyawa kimia ***"building blocks"***.
- Publikasi kami terkait proses produksi ***levulinic acid*** merupakan topik yang paling banyak di kutip sesuai ***Google Scholar***.

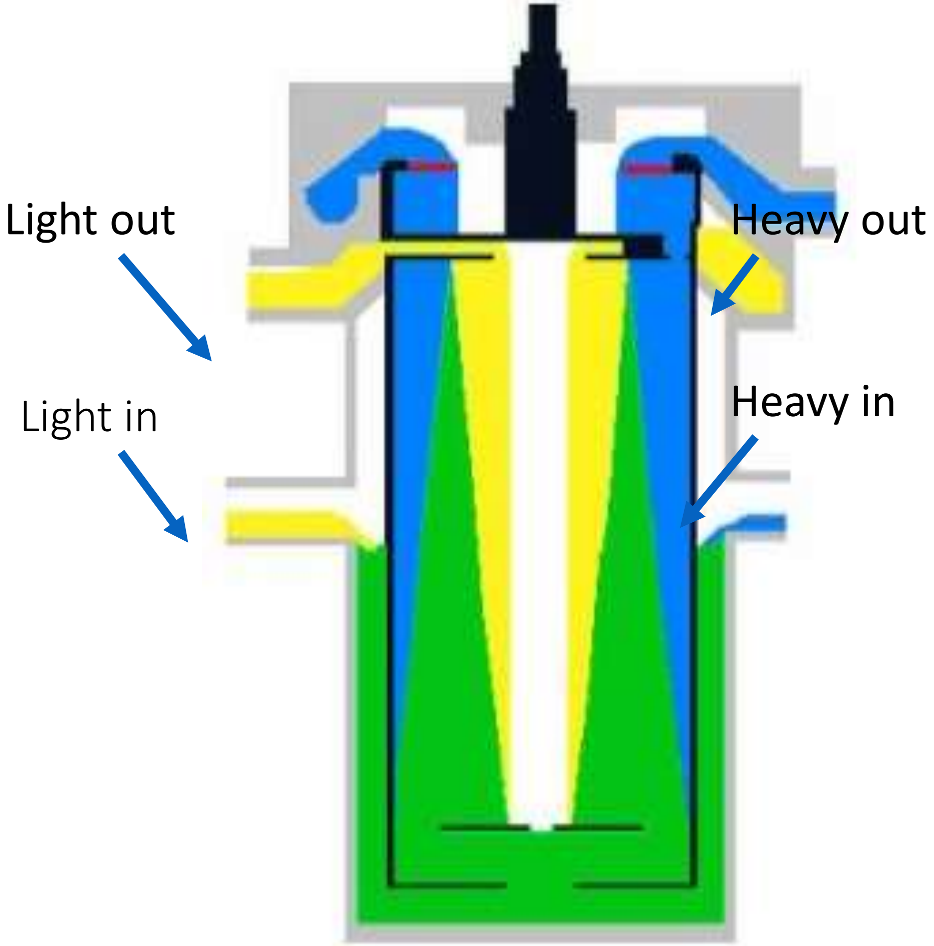
Dengan konteks pemikiran valorisasi dengan penerapan ***platform biorefinery*** dengan alur ‘***biological platform’*** dan ‘***thermochemical platform***’, kegiatan penelitian dan pengembangan yang telah kami lakukan dalam kerjasama **riset internasional** adalah:

i. ***‘Valorisation of Indonesian renewable resources and particularly Jatropha curcas using the biorefinery concept***’ (2006-2010) yang mendapat dana dari *The Royal Netherlands Academy of Arts and Sciences* (KNAW) dalam program kerjasama riset ITB – University of Groningen (RuG) dan melibatkan Wageningen University (WUR) NL, dan BPPT.

ii. ***‘Breakthrough in Biofuels: Mobile Technology for Biodiesel Production from Indonesian Resources’*** (2009 – 2014) yang mendapat dana dari Netherlands Organization for Scientific Research (NWO), dalam program kerjasama riset ITB– RuG dan melibatkan WUR dan UGM.



Mobile Biodiesel processing System : Centrifugal contactor-separator (CCS)



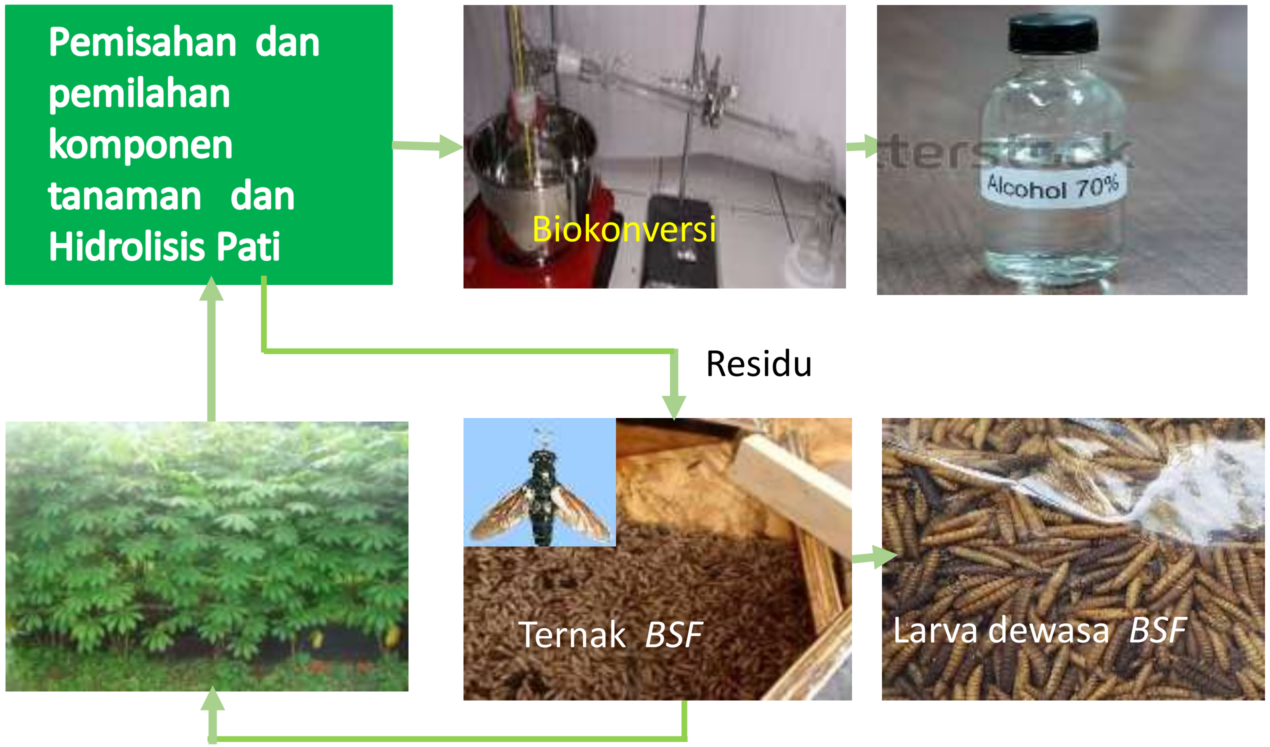
(patented in Indonesia –ITB and Europe)

NATIONAL GEOGRAPHIC INDONESIA
BioChem Prima International
JATROPHA
EXPEDITION 2006
ATAMBUA-DENPASAR-BANDUNG-JAKARTA

Dalam lingkup riset nasional, valorisasi sumber daya hayati yang fokus pada **peran penting kehadiran agen hayati yang secara genetik direkayasa untuk menghasilkan produk yang diinginkan** pada topik (i), dan dalam perlakuan awal (*pretreatment*) untuk meningkatkan efisiensi biokonversi oleh lalat BSF pada topik (ii) serta **integrasi termokonversi dengan biokonversi** untuk menghasilkan berbagai bioproduk yang efisien seperti biokomposit dan ethanol.

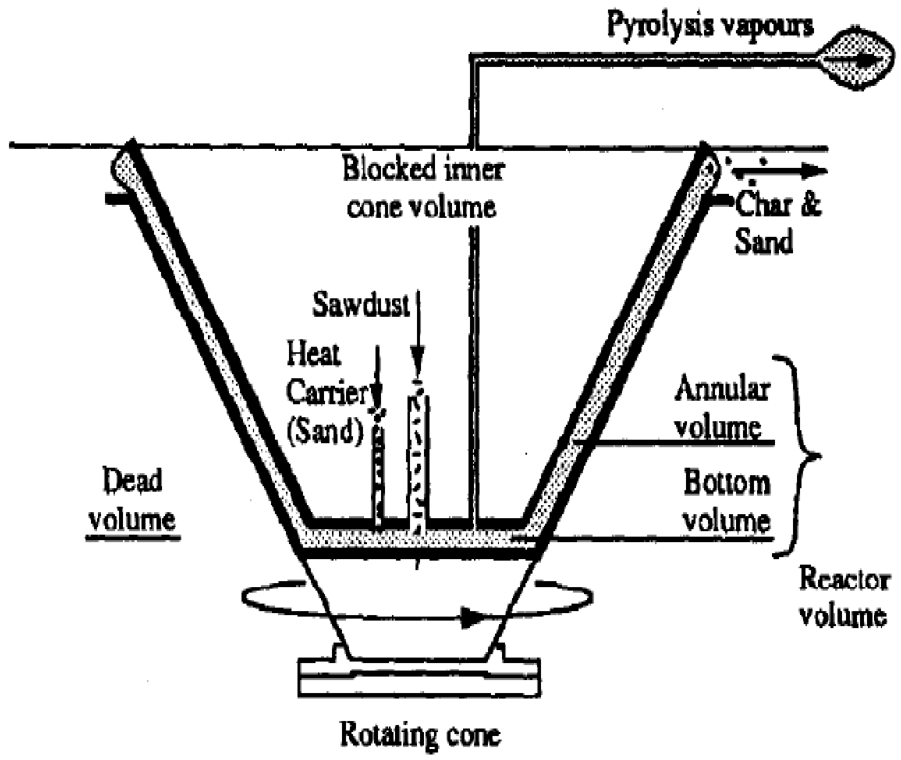
i. **Perancangan sistem produksi terintegrasi isobutanol atau ethanol, dan bioproduk** lainnya dari Tanaman Singkong.
(Program S3*:* **Gabriel Bagus Kennardi)**
(Program : S2= **Peter X** dan S1=18 orang)

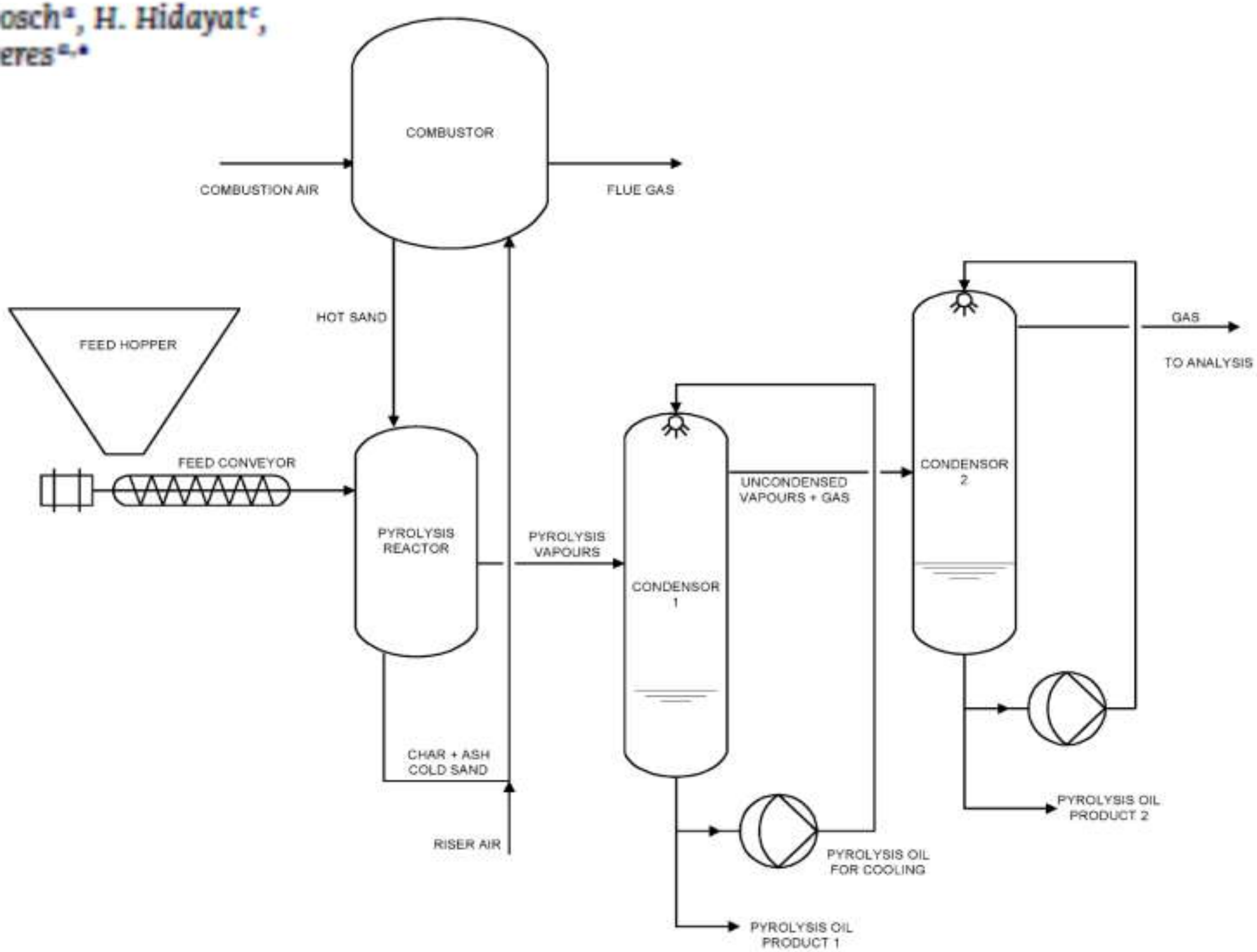
ii. **Peningkatan efisiensi sistem biokonversi limbah pertanian** menggunakan **larva *black soldier fly*** *(BSF, hermetia illucens*)
(Program S3**: Dr. Ateng Supriatna)**



Valorisation of *Jatropha curcas* L. plant parts: Nut shell conversion to fast pyrolysis oil

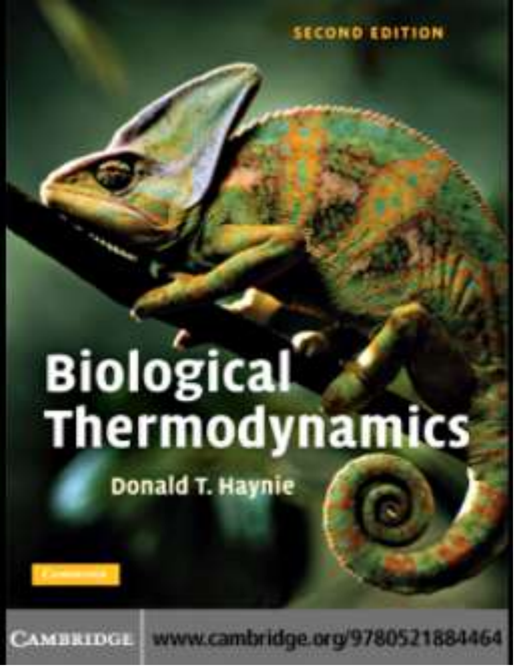
R. Manurung[d], D.A.Z. Wever[b], J. Wildschut[b], R.H. Venderbosch[a], H. Hidayat[c], J.E.G. van Dam[c], E.J. Leijenhorst[a], A.A. Broekhuis[a], H.J. Heeres[a,*]





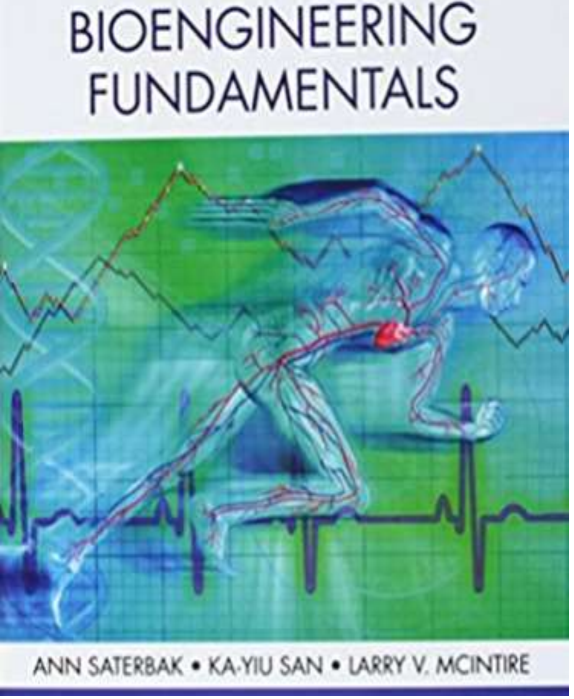
Schematic representation of the bench scale flash pyrolysis set-up used in our study.

V. PERAN AIR DALAM KONVERSI TERMO-KIMIA DAN ELEKTRO-KIMIA



The First Law is a conservation law: energy can be changed from one form to another, but in all its transformations energy is neither created nor destroyed.

The Second Law is about the tendency of particles to go from being concentrated to being spread out in space – spontaneously. It is also about the tendency of energy to go from being "concentrated" to being "spread out" – spontaneously: $\Delta S \geq 0$



Calculation of Enthalpy in Reactive Processes

During **chemical reactions, rearranging the bonds between the atoms** of reactants and products causes changes in the internal energy of a system**.**

In reactions, **energy is required to break the existing bonds of the reactants**, and **energy is released during bond formation to create the products**.

The difference between the final and initial energy states of the products and reactants is known as the heat of reaction.

Chemical reactions can be classified as either **endothermic** or **exothermic**.

An **endothermic** process requires **more energy to break the bonds of the reactants** than is released when the bonds of the products are formed.

Photosynthesis is an example of an **endothermic reaction** because energy is required for the reaction to occur.

During an **exothermic** reaction, **more energy is released when the bonds of the products** are formed than is required to break the bonds of the reactants.

Glycolysis is an **exothermic reaction** because energy is released as glucose is broken down. That is, an exothermic process generates energy.

In an exothermic reaction, the heat of reaction is negative in value. On the other hand, an endothermic reaction consumes energy, and the heat of reaction is positive in value.

The **standard heat of combustion: (ΔHc°)** is the specific enthalpy change associated with the combustion of 1 mol of a substance with oxygen with both reactants and products at a reference temperature and pressure (usually 25°C and 1 atm).
Tabulated heat of combustion values assume that all carbon in the reactant is converted to $CO_2(g)$; all hydrogen to $H_2O(l)$; all nitrogen to $N_2(g)$; and all sulfur to $SO_2(g)$. Compounds involved in a combustion process most often contain carbon.
Also, compounds with elements other than C, N, H, O, and S do not have heat of combustion values. **The standard heats of combustion for $O_2(g)$ and the combustion products $CO_2(g)$, $H_2O(l)$, $N_2(g)$, and $SO_2(g)$ are zero.**

An example is the combustion of caffeine ($C_8H_{10}O_2N_4$)

$$C_8H_{10}O_2N_4(s) + 19/2\ O_2(g) \rightarrow 8\ CO_2(g) + 5\ H_2O(l) + 2\ N_2(g)$$

The standard heats of combustion of O_2, $CO_2(g)$, $H_2O(l)$, and $N_2(g)$ are zero. The **ΔHc°** for one mole of **$C_8H_{10}O_2N_4$**, and hence of the combustion reaction, is given as -**4247 kJ/mol**. Since is negative, the combustion reaction is exothermic.

Heats of Combustion

Compound	Formula	Molecular weight, M (g/mol)	State	Heat of combustion $\Delta \hat{H}_c^o$ (kJ/mol)
Glutaric acid	$C_5H_8O_4$	132.116	c	−2150.9
Glycerol	$C_3H_8O_3$	92.095	l	−1655.4
			g	−1741.2
Glycine	$C_2H_5O_2N$	75.067	c	−973.1
Glycogen	$(C_6H_{10}O_5)_x$ per kg		s	−17530.1*
Guanine	$C_5H_5ON_5$	151.128	c	−2498.2
Hexadecane	$C_{16}H_{34}$	226.446	l	−10699.2
			g	−10780.5
Hexadecanoic acid	$C_{16}H_{32}O_2$	256.429	c	−9977.9
			l	−10031.3
			g	−10132.3
Histidine (L-)	$C_6H_9O_2N_3$	155.157	c	−3180.6
Hydrogen	H_2	2.016	g	−285.8
Hydrogen sulphide	H_2S	34.08		−562.6
Methane	CH_4	16.043	g	−890.8
Methanol	CH_4O	32.042	l	−726.1
			g	−763.7
Morphine	$C_{17}H_{19}O_3N.H_2O$		s	−8986.6*
Nicotine	$C_{10}H_{14}N_2$		l	−5977.8*
Oleic acid	$C_{18}H_{34}O_2$		l	−11126.5

Reaction of sodium with water

Sodium metal reacts rapidly with water to form a colourless solution of sodium hydroxide (NaOH) and hydrogen gas (H_2). The reaction is exothermic. The reaction is slower than that of potassium , but faster than that of lithium.

$$2Na(s) + 2H_2O \rightarrow 2NaOH(aq) + H_2(g)$$

Acids and Bases React with Metals

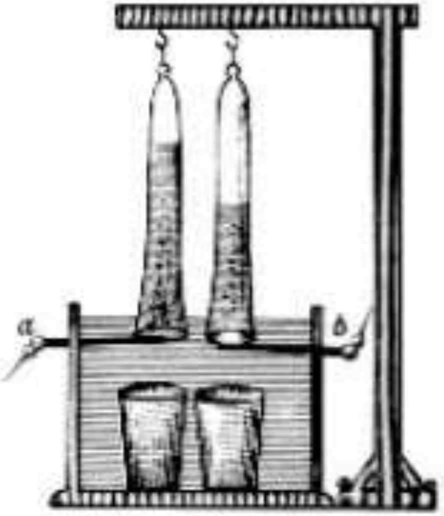
Acids react with most metals to form a salt and hydrogen gas. Metals that are more active than acids can undergo a single displacement reaction.

$$Zn(s) + 2\,HCl(aq) \rightarrow ZnCl_2\,(aq) + H_2\,(g)$$

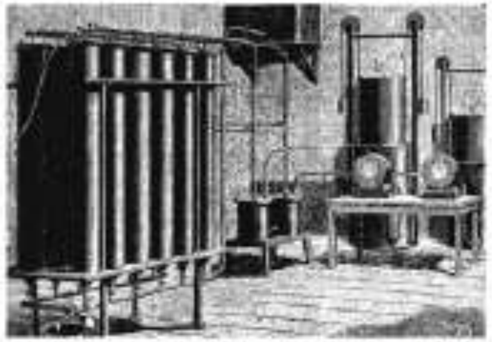
Bases also react with certain metals, like zinc or aluminum, to produce hydrogen gas

$$Zn(s) + 2\,NaOH(aq) + 2\,H_2O(l) \rightarrow Na_2Zn(OH)_4(aq) + H_2\,(g)$$

Hydrogen Production by Electrolytical Water Splitting
Known for more than 200 years.



Test set-up of Ritter



Alkaline electrolyser around 1900

- Invention of voltaic pile (1799) enabled investigations of electrolytic approaches
- Main principle demonstrated around 1800 by J. W. Ritter, William Nicholson and Anthony Carlise
- Today 3 technologies available:
  - Alkaline electrolysis (AEL)
  - Electrolysis in acid environment (PEM electrolysis - PEMEL) (SPE water electrolysis)
  - Steam electrolysis (High temperature electrolysis - HTEL or SOEL)

$$2\,H_2O \rightarrow 2\,H_2 + O_2$$

Johann Wilhelm Ritter (1776-1810)

Picture credits: all www.wikipedia.org

Fraunhofer

Electrolysis is the use of an electric current to cause chemical reaction which wouldn't otherwise happen.

Anode Reaction: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$ - 0.40 V

Cathode Reaction: $4H^+ + 4e^- \rightarrow 2H_2$ - 0.83 V

$2H_2O \rightarrow 2\ H_2 + O_2$ - 1,23 V

Energi yang dibutuhkan untuk memutus ikatan atom pada H_2O adalah 285820 kJ/k mol , atau 15,8 MJ/kg. Dari reaktan 1 kg air dihasilkan 1/18 kmol H_2, atau 1/18x2= 0.111 kg H_2. Sehingga untuk menghasilkan 1 kg H_2 diperlukan energi memutus ikatan H_2O sebesar 142 MJ.

Reaksi pembakaran Hidrogen:

$$2\ H_2 + O_2 \rightarrow 2\ H_2O$$

Nilai kalor H2 adalah 285820 MJ/kmol, atau 142 MJ/kg.

Petanyaannya Efisiensi konversi elektrolisis berapa ? Saat ini berkisar 40 - 80 %.

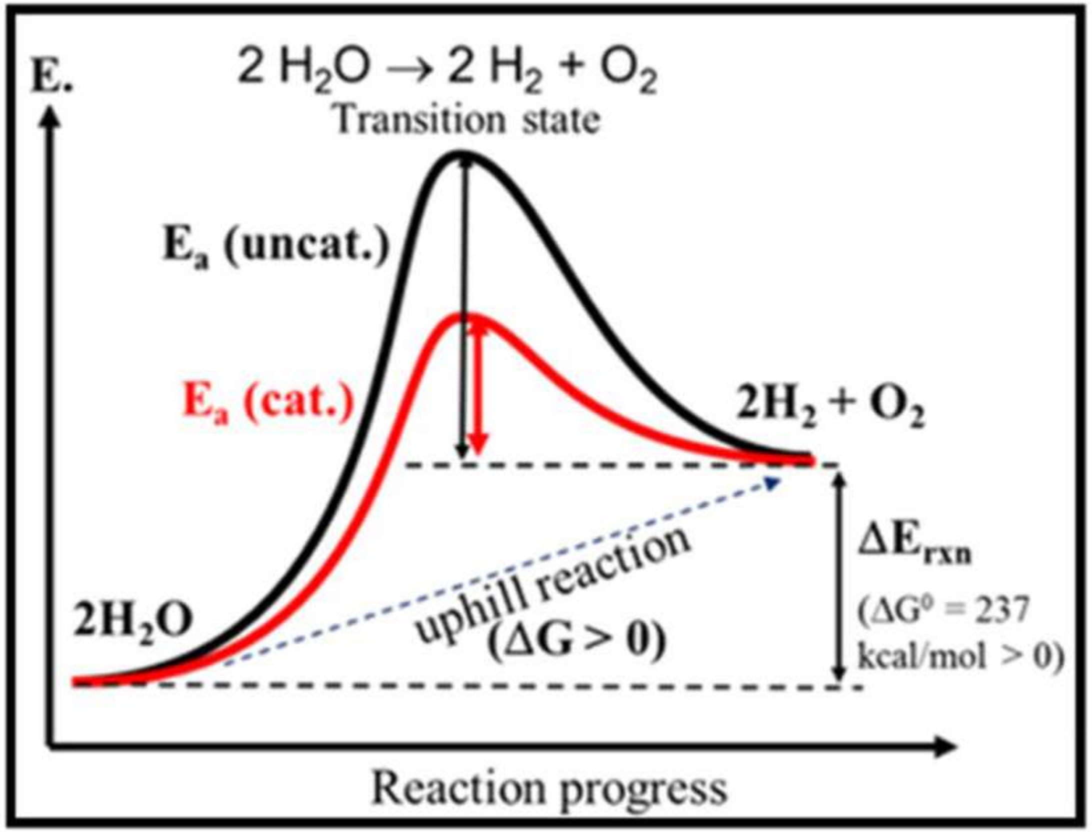
Anodic and cathodic reactions of water electrolysis in acidic and alkaline media.

	Acidic	Alkaline
Anode	$2H_2O \rightarrow 4H^+ + O_2 + 4e^-$	$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$
Cathode	$2H^+ + 2e^- \rightarrow H_2$	$2H_2O + 2e^- \rightarrow 2OH^- + H_2$

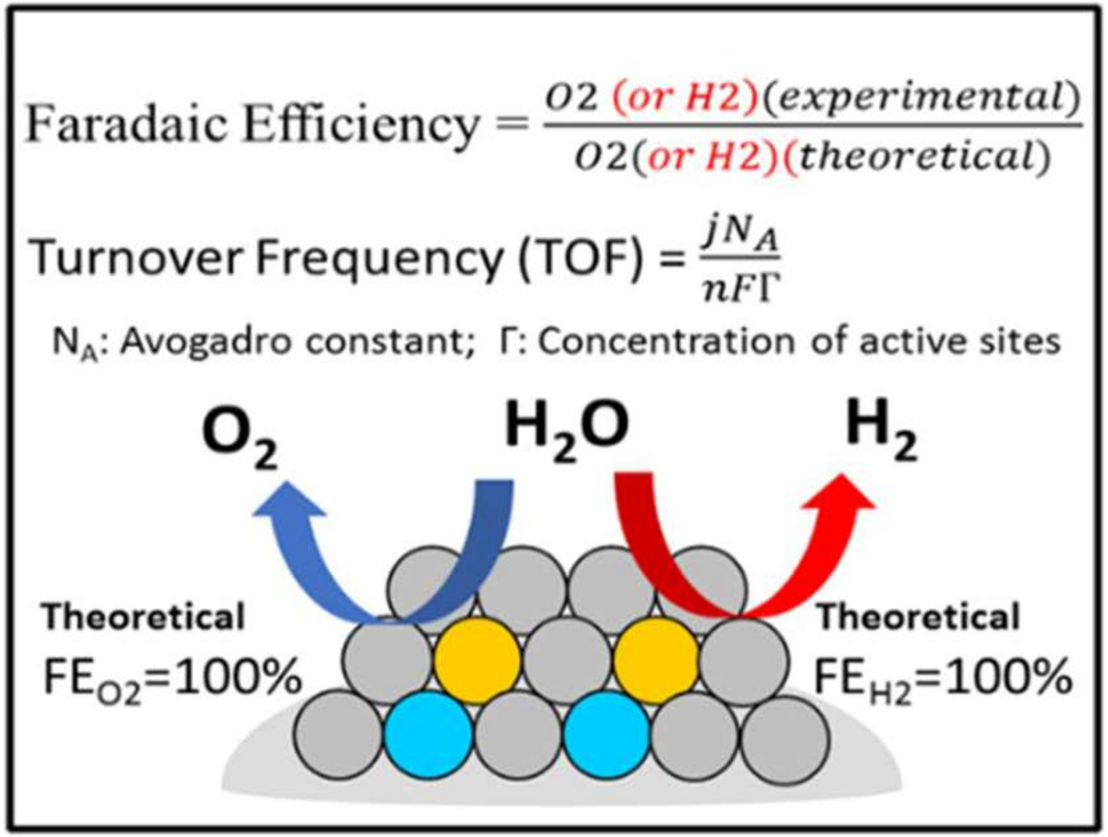
Efficiency:

- Essentially all of the operating costs of commercial electrolyzers are associated with the cost of electricity, hence increases in efficiency directly lower the operating costs.
- Efficiency can be increased relative to demonstration systems by employing optimized: electrocatalysts (PtNi–Ni NA/CC, NiCo2Px etc), heat (T), and strongly acidic or strongly alkaline electrolytes.

(Chengxiang Xiang, Principles and implementations of electrolysis, ***Mater. Horiz.*****, 2016, 3, 169--173**).



A

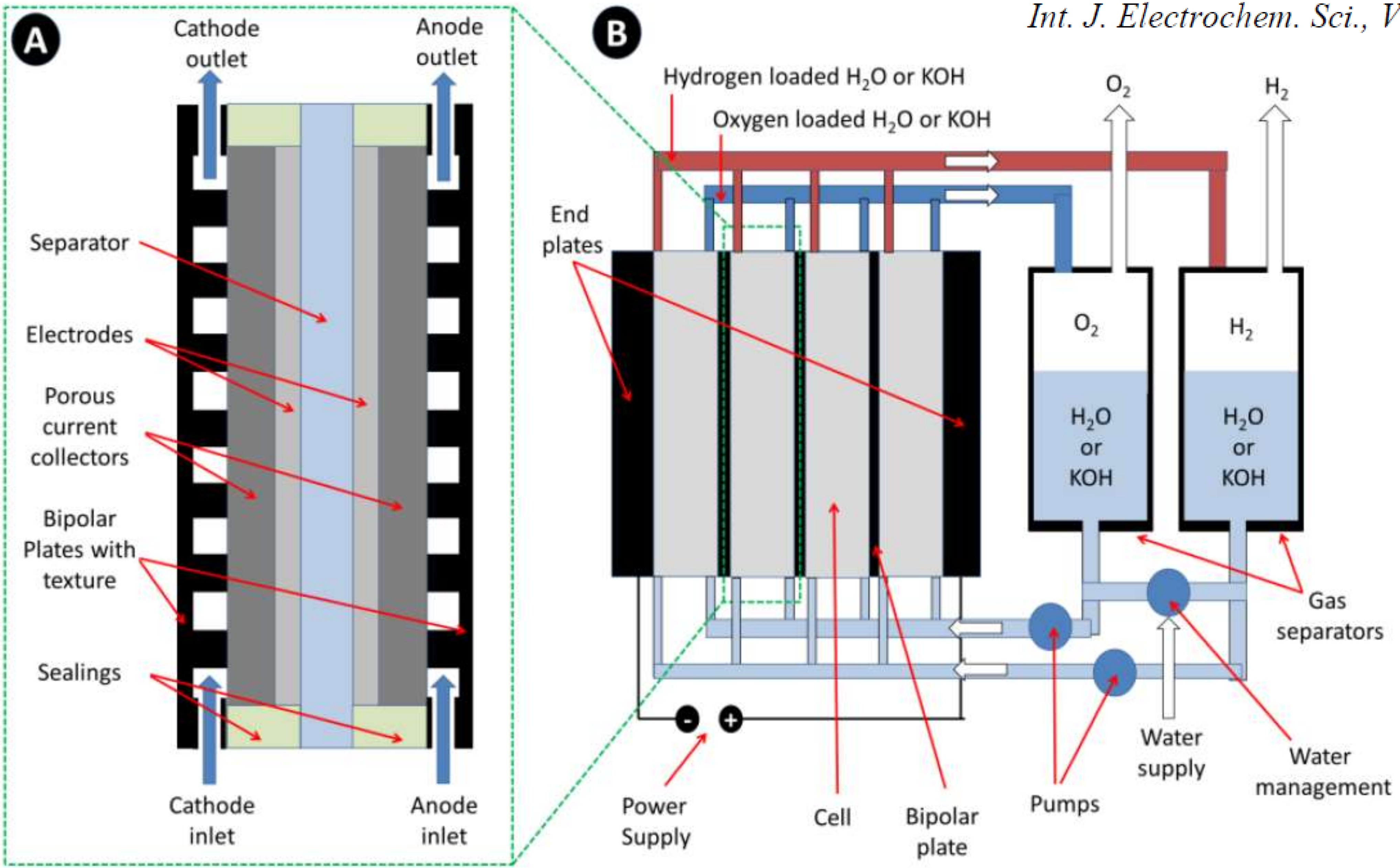


B

A. Schematic illustration of the catalyst's role in lowering the activation energy barrier.

B. Schematic illustrations of the performance evaluation parameters of electrocatalyst on efficiency in term of faradaic efficiency and turnover frequency

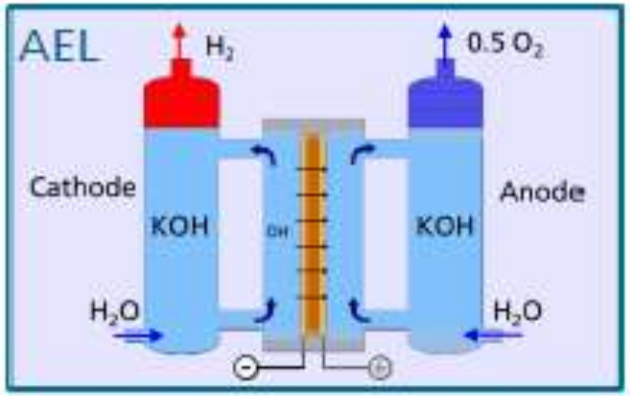
Wang *et al. Nano Convergence (2021) 8:4*

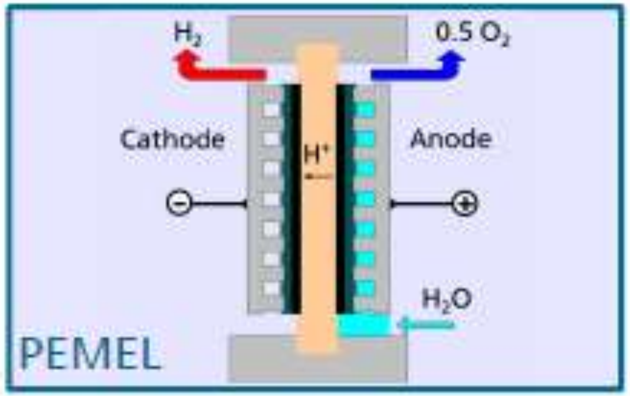


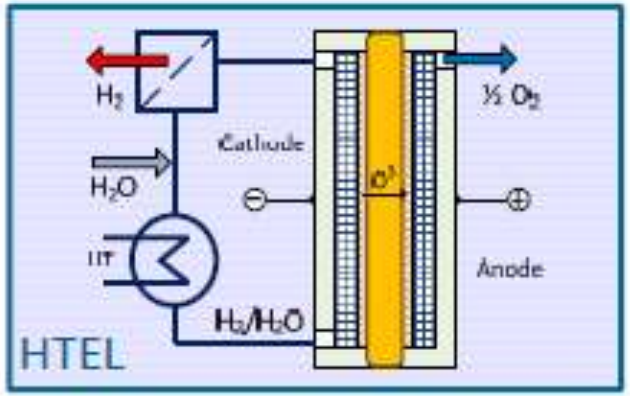
Schematic illustrations of a water electrolysis cell (A) and a bipolar water electrolysis system (B).

Water Electrolysis
Three approaches for hydrogen and oxygen production

Technology	Temp. Range	Cathodic Reaction (HER)	Charge Carrier	Anodic Reaction (OER)
Alkaline electrolysis	40 - 90 °C	$2H_2O + 2e^- \Rightarrow H_2 + 2OH^-$	OH^-	$2OH^- \Rightarrow \frac{1}{2}O_2 + H_2O + 2e^-$
Membrane electrolysis	20 - 100 °C	$2H^+ + 2e^- \Rightarrow H_2$	H^+	$H_2O \Rightarrow \frac{1}{2}O_2 + 2H^+ + 2e^-$
High temp. electrolysis	700 - 1000 °C	$H_2O + 2e^- \Rightarrow H_2 + O^{2-}$	O^{2-}	$O^{2-} \Rightarrow \frac{1}{2}O_2 + 2e^-$







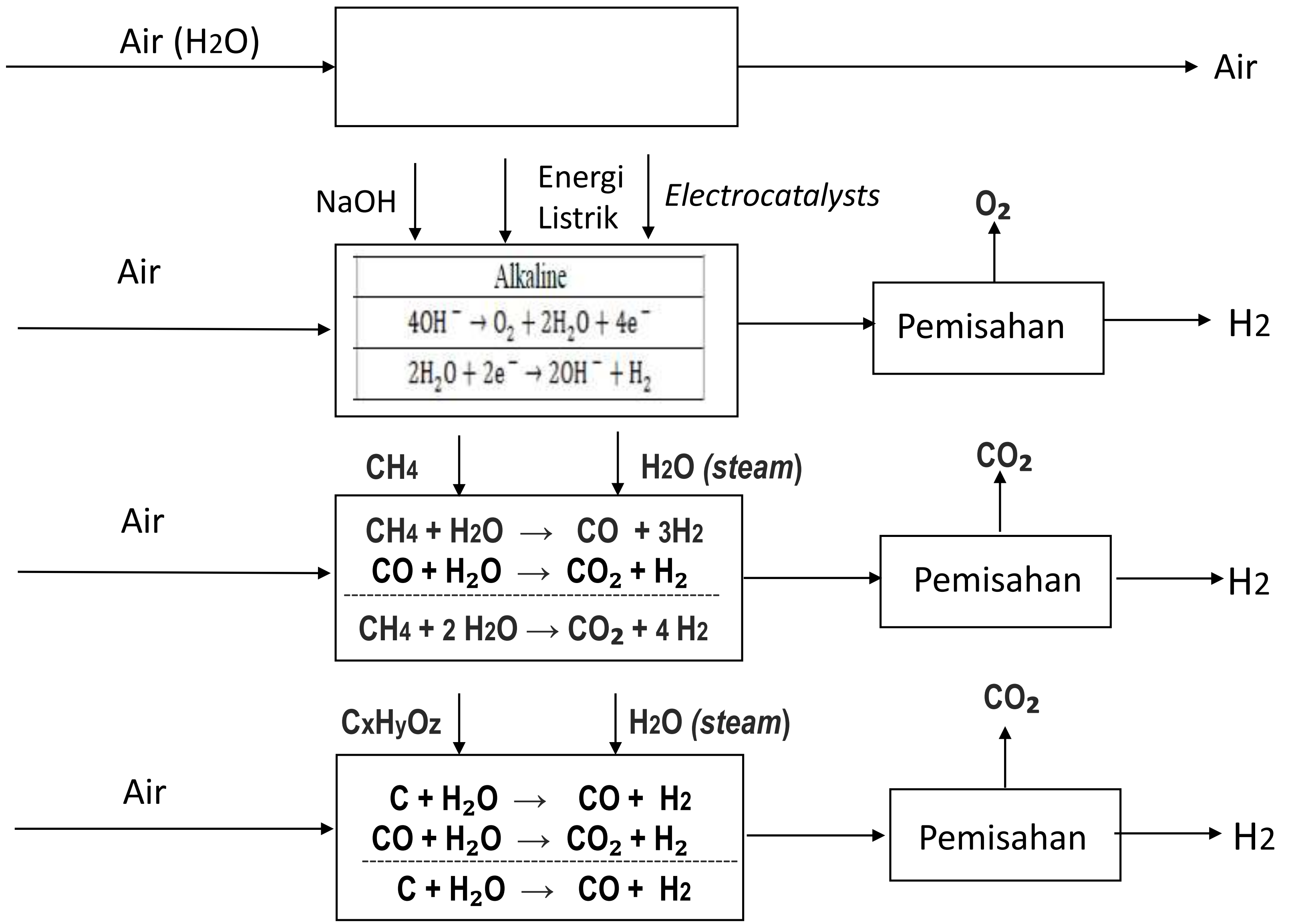
Fraunhofer

US Department of Energy
Hydrogen and Fuel Cell Technologies Office

Hydrogen fuel is the most promising alternative fuel for the future. It have a high calorific value. and its only combustion product is water, so it is pollution free. It yields almost double the energy provided by jet fuels. But it is not used as domestic fuel, due to several reasons :

1. **Hydrogen is not easily available and cost of production is high [4 US $/kg (2022), 1 US $/kg (2030)]**
2. **It is not easy to store.**
3. **Hydrogen is highly explosive.**
4. **It does not burn at a slow rate.**
5. **Transport of hydrogen is very difficult.**

VI. RANGKUMAN

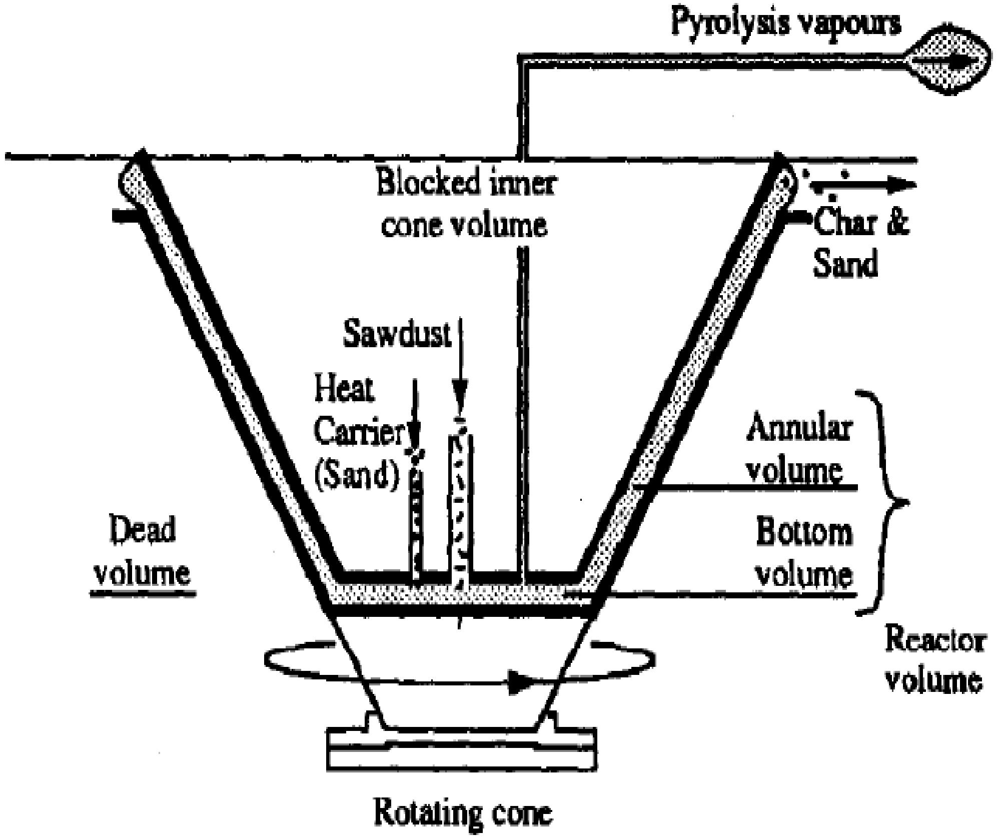


Bahan bakar air: ***Hoax***
Tidak mungkin air menjadi bahan bakar tanpa ada pasokan energi dari luar.

Produksi **H_2** melalui ***alkaline electrolysis*** berkembang pesat seiring tersedianya energi listrik dari tenaga surya dan angin.

48 % produksi **H_2** dunia saat ini dihasilkan dari alur proses ini: ***steam-methane reforming.***

30 % produksi **H_2** saaat ini dari ***hydrocarbons cracking*** serta 18 % dari ***coal gasification.***



Konversi termo-kimia limbah biomassa menjadi bahan bakar *diesel, gasoline* dan *jetfuels*

- Air bukanlah bahan bakar melainkan produk dari hasil pembakaran. Peran air dalam produksi bahan bakar khususnya hidrogen adalah sebagai medium. Melalui pasokan energi lain, air dapat dikonversi menjadi bahan bakar, seperti hidrogen.
- Air digunakan sebagai medium atau reaktan untuk menghasilkan H_2 pada proses konversi termokimia gas alam (CH_4) dan gasifikasi batu bara atau biomassa.
- Konversi air menjadi hidrogen sudah dikenal sejak 200 tahun lalu melalui penemuan prinsip elektroysis sekitar tahun 1800, dan prinsip *alkaline electrolyser* sekitar tahun1900.
- Pengembangan elektrolisis air untuk menghasilkan hidrogen mendapat perhatian yang makin luas melalui integrasikan energi terbarukan (energy surya dan angin) sebagai sumber energi untuk konversi air secara elektrolisis.
- Eletrolisis secara alkalin (*alkaline electrolysis*) sudah mencapai teknologi yang dewasa untuk penggunaan energi industrial pada rentang kapasitas MW yang bisa diadaptasikan untuk kebutuhan pasar pada berbagai skala.
- ITB dapat menjadi pelopor menuntun penggunaan *alkaline ektrolysers* untuk berbagai kebutuhan dengan mengkaji: efisiensi, biaya, kestabilan dan keamanan.

Terima Kasih