

# Biofuels: Mistake or Solution?

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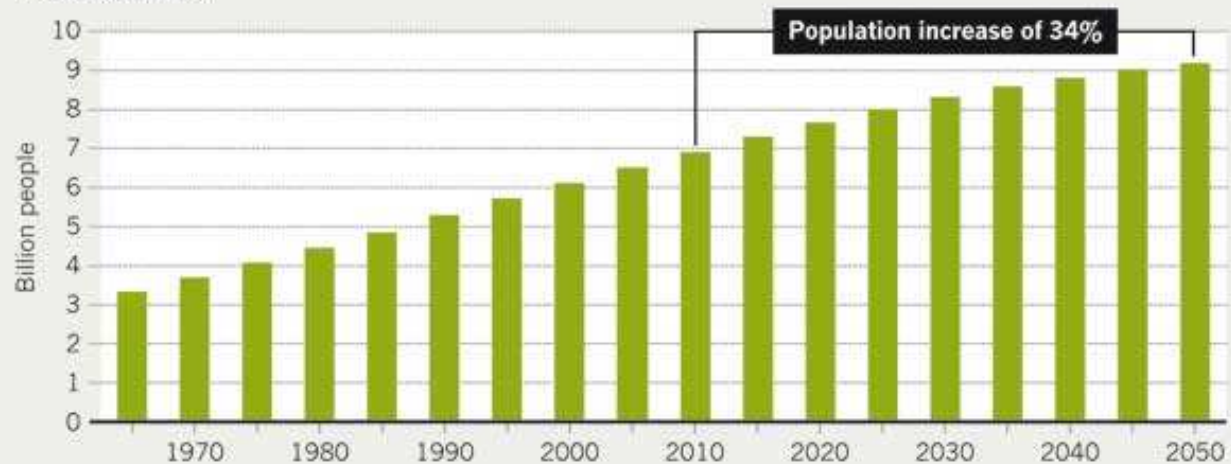




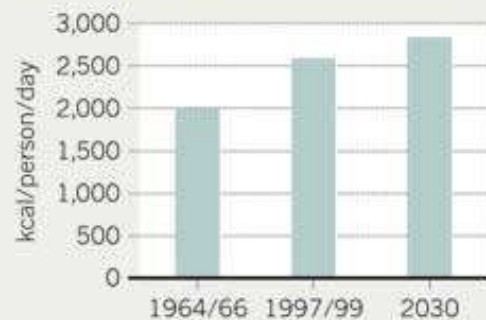
# GROWING CHALLENGES

Between now and 2050 the world's population is predicted to increase to more than 9 billion people. Each person will also be consuming more calories per day and using more energy to power their lives. Food and fuel supplies will need to massively increase to meet these needs.

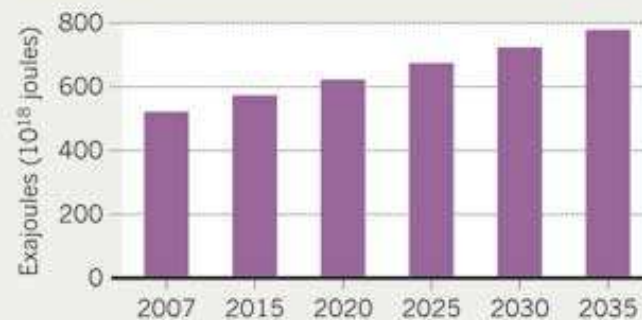
## WORLD POPULATION

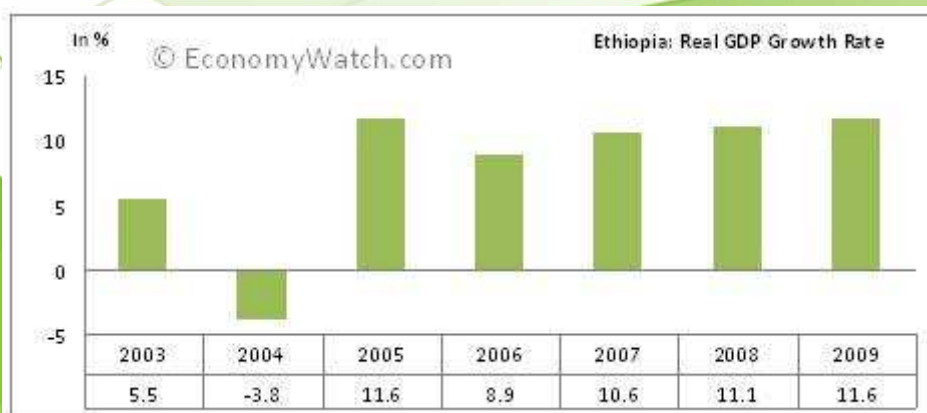
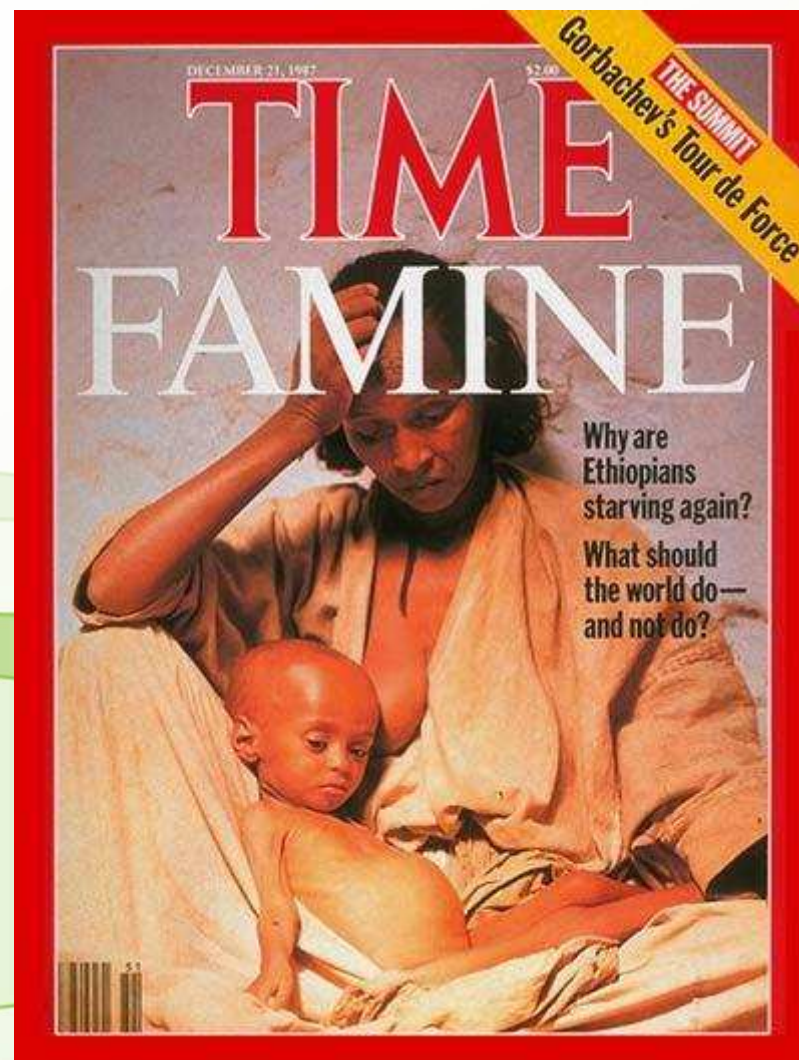


## DAILY CALORIE INTAKE



## GLOBAL ENERGY USAGE



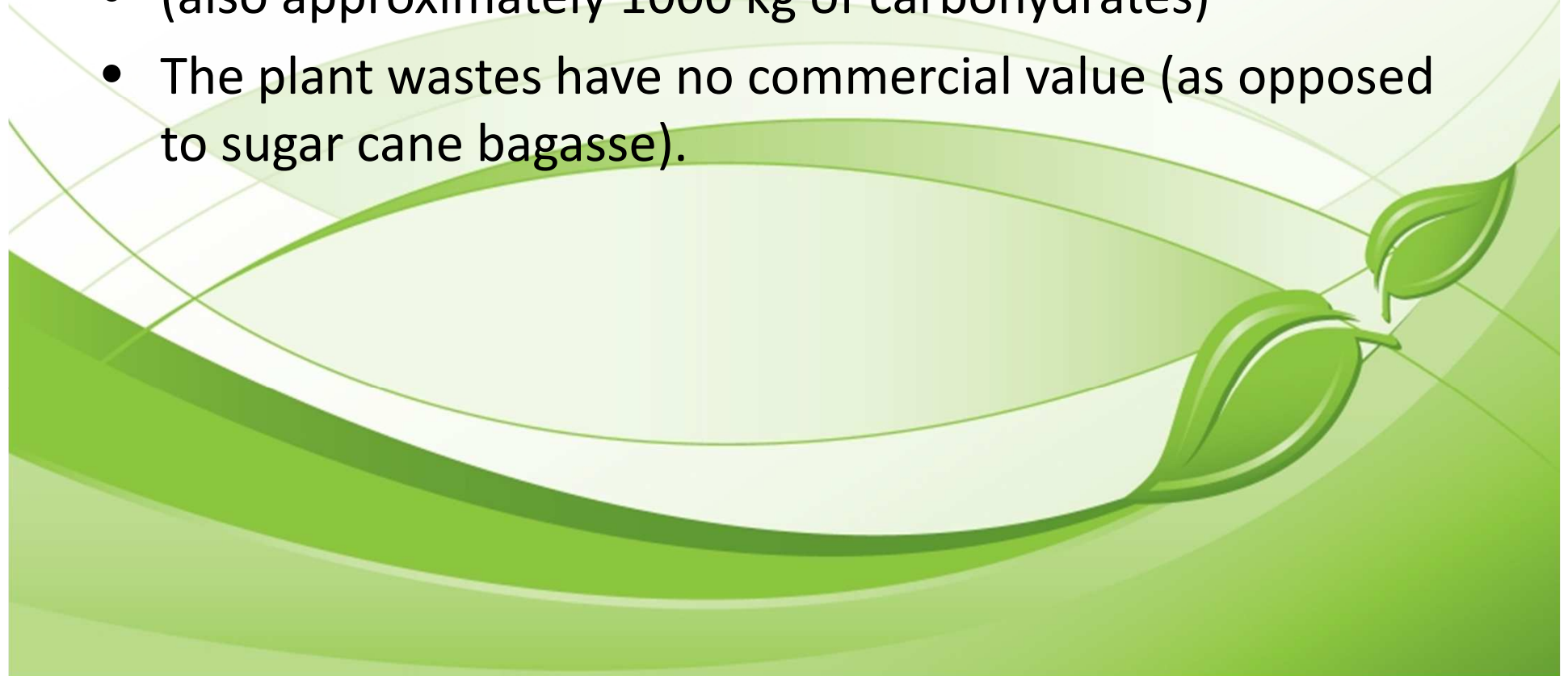


- You have 1 kg of corn:
- You can use it to give food to a family for 1 day or go with a car 3 to 4 km?
- You can produce ca. 5000 kg of corn per ha and per year.
- This corresponds to approximately 2000 L of ethanol.
- You need ca. 500 L of petroleum to harvest and process the corn.
- Is this really an efficient way of using fertile soil to produce biofuels?

- Brazil produces enough sugar to satisfy both the food market and the ethanol fuel market.
- Sugar cane is more efficient: 8000 L of ethanol per ha and per year.
- You need ca 500 L of petroleum to harvest and produce the sugar.
- However, you don't need any fertilizer and the net energy outcome is approximately 85% compared to 30% for corn.



- Soy beans are even worse than corn: only 500 L of oil per ha and per year.
- However, soy beans yield approximately 1000 kg of proteins per ha and per year.
- (also approximately 1000 kg of carbohydrates)
- The plant wastes have no commercial value (as opposed to sugar cane bagasse).

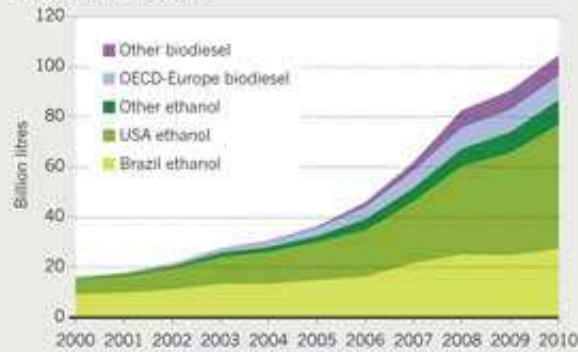


- Palm oil (dendê) has a much higher productivity (5000 L per ha and per year).
- The palm tree is not cut and no fertilizers are necessary.
- However, large devastation of native forests to plant palm trees occurs, mostly in Indonesia and Malaysia.
- Other kinds of palm and coconut trees (babaçu, buriti, etc.) produce more oil than soy beans.

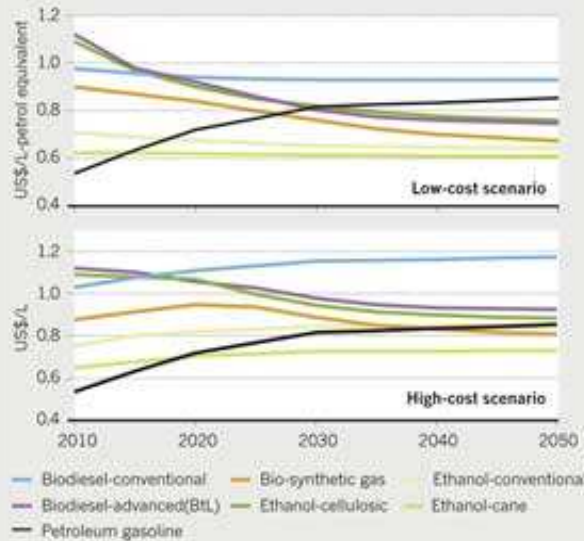
# THE RISE OF BIOFUELS

Biofuel production now tops 100 billion litres per year. Different fuel types vary in their costs, carbon emissions and impact on land use.

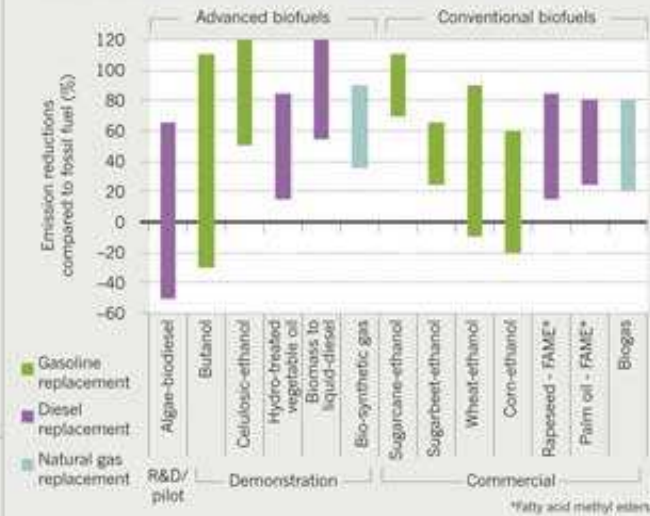
## GLOBAL BIOFUEL PRODUCTION



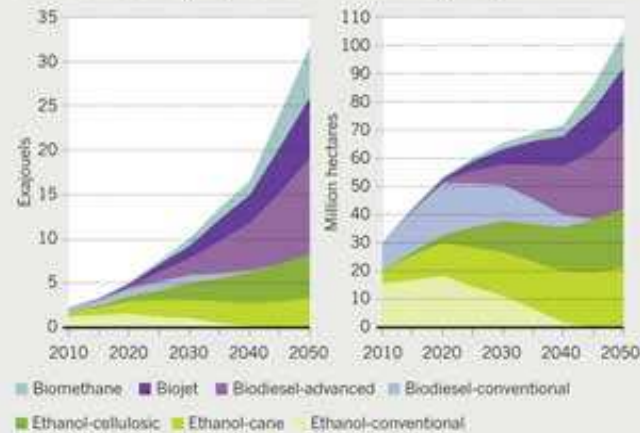
## COSTS OF VARIOUS BIOFUELS COMPARED TO PETROL (GASOLINE)



## LIFE-CYCLE GREENHOUSE-GAS EMISSIONS OF CONVENTIONAL AND ADVANCED BIOFUELS

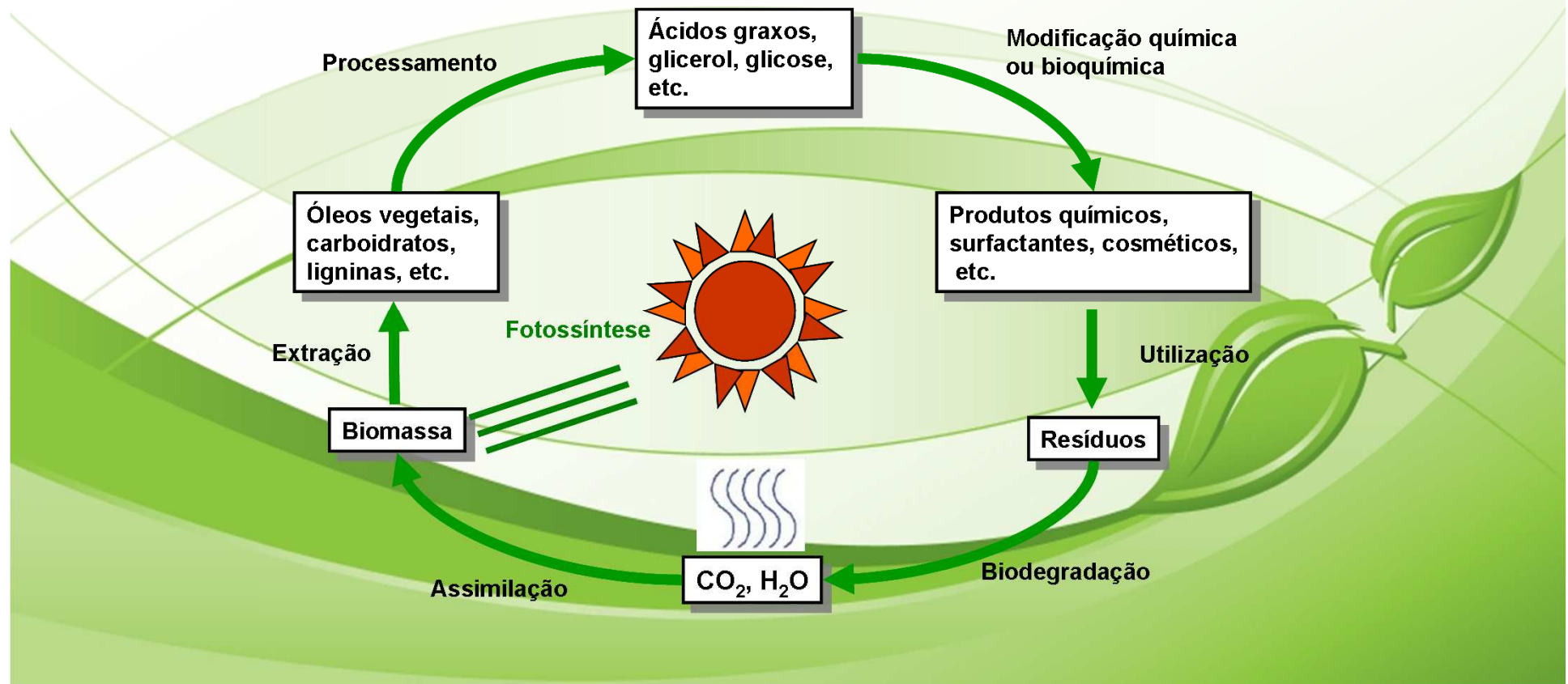


## DEMAND FOR BIOFUELS (LEFT) AND RESULTING LAND DEMAND (RIGHT)



# Sustainability

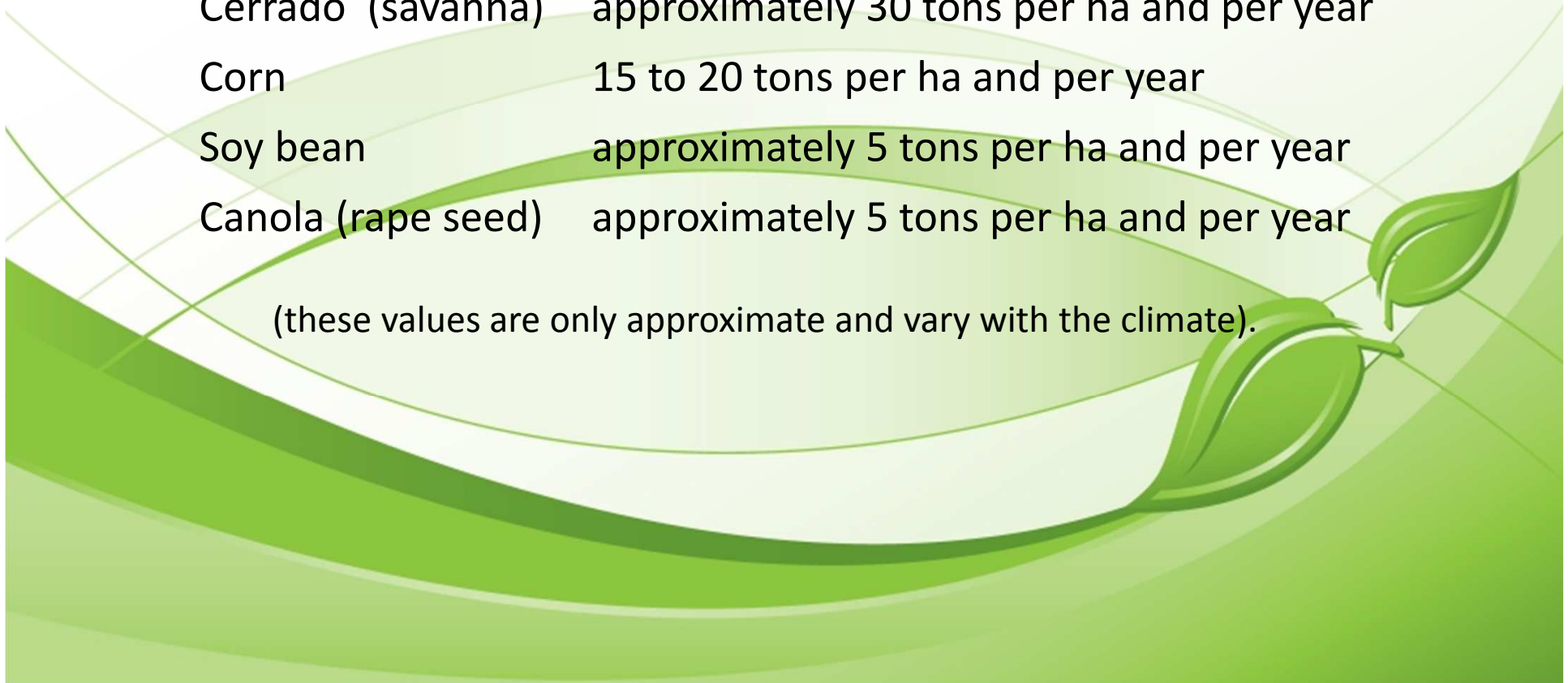
- A high production of biomass (which means a high assimilation of  $\text{CO}_2$  from the atmosphere) is necessary to make biofuel production sustainable.



# Biomass Production

Switch grass	up to 120 tons per ha and per year
Sugar cane	approximately 80 tons per ha and per year
Rain forest	approximately 60 tons per ha and per year
Cerrado (savanna)	approximately 30 tons per ha and per year
Corn	15 to 20 tons per ha and per year
Soy bean	approximately 5 tons per ha and per year
Canola (rape seed)	approximately 5 tons per ha and per year

(these values are only approximate and vary with the climate).

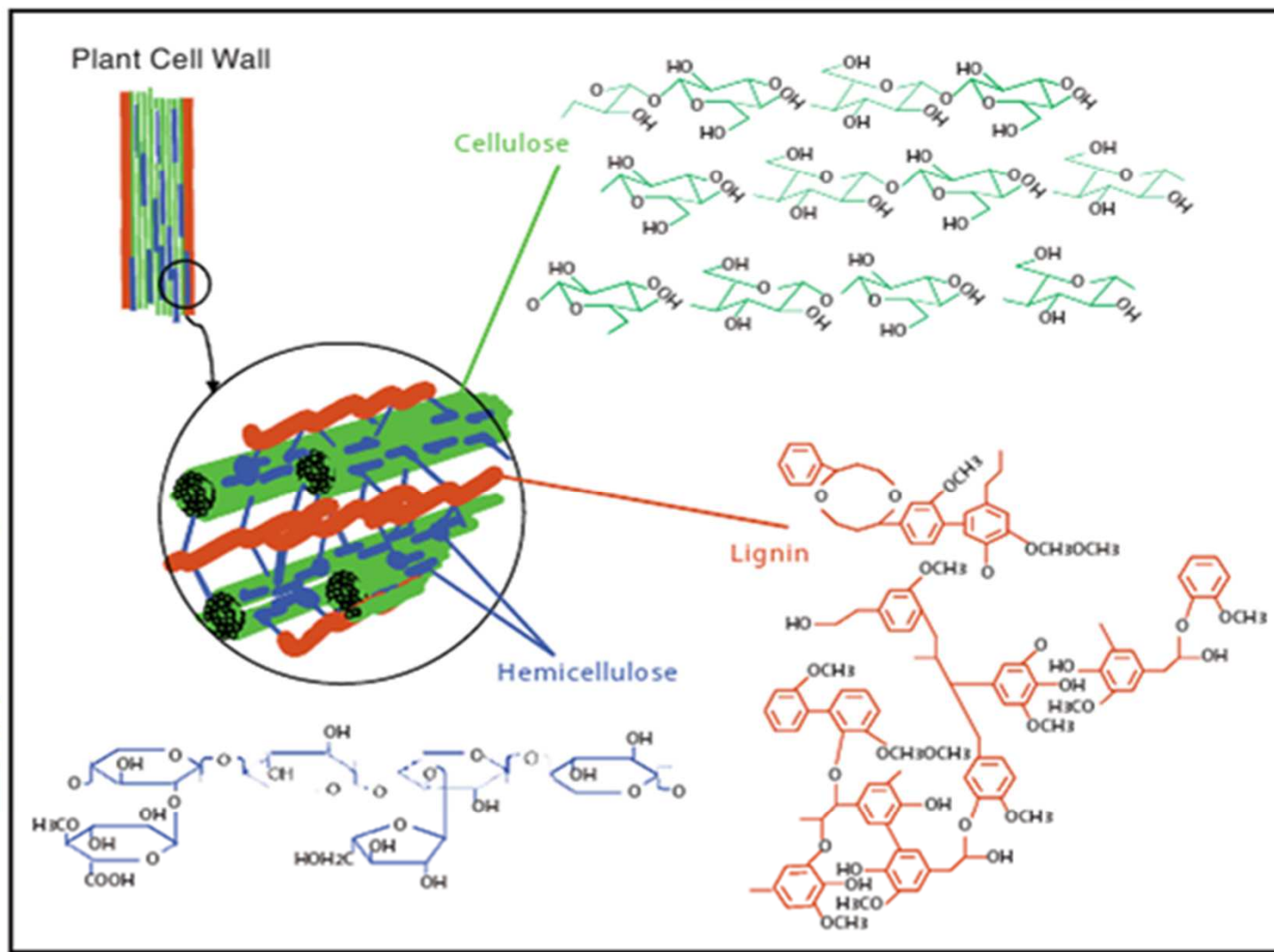


## Conclusions on First Generation Biofuels

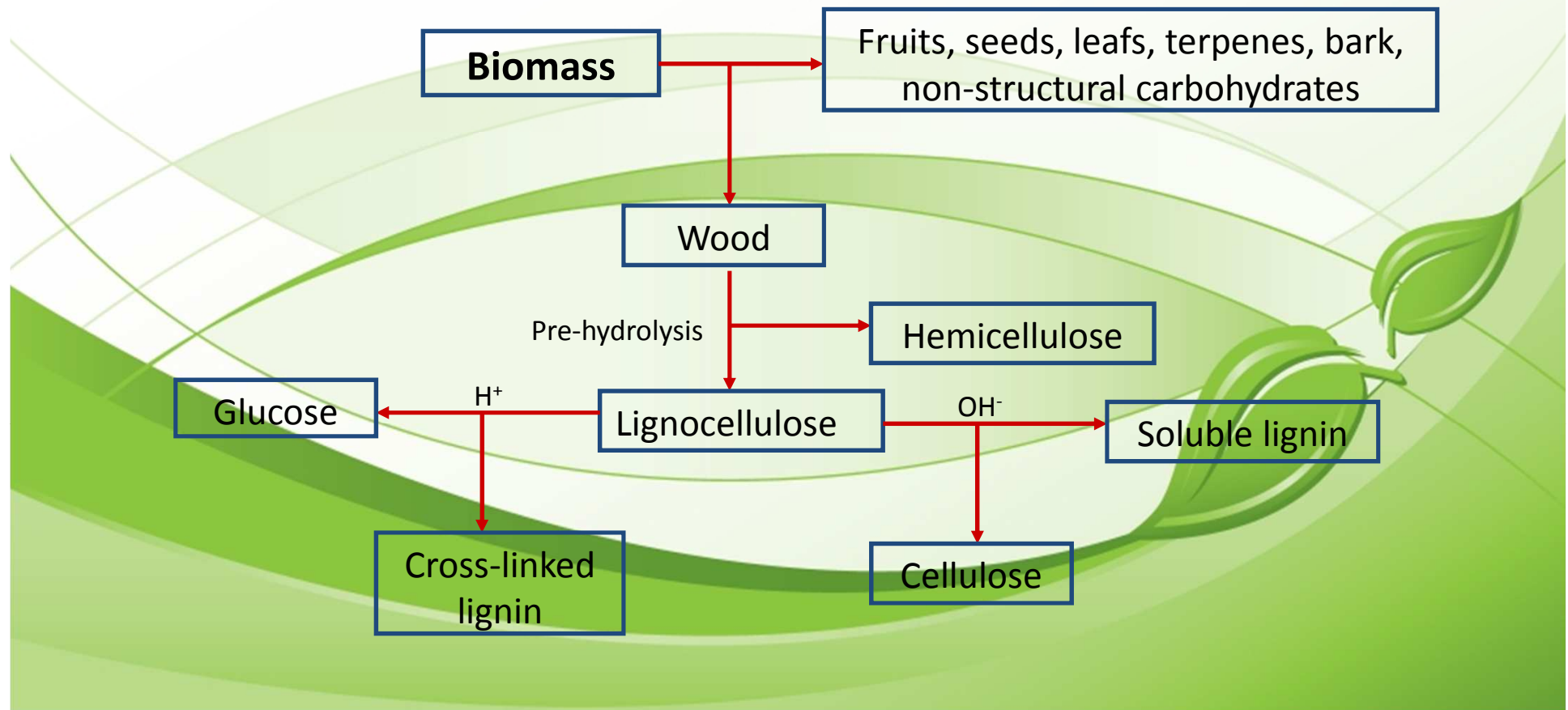
- Only ethanol from sugar cane is economically and environmentally correct.
- All other ethanol production - from sugar or starch - is not efficient and occupy fertile soil.
- Biodiesel production from palm oil is potentially interesting.
- However, no rain forests should be cut down; only land that has no other destination.
- All other crops produce little oil and not enough biomass to be sustainable.
- Furthermore, they need fertilizers and occupy fertile soil.

## Second Generation Biofuels

- In the literature different definitions of second and third generation biofuels are found.
- In this talk, all biofuels obtained from any kind of not-edible biomass are treated as second generation biofuels.
- Agricultural and wood residues consist of 40 to 50% cellulose, 25 to 30% hemicelluloses and 20 to 30 % lignin.

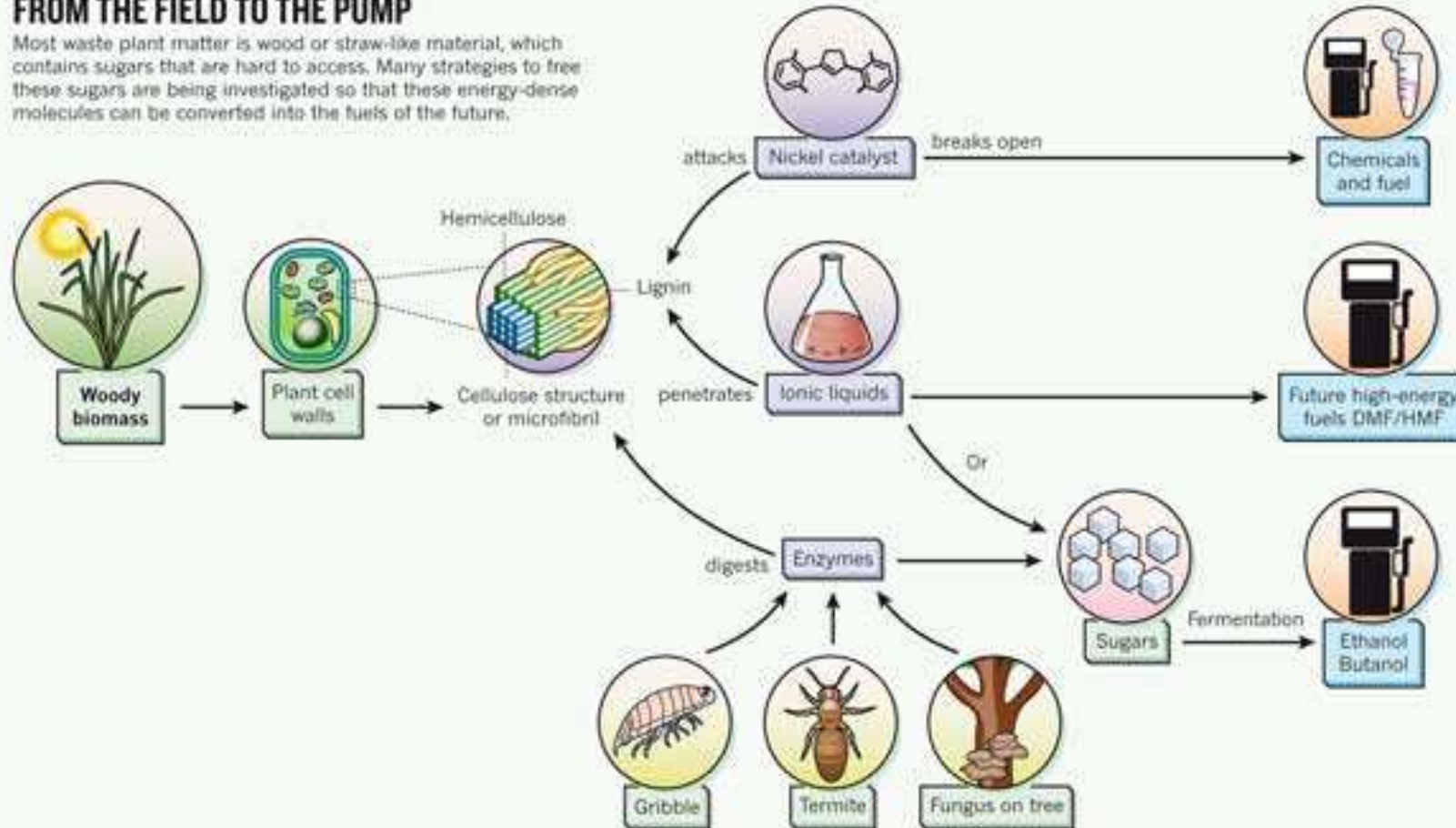


- They are very abundant and could easily substitute for all kinds of liquid and solid fuels.
- However, their separation and transformation into liquid fuels is difficult and up to now not economically viable.

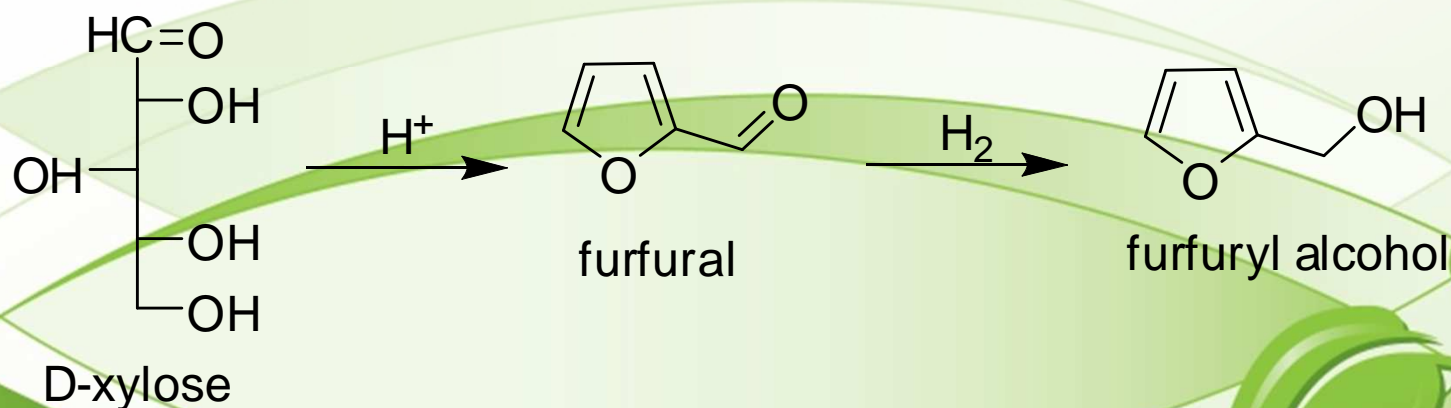


## FROM THE FIELD TO THE PUMP

Most waste plant matter is wood or straw-like material, which contains sugars that are hard to access. Many strategies to free these sugars are being investigated so that these energy-dense molecules can be converted into the fuels of the future.

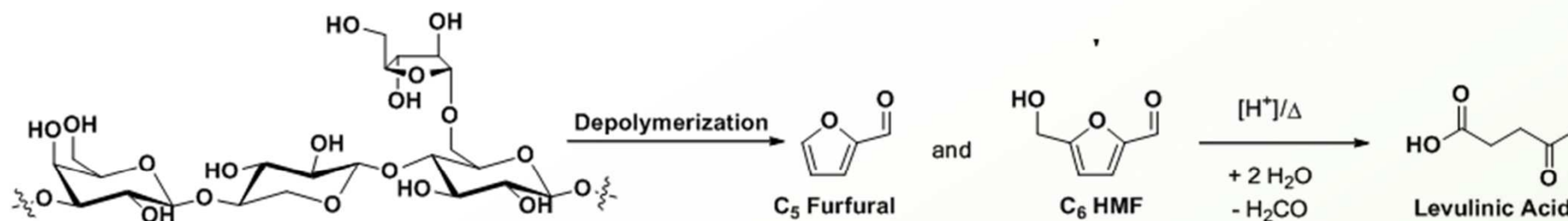


- Hemicelluloses can be easily separated from the biomass by acid hydrolysis or steam explosion.
- Hemicelluloses are mainly composed of xylose which can be fermented to ethanol or dehydrated to furfural, a valuable chemical feedstock.

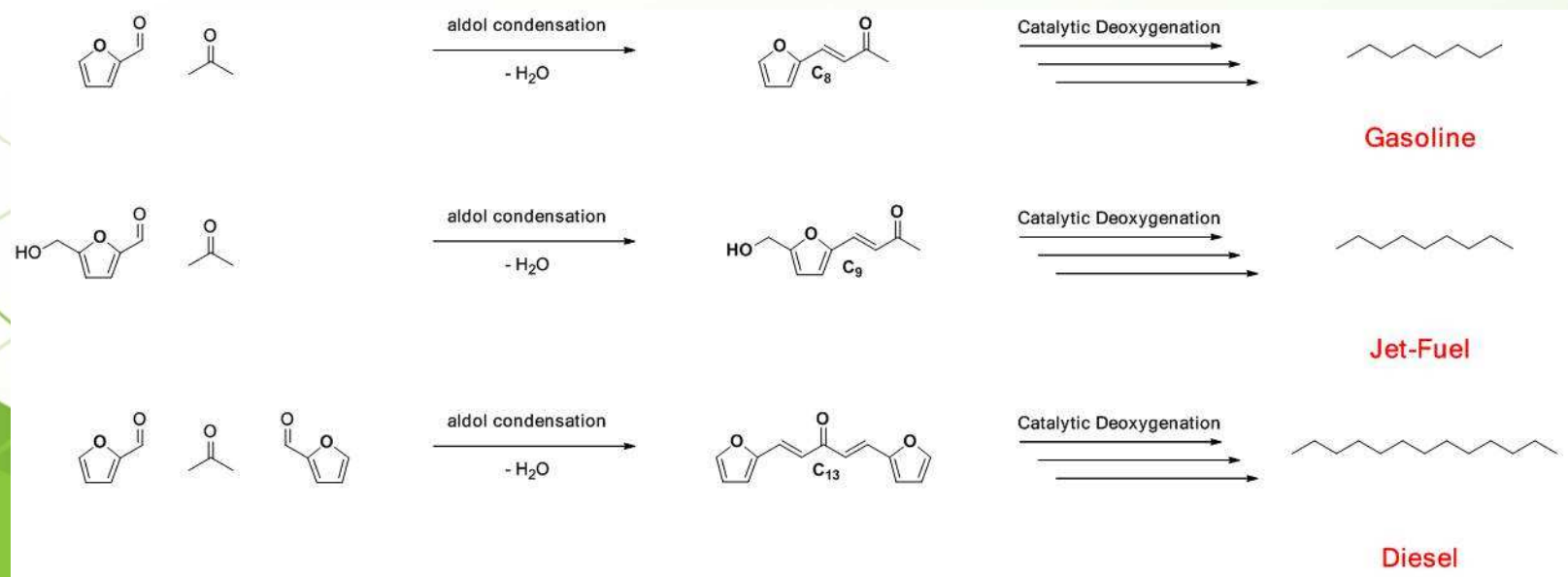


- Separation of cellulose and lignin is difficult. Cellulose is mostly crystalline, insoluble in most solvents and chemically bonded to lignin.
- The strong hydrogen bonds between the beta-D-glucose polymeric chains of cellulose can be broken under drastic conditions or by ionic liquids, and the amorphous cellulose hydrolyzed to glucose.
- However this is costly and energy intensive and can form by-products which make posterior fermentation more difficult.

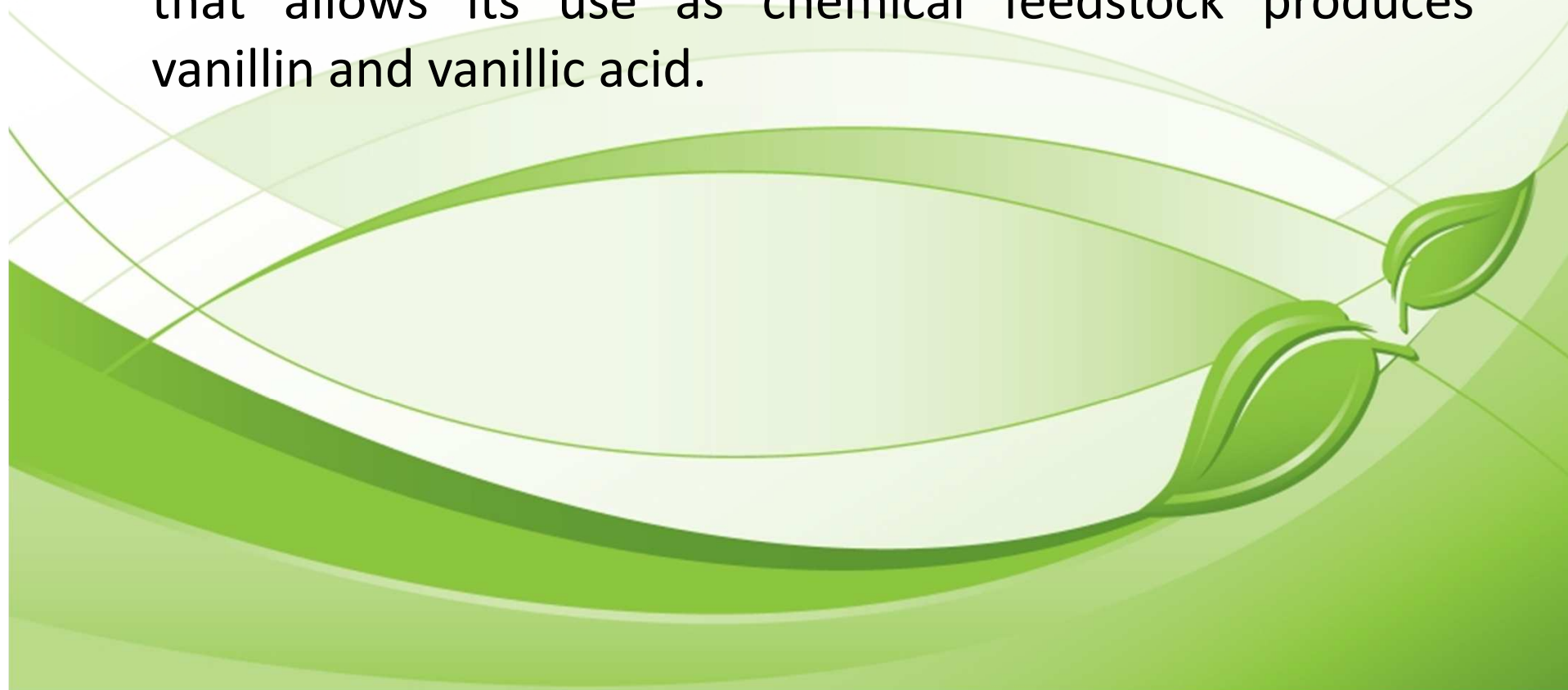
- Enzymatic hydrolysis of cellulose requires the removal of the hemicelluloses and at least part of the lignin.
- This is slow and very expensive as commercial cellulase is only produced by Novozymes for an uneconomically high price.
- Iogen, one of the leaders of enzymatic hydrolysis of cellulose, has not accepted a credit of 500 million dollars from the Canadian government, as they cannot guarantee commercial production of glucose from cellulose within the next 5 to 10 years.
- Acid hydrolysis by strong acids gives good yields of glucose; however, the recycling of the acids is very problematic.
- Acid hydrolysis by dilute acids needs drastic conditions (180 to 220 °C), which form large amounts of byproducts.

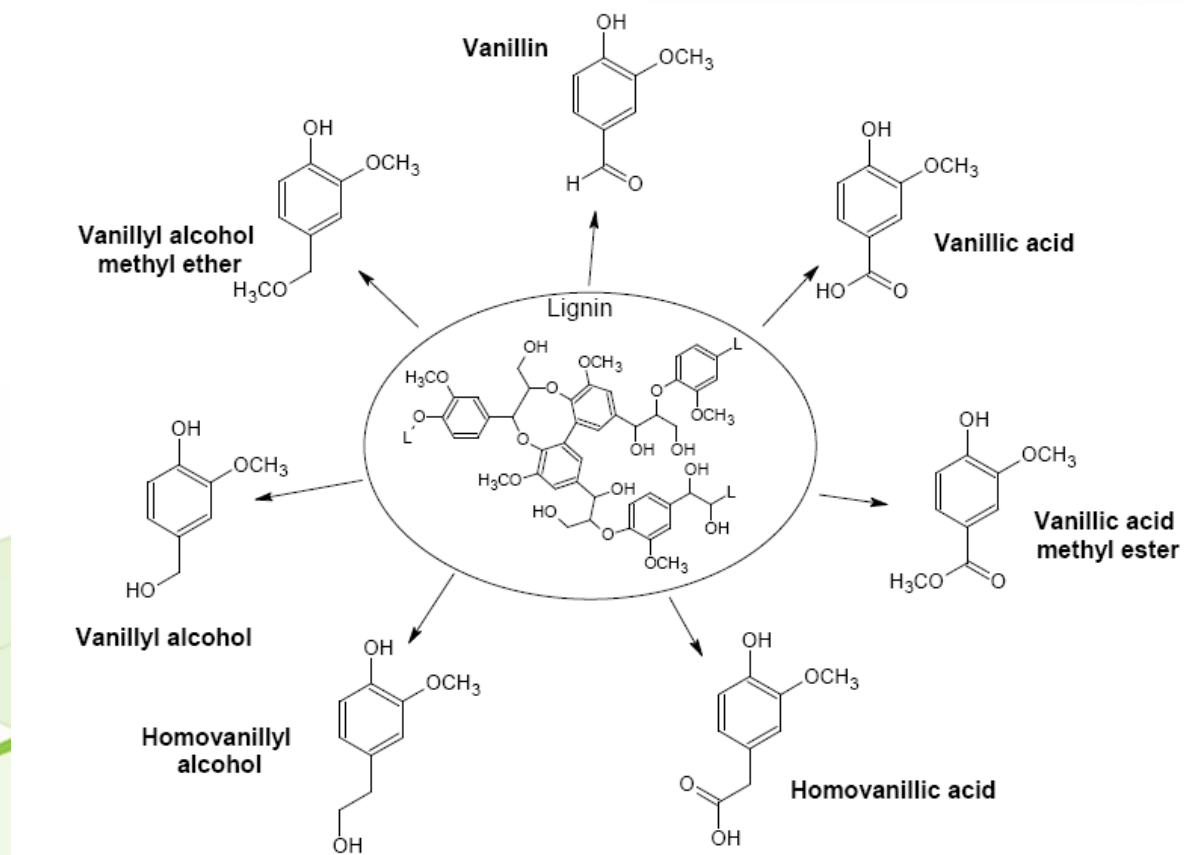


(Hemi)cellulose; C<sub>5</sub> and C<sub>6</sub> Sugars



- Lignin is a valuable feedstock for phenols that can be used as a component in thermoplastics.
- Lignin is obtained in large amounts in pulping processes and is mostly burned, as the only commercial process that allows its use as chemical feedstock produces vanillin and vanillic acid.





On the other hand, lignin may be transformed into liquid fuels by hydrogenation and hydrogenolysis (an area of intensive research).

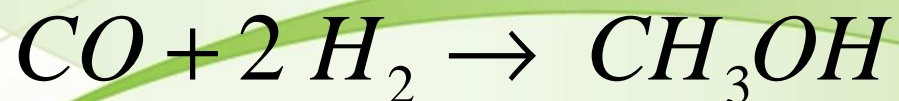
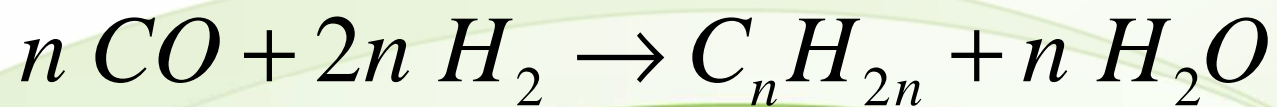
- In order to avoid separation of the different components, biomass as a total may also be gasified or pyrolyzed.

- Gasification with air produces a gas of low calorific value, which can be used for the production of steam or electricity, and was used in vehicle engines during the Second World War.



**German WW II retro-fitted  
“Holzvergaser”**

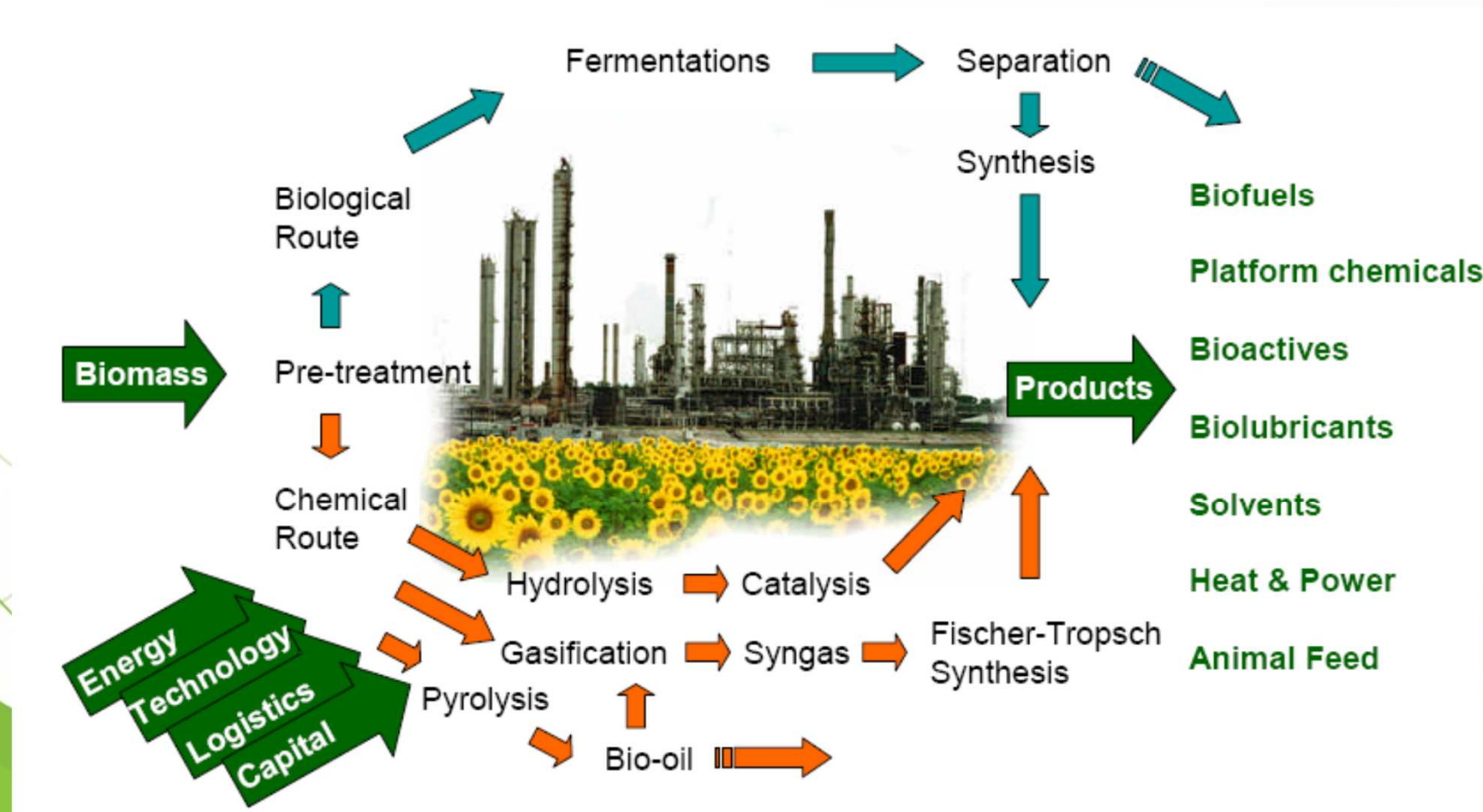
Gasification with oxygen produces synthesis gas (CO+H<sub>2</sub>) which may be used for Fischer-Tropsch synthesis to form hydrocarbons, or for methanol synthesis (and for other chemicals).



- Fast pyrolysis of biomass in a moving or fluidized bed is a very interesting alternative. Biooil (ca. 50%), Biochar (ca. 35%) and low energy gas (ca. 15%) are produced, the latter being used to maintain the process.
- This process is being considered most favorable by many laboratories throughout the world.
- Biooil needs upgrading to reduce its oxygen content and make it thermally stable for transport and use.
- Biochar is an active carbon source with high surface area which can be used as fertilizer or as a substitute for active carbon in purification and as a catalyst support.

## Second Generation Biofuels

- Personally, I don't think that separation of the components followed by enzymatic hydrolysis of cellulose will become commercial in a short or medium period of time.
- Gasification is much easier and, using methanol as platform, many important chemicals and liquid fuels can be produced.
- I believe that fast pyrolysis is the most promising method as it produces biooil in good yield, which is not too difficult to upgrade, and biochar, which is a valuable source of active carbon with many applications.



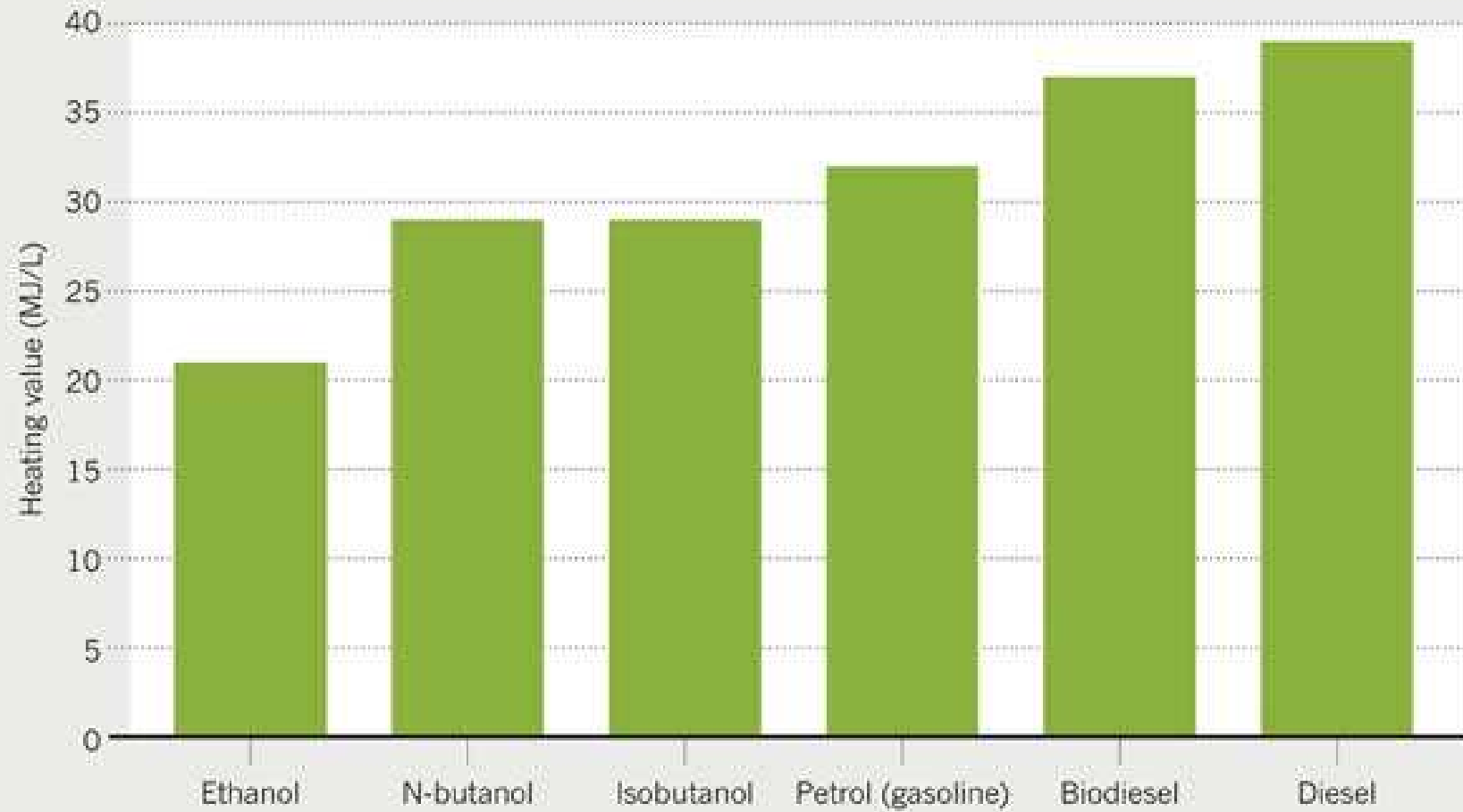
- Different chemicals and fuels can be obtained from glucose, using genetically engineered enzymes:

Diterpenes (diesel substitute)	Amyris
1,4-butanediol (polymers)	Genomatica
Adipic acid (polymers)	Hydrocarbon Research
Butanol (gasoline substitute)	DuPont/BP
6-aminocaproic acid (polymers)	Genomatica
1,3-propanediol (from glycerin)	DuPont

- However, scale-up is very difficult (see problems of DuPont and Hoechst) and large scale production needs several years of development. Such processes will only be really successful if cellulose could be used as feedstock for enzymes.

## PACKING HEAT

Biofuels vary in their energy density, but they all fall short of their petroleum-derived models.



## Second Generation Biodiesel

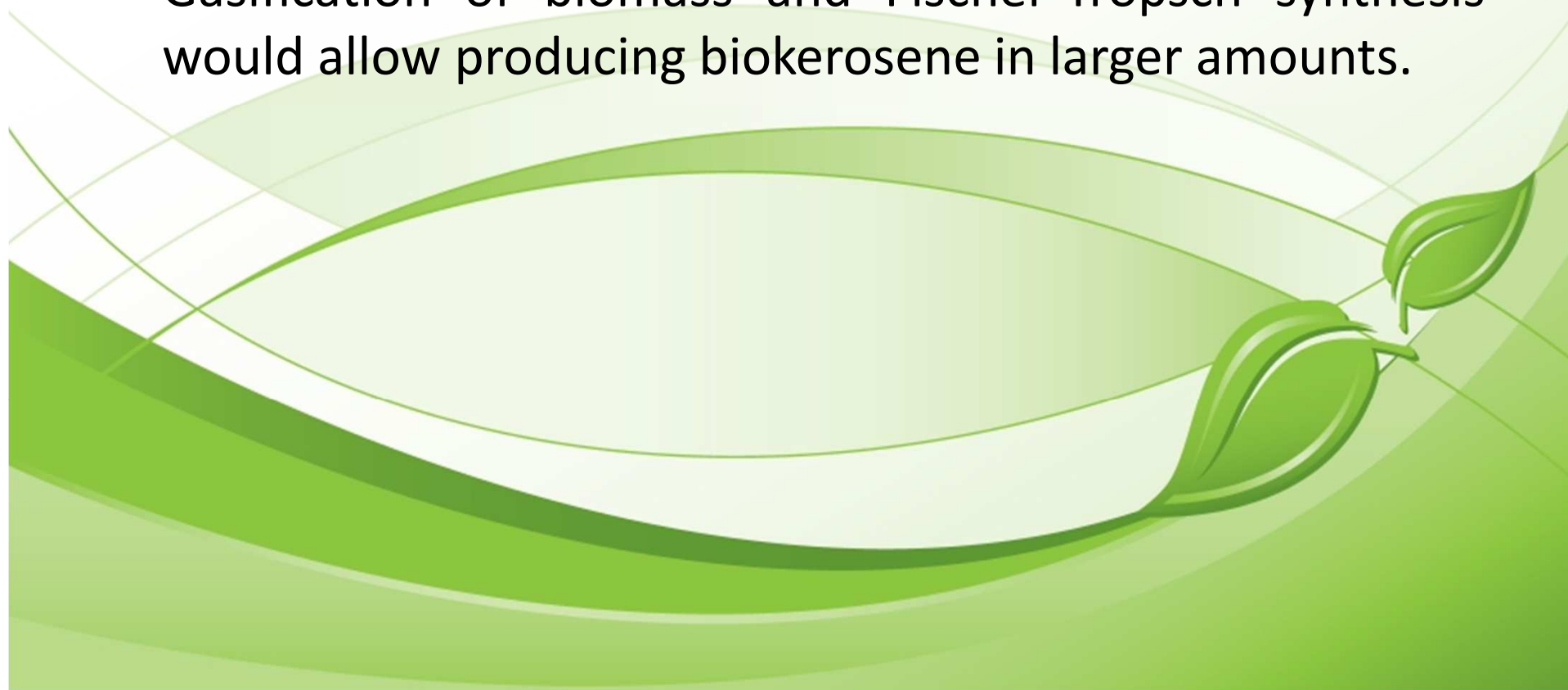
- Some second generation biodiesel is already produced by transesterification of animal fats, used vegetable oils, oily components of sewage, tall oil, etc.
- This production is important for environmental reasons; however, the quantity available is small.
- Presently more than 90% is first generation biodiesel, produced in Brazil from soy bean oil, which should be reduced as its productivity (in L per ha and per year) is very low.

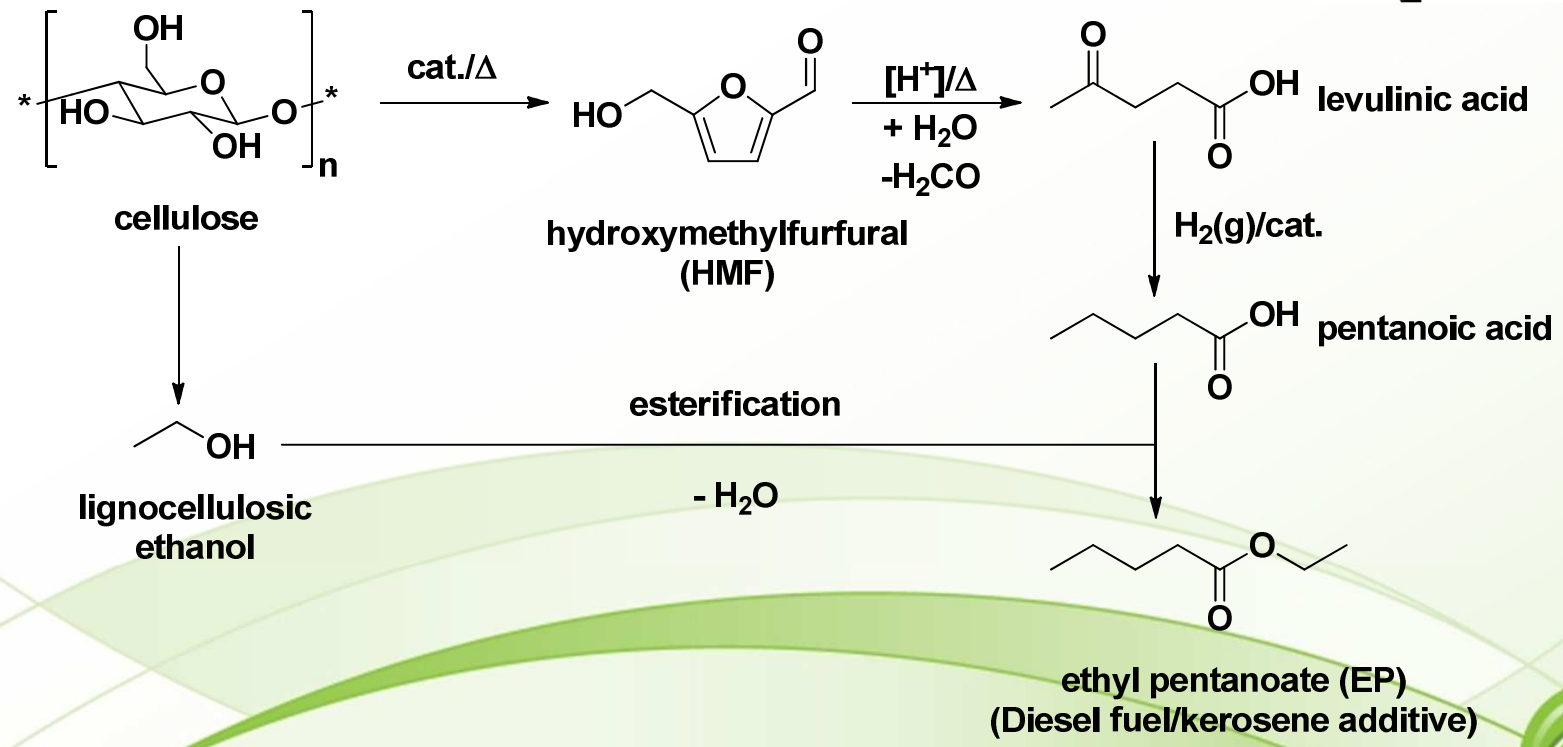
- Ricinus oil (mamona) is not appropriate because it is used in industry for polyurethane production and has a much higher value than other oils.
- Jatropha (pinhão manso) needs more water and a more fertile soil than predicted and is not growing as well in Brazil as it is in India.
- Only palm oil (dendê, babaçu) can be obtained in quantities which would allow a continuous production of biodiesel without harming the production of food.

- Biodiesel from algae oil seems to be promising, as up to 150.000 kg of oil per ha and per year are reported, however, no large scale production has been successful up to now.
- Contamination of the algae seems to be the biggest problem. Furthermore, the algae have to be ground in order to extract the oil, which is rather inefficient.
- Costs of oil from microalgae are, therefore, very high and it is not expected that they will become competitive in the next 10 years.



- Biokerosene must have a low freezing point which is not found for conventional biodiesel which uses no additives. Methyl esters of short-chain (8 to 12 C) fatty acids are suitable; however, the production of these esters is low.
- Gasification of biomass and Fischer-Tropsch synthesis would allow producing biokerosene in larger amounts.





## Other Chemicals from Biomass

- It is certainly possible to substitute (at least partially) petroleum as feedstock in the chemical industry.
- Some chemical products are more easily obtained from biomass or vegetable oils than from petroleum, as the former are already functionalized.
- Biorefineries could be built or are already partially in use; however this is not a topic for this talk.

## Conclusions

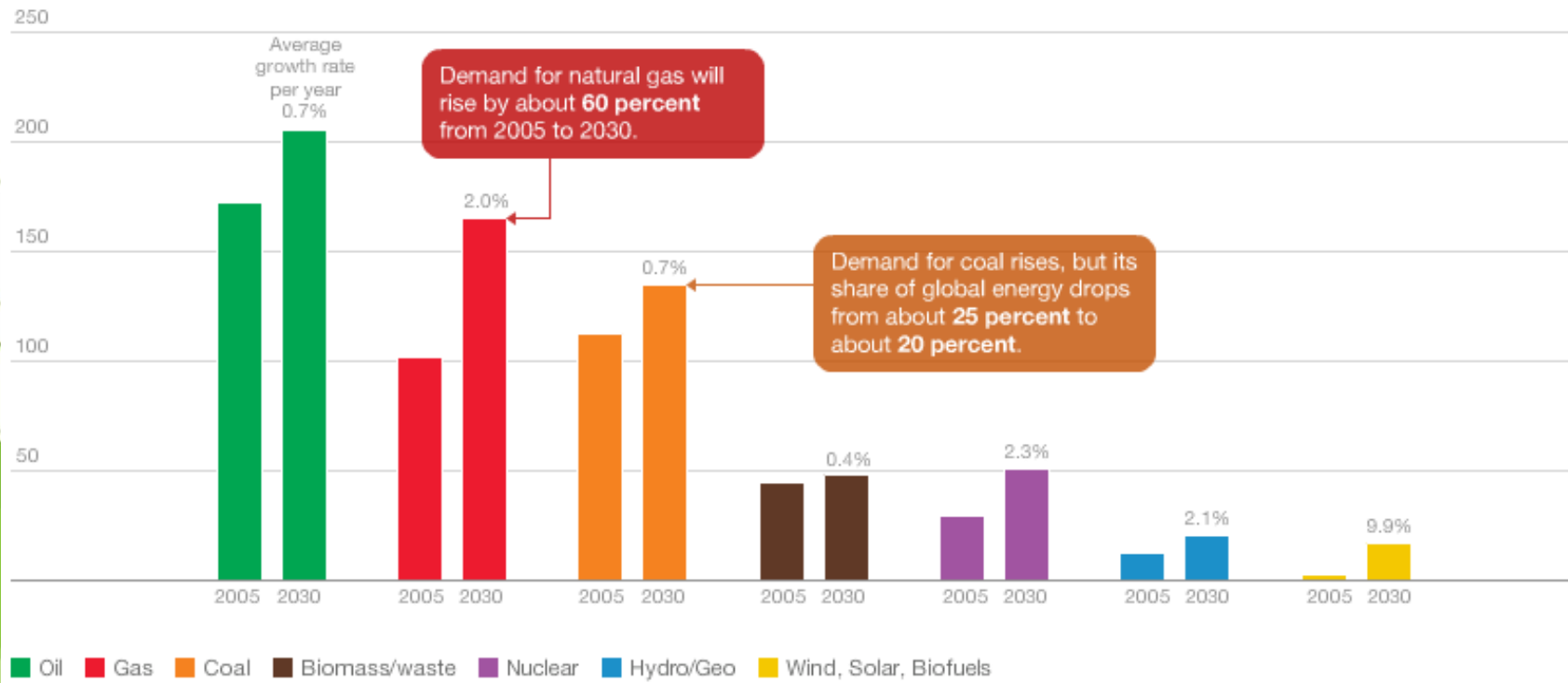
- Only sugar cane is an economical and environmentally friendly source of ethanol.
- Second generation ethanol from cellulose will need at least another 10 years to become economically feasible.
- Substitution of diesel by biodiesel will be limited as the productivity of oil from plants is small.
- Soy bean and canola oil should not be used for biodiesel and palm oil should be obtained without cutting down rainforests.
- Oil from microalgae may become an important substitute for diesel; however, at least 10 years will be necessary to overcome the present difficulties.
- To my opinion biofuels will compliment petroleum fuels, but will never be able to substitute them totally.



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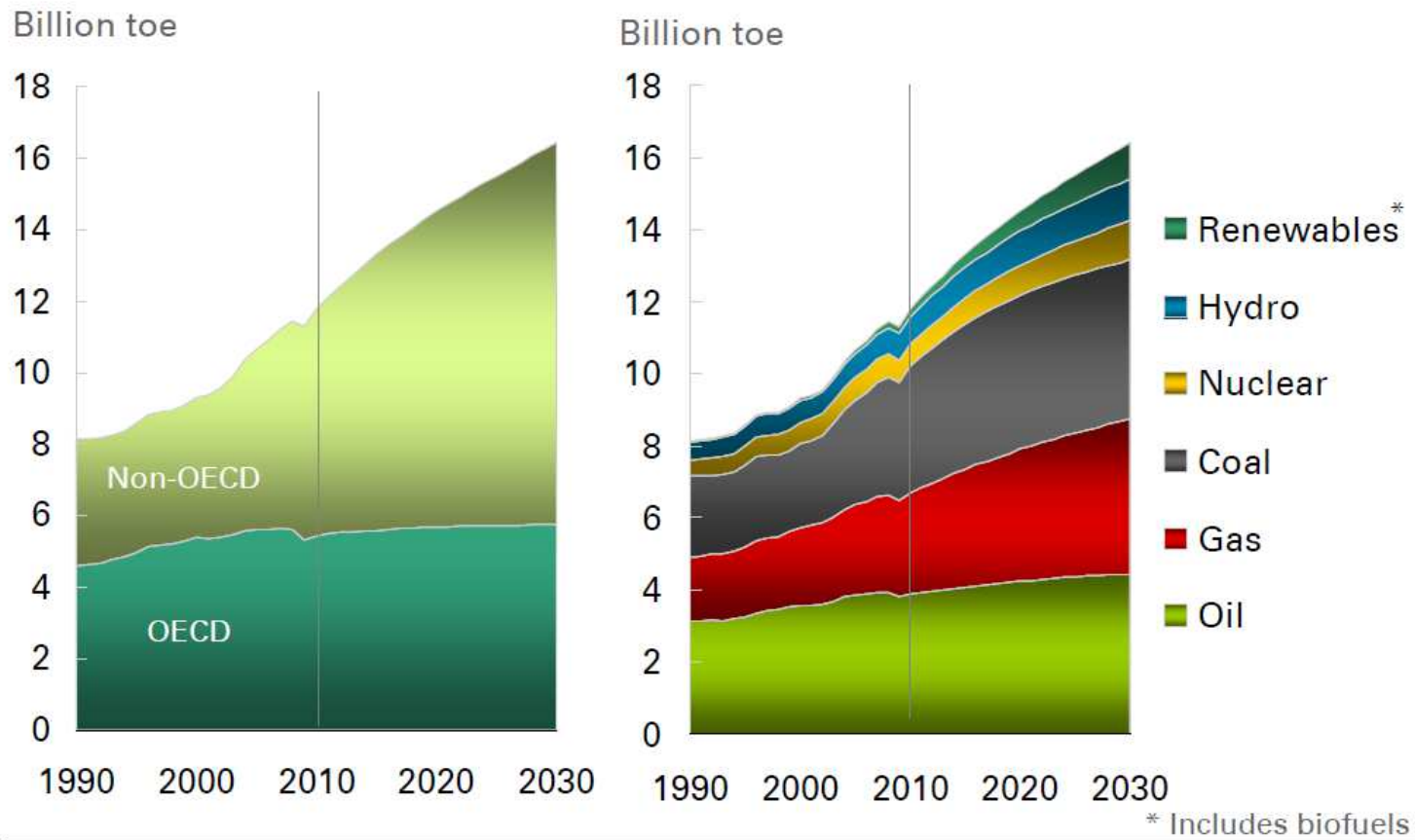
### Global demand by fuel

Quadrillion BTUs





## Non-OECD economies drive consumption growth...



- According to most published information, biofuels can totally substitute petroleum products and second generation biofuels are ready to come onto the market.

**THIS IS NOT TRUE!**

- As the industry is showing, there is no immediate solution available for cellulose hydrolysis to ethanol or for obtaining biodiesel from algae oil.
- Be very careful in believing what is being published on the preparation of biofuels.

**MOST RESULTS ARE OF NO PRACTICAL USE!**



My personal conclusion:

**BULLSHIT IS THE  
ULTIMATE RENEWABLE  
SOURCE.**