PERENNIAL GRASSES IN BIOBASED ECONOMY

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According to 4FCROPS (www.4fcrops.eu) energy crops categorized:

Oil crops (sunflower, rapeseed, Ethiopian mustard, etc.)

Fibre crops (kenaf, flax, hemp, cotton, etc.)

Lignocellulosic crops (giant reed, switchgrass, miscanthus, cardoon, reed canary grass, etc.)

Short rotation forestry (eucalyptus, poplar, willow, etc.)

Sugar crops (sweet sorghum, sugar beets, etc.)

Energy crops should have:

- High yields (biomass yields, oil yields, sugar yields)
- Low production cost (low inputs for water and fertilizers, etc.)
- Environmental friendly way of cultivation
- The ability to be cultivated in low fertility agricultural areas and/or marginal land with satisfactory yields in order to avoid the competition with food

Perennial grasses considered ideal energy crops

Which are the *main driving forces* for the cultivation of *energy crops*?

- The growing need for **starch** and **sugar** plant species as source for **bioethanol production**
- The growing need for **biodiesel**, **aviation biofuels** and **biochemicals** from **oil crops**
- The growing need for **solid biomass** to obtain **heat and electricity**, either directly through combustion or indirectly through conversion for use as fuels. **Lignocellulosic-rich raw materials** can used to produce fuel like **methanol**, **biodiesel**, **synthetic gas**, and **hydrogen** (using thermal and thermochemical processes by direct or indirect liquefaction or gasification) and **ethanol** (through hydrolysis and subsequent fermentation)
- To produce **biogas** from energy/biomass crops

Research on perennial grasses in EU

For more than two decades three perennial grasses are being investigated in the Mediterranean region, namely **miscanthus**, **switchgrass** and **giant reed.**

Currently, in the framework of the three EU projects **OPTIMA** (www.optimafp7.eu), **OPTIMISC** (https://optimisc.uni-hohenheim.de/92416) and **GRASS MARGINS** (www.grassmargins.com) perennial grasses are being investigated (2011-2016) with emphasis on breeding, Eco physiology, crop management, economic and environmental analysis as well as the end uses.

Main advantages of the perennial grasses

their high yield potential

the high contents of lignin, cellulose and hemicellulose polysaccharides

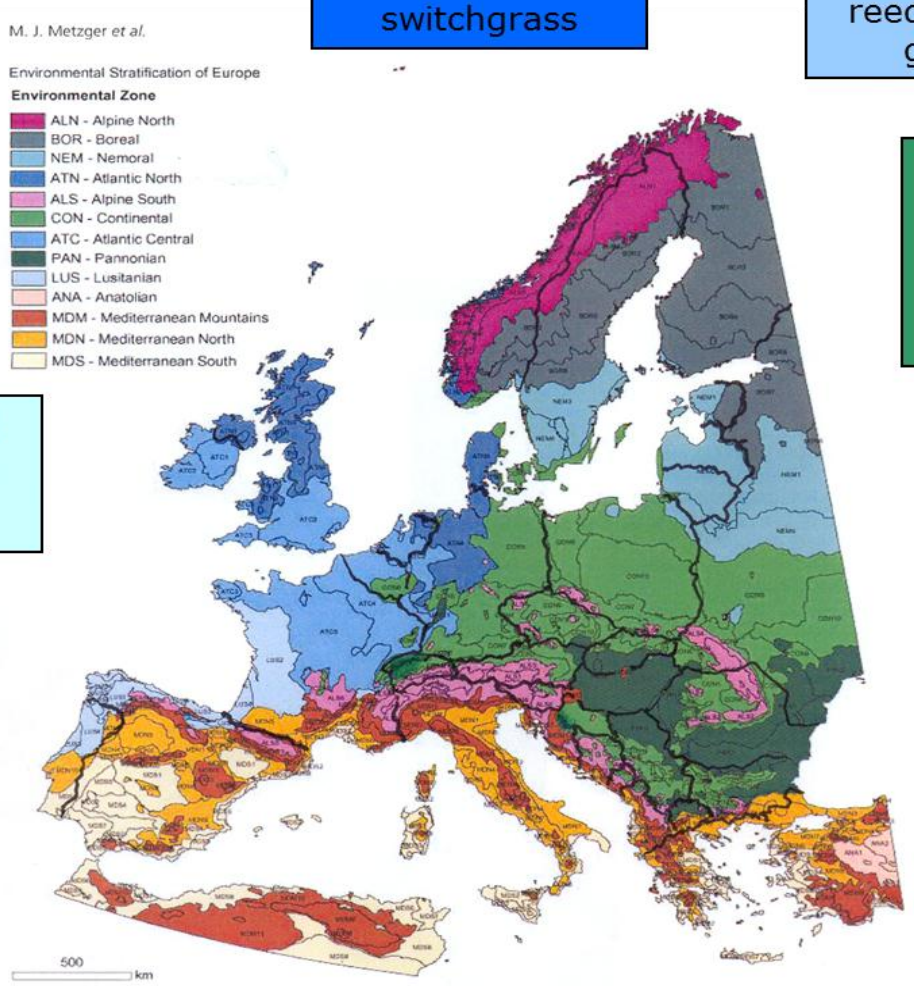
their positive social and environmental benefits

can be grown on marginal or degraded lands

Agronomic details for six perennial grasses that have been studied in Europe

	Reed canary grass	Switchgrass	Miscanthus	Giant reed	Cardoon	Harding grass
Area of origin	Europe	North America	South East Asia	Asia and Mediterranean	Mediterranean	Mediterranean
Available genetic resource	Many variables available	Many variables available	Many variables available	Wild genetic base	Wild genetic base	Wild genetic base
Photosynthesis system	C3	C4	C4	C3	C3	C3
Yield (t ha-1)	4 - 15	10 - 25	10 - 30	15-35	10 - 22	5-10
Raw material characteristic	Lignocellulosic biomass	Lignocellulosic biomass	Lignocellulosic biomass	Lignocellulosic biomass	Lignocellulosic biomass/Oil seed	Lignocellulosic biomass
Adaption range in EU	Cold and wet regions of EU	Cold and warm regions of EU	Cold and warm regions of EU	Warm region of southernEU	Mediterranean regions	Cold and warm regions of EU
Rotation time	10 – 15 yrs	15 yrs	15 – 20 yrs	15 – 20 yrs	4 – 5 yrs	10-15
Establishment	seed	seed	Rhizomes	Rhizomes or stem cuttings	seed	seed
Harvest time	Autumn/early spring	Autumn/early spring	Autumn/early spring	Autumn/early spring	Summer	Summer
Required machinery	Normal farm equipments	Normal farm equipments	Special farm equipments	Special farm equipments	Special farm equipments	Normal farm equipments
Fertilizers input (kg ha-1 N):	50 - 140	0 - 70	0 - 100	50 - 100	50 - 100	50 - 140
Pesticide and herbicides	First year and post-harvest	First year and post-harvest	First year and post-harvest	First year and post-harvest	First year and post-harvest	First year and post-harvest

Geographical distribution for five perennial grasses in Europe (www.4fcrops.eu)



Atlantic north: Miscanthus and switchgrass

Nemoral: reed canary grass

Continental: miscanthus, reed canary grass, switchgrass

Lusitanian: miscanthus, switchgrass

Atlantic central: Miscanthus and switchgrass

Mediterranean north: miscanthus, giant reed, switchgrass

Mediterranean south: Giant reed, cardoon, switchgrass

Giant reed and Miscanthus: two very important perennial grasses established by rhizomes (and/or stem cuttings, plantlets)

Giant reed

- Giant reed is appropriate for two climatic zones; the Mediterranean north and south.
- In Europe yields from 7 to 61 t/ha have been reported. Its realistic dry yields varied from 20-30 t/ha.
- The gross calorific value of its dry biomass is 4200 kcal/kg with ash content between 4 and 5%.
- High establishment cost.

Miscanthus

- Miscanthus is appropriate for the whole Europe apart from the Nemoral climatic area (*due to low temperatures in winte*r) and Mediterranean south area (due to its relatively higher needs for water).
- It is cultivated in a total area of 4,500 ha and its yields ranged from 10 to 30 t/ha dry yields.
- It's the one with the highest research efforts.

Switchgrass and cardoon: perennial crops established by seeds

Switchgrass

- Switchgrass can be cultivated successfully in most climatic areas of Europe (due to lowland and upland varieties).
- It is reported yields up to 20 t/ha for switchgrass grown in southern EU (www.switchgrass.nl) in the second and the third growing period (15-20 years lifetime).
- Its research started from USA.

Cardoon

- It is considered as a bioenergy crop with many used uses such as for solid biofuels, for oil production, etc.
- It is a crop with low water requirements and is considered suitable to drought conditions of semi-arid Mediterranean environments.
- The dry matter yields that can be expected could be up to 14 t/ha, while the seed yields could be 1.2 t/ha (25% oil content in the seeds).

Reed canary grass and Phalaris aquatica; the first for the north and the second for the south of Europe

Reed canary grass

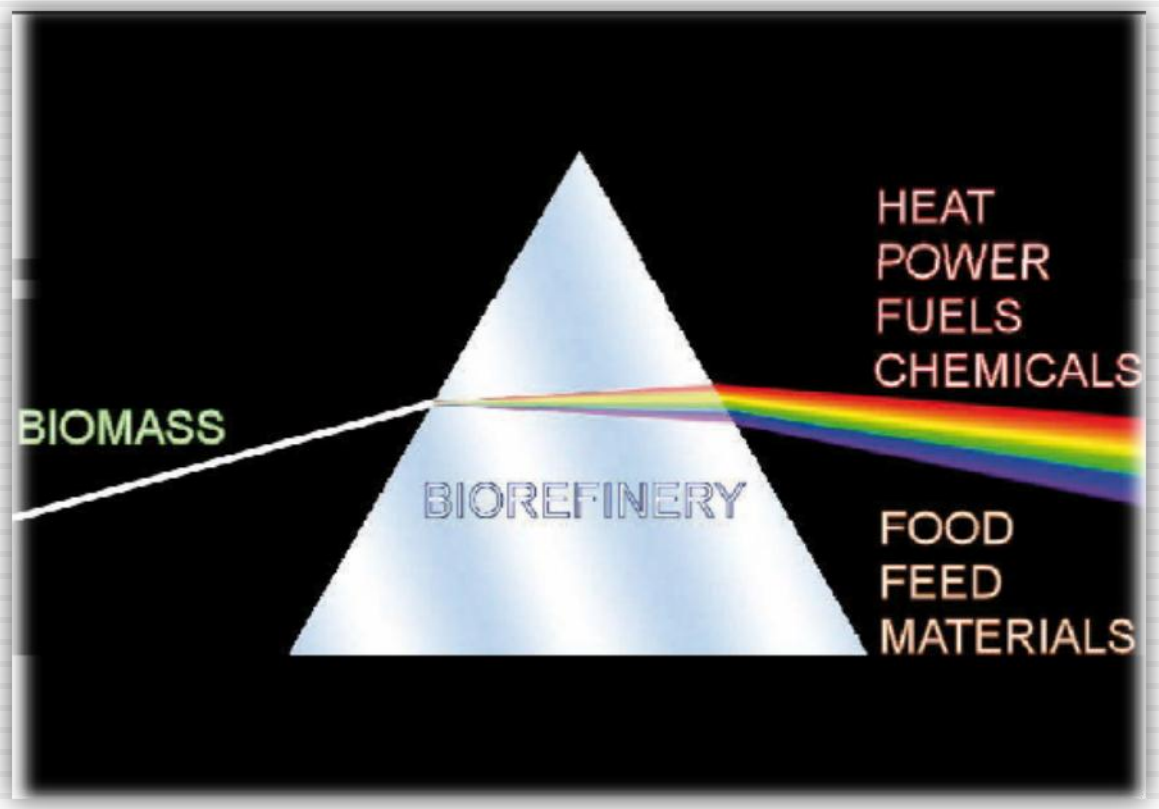
- Reed canary grass is ideal perennial grass for the Nemoral climatic area of Europe.
- In Sweden (20.000 ha) and Finland (1000 ha) use to be harvested in early spring as dead material.
- It's lifetime time is 10-15 years (10 – 15 harvestings)

Phalaris aquatica

- Harding grass is probably a native of the Mediterranean region of Europe and can be cultivated successfully in the Mediterranean region.
- It is a C3 grass established by seed.
- No need for irrigation since it regrowth in September and use the rainfalls of winter and spring.

The members of IEA Bioenergy Task 42 have agreed on the following definition for biorefinery: "Biorefinery is the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat)"

IEA Bioenergy 42 "biorefinery"



According to IEA Bioenergy 42 there are two types of Biorefinery

Energy-driven biorefinery

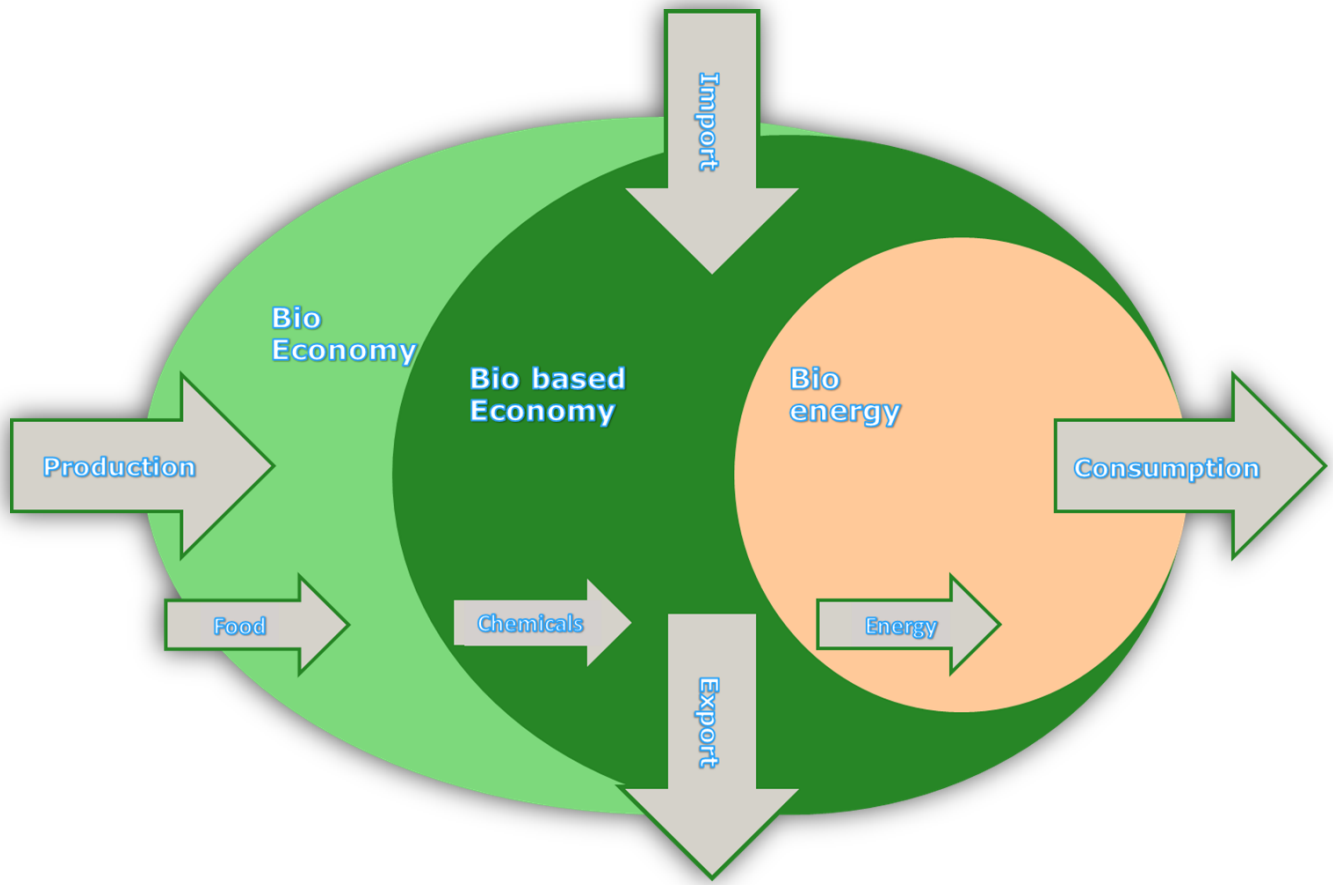
- The **"Energy-driven"** Biorefinery
  The main target is the production of biofuels and bioenergy. The biorefinery aspect adds value to co-products.

Product driven biorefinery

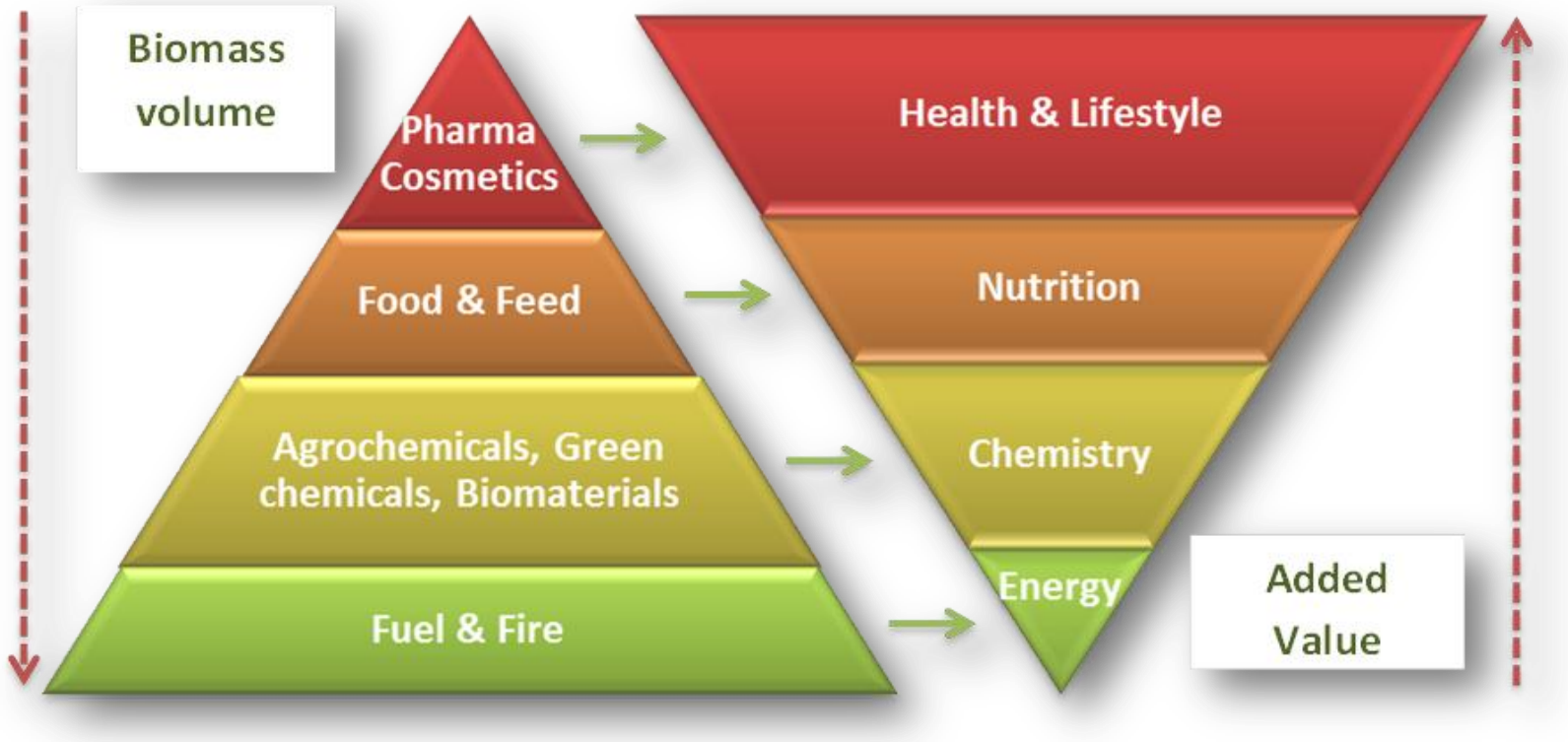
- The **"Product-driven"** Biorefinery
  The main target is production of food/feed/chemicals/materials, in general by biorefinery processes. Often side-products are used for the production of secondary energy carriers (power/heat) both for in-house applications as well as for distribution into the market.

Bioeconomy: *Biobased products* and bioenergy

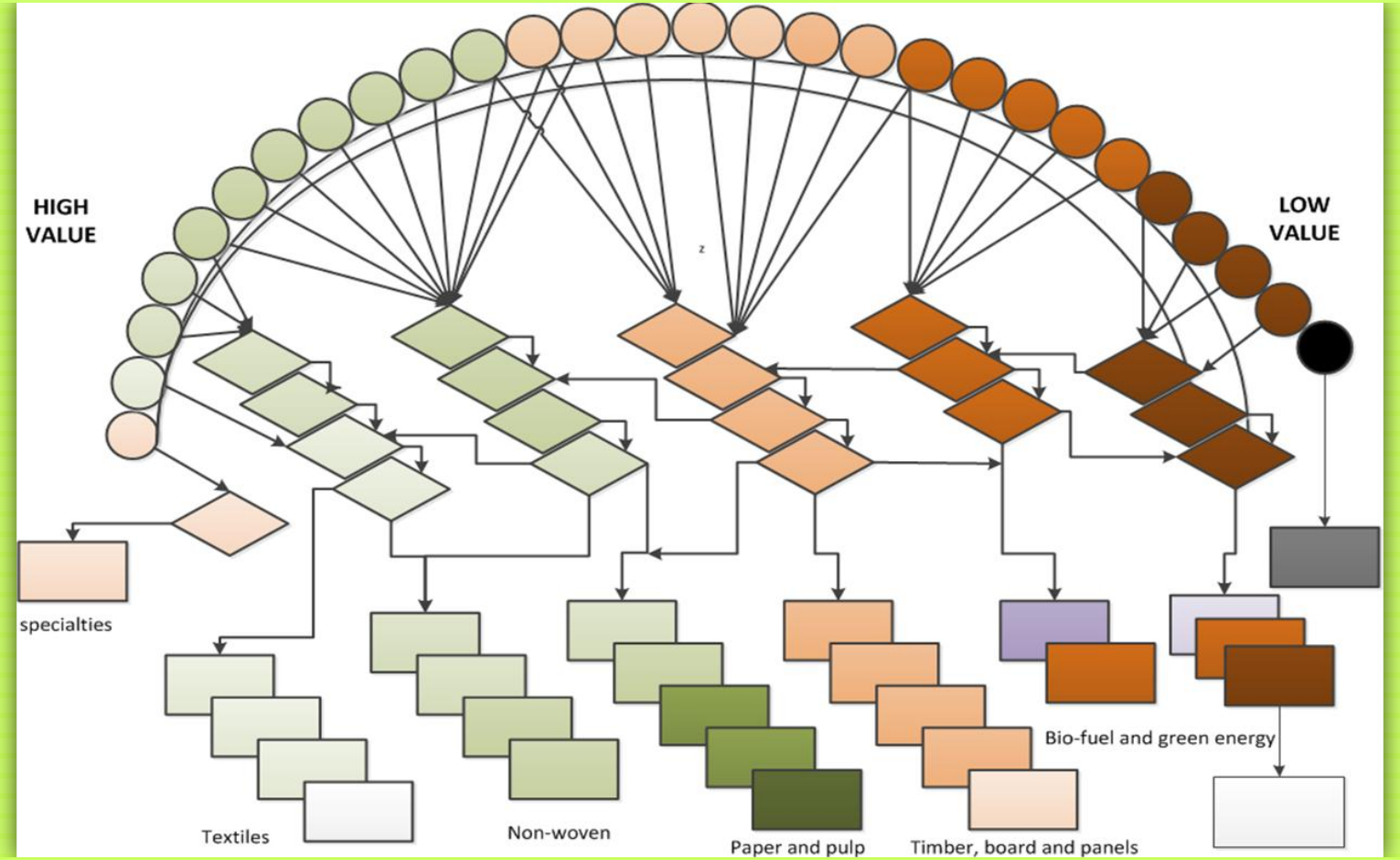
In the **bioeconomy** concept it is included the **biobased economy**, while **bioenergy** is a part of the biobased economy (Source: Dr. Jan van Dam, DLO).



Pyramid value of the added economic value of the biomass uses



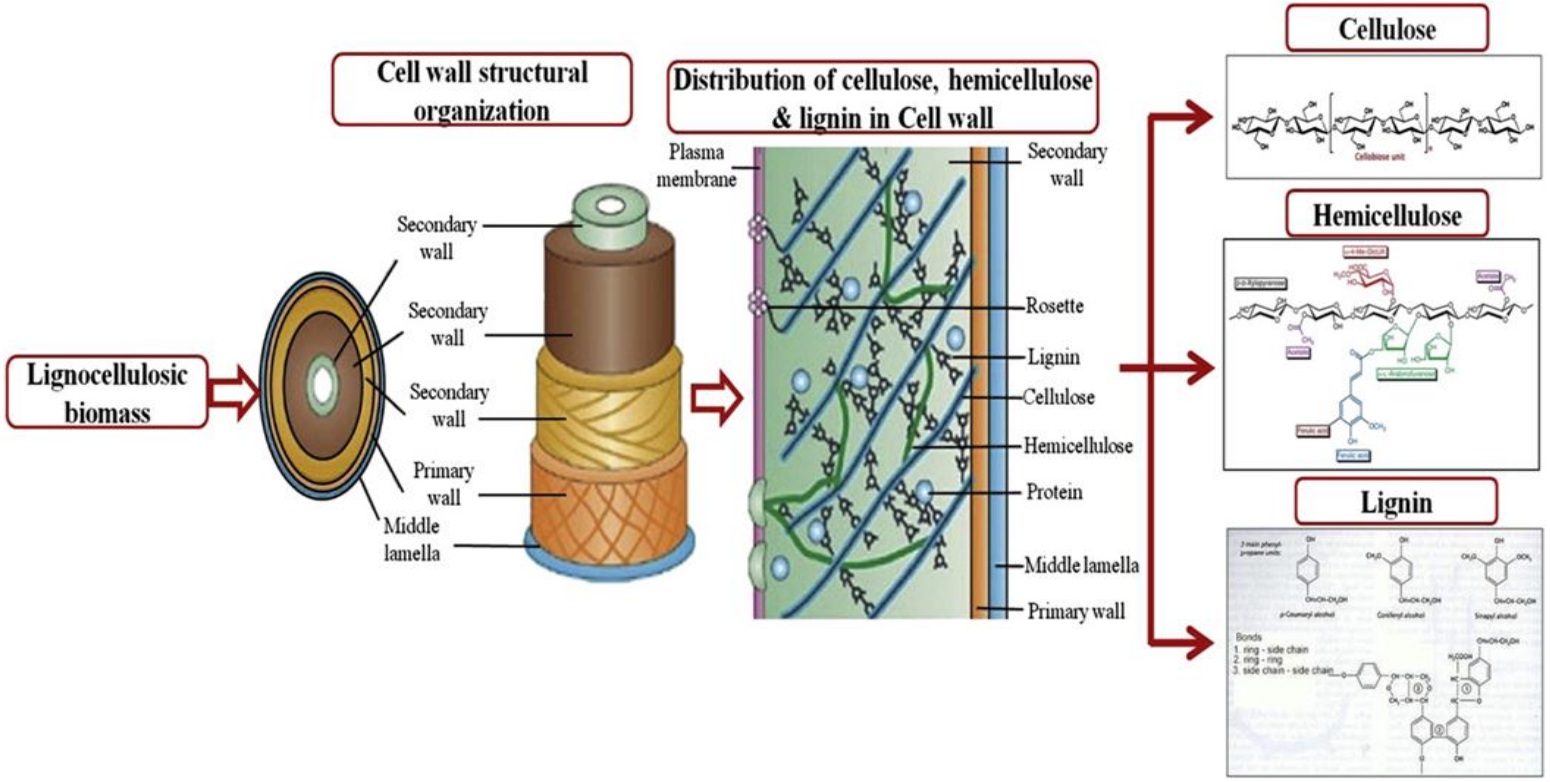
- The added value is the highest at the top of the pyramid and the lowest at the bottom. On the contrary, the volume of biomass needed for the applications is the lowest at the top of the pyramid and the highest at the bottom of the pyramid (www.bio-basedeconomy.nl).



Markets matrix

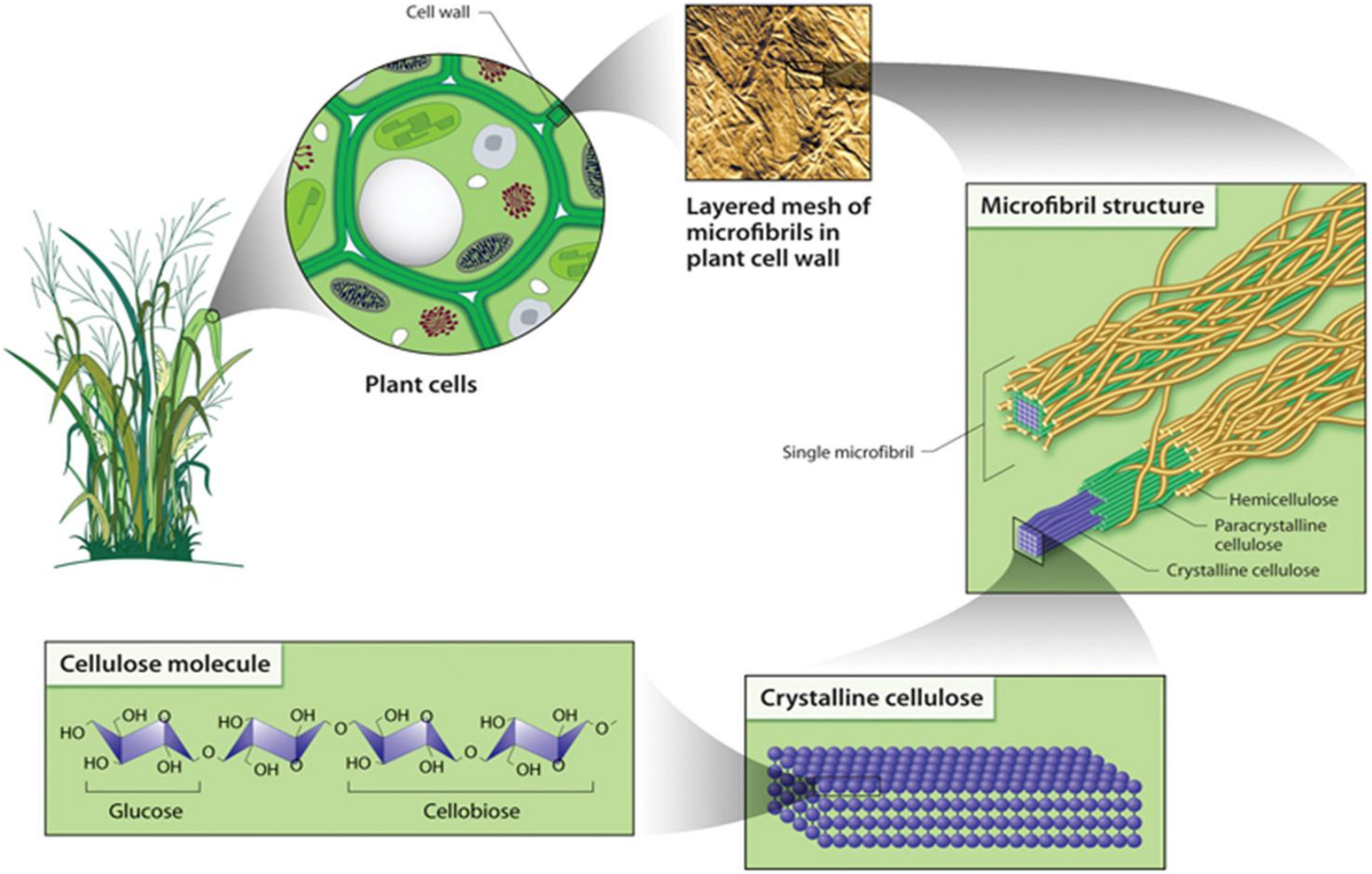
Source: DLO (The Netherlands) for EPNOE project

Lignocellulosic biomass contains:
40-50% cellulose, 25-35% hemicellulose and 15-20% lignin

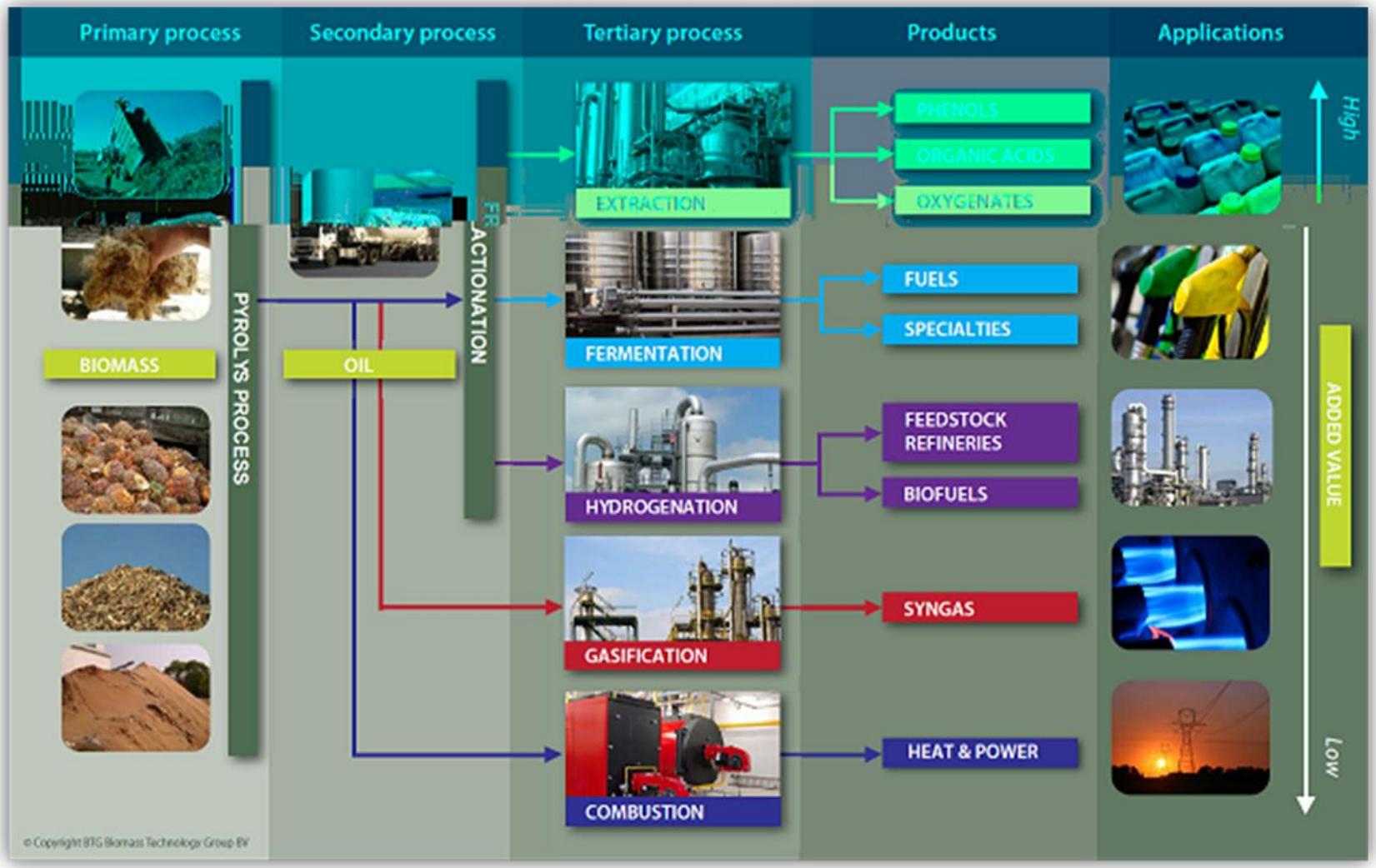


- Proteins, oils, pectins and ash make up the remaining fraction of lignocellulosic biomass.
- Lignocellulosic biomass can be converted into energy by thermochemical processes (combustion, pyrolysis and gasification) or by fermentation of carbohydrates to produce methane and second generation ethanol along with several by-products.

Characteristics of lignocellulosic biomass



The products of pyrolysis and torrefaction (the pyrolysis oil and biochar) can be used directly for energy production, but can also act as a feedstock for further processing and upgrading to biobased products

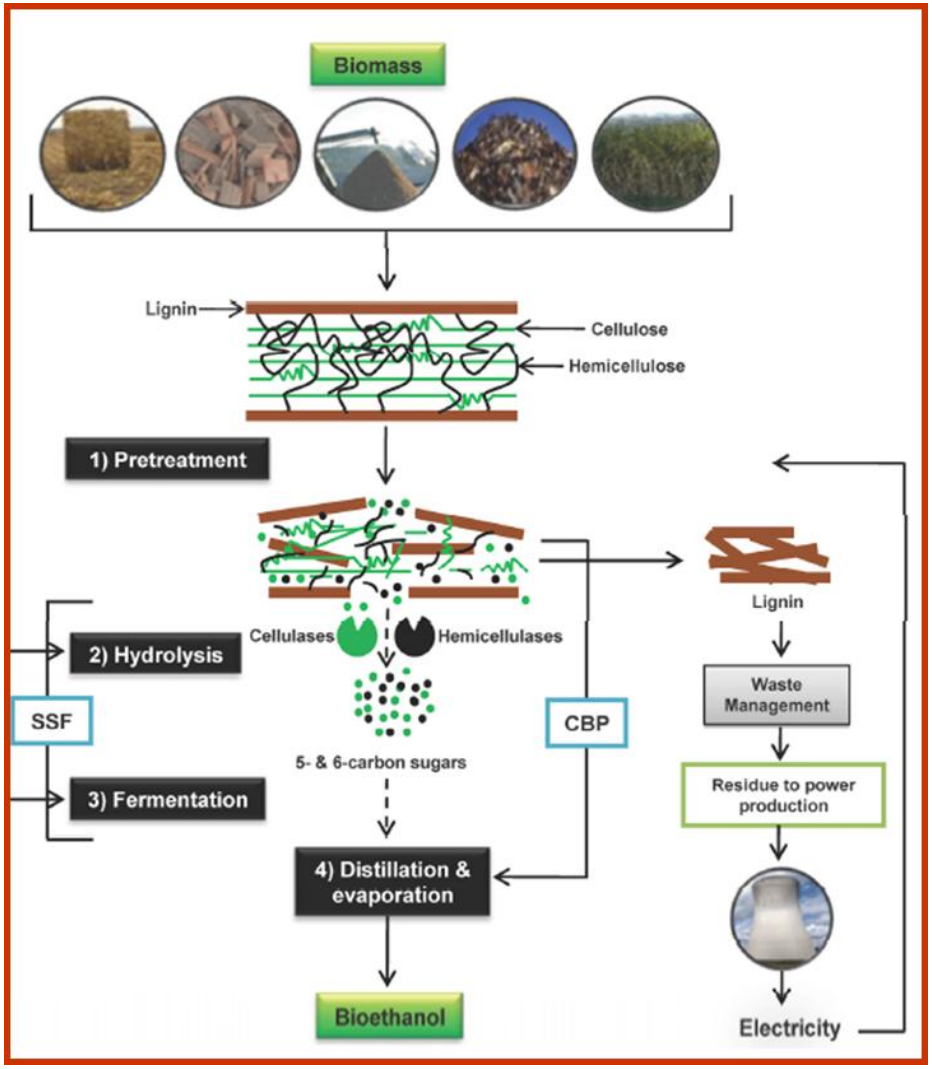


Categorization of possible bio-products

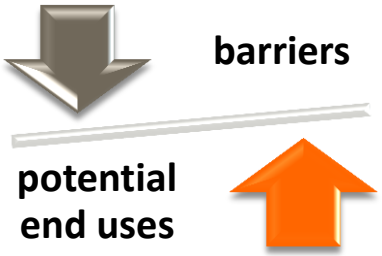
C1	• CH4, CO, Methanol, Formic Acid
C2	• Ethylene, Ethyl acetate, Ethanol, Acetic Acid
C3	• Lactic acid, Acrylic acid, Propylene, Glycerol
C4	• N-Butanol, iso-Butanol, iso-Butene, Succinic acid
C5	• Furfural, Itaconic acid, Levulinic acid, Xylitol
C6	• Sorbitol, Apidic acid, Citric acid, Lysine
Cn	• PHA, Para-xylene, Fatty acid derivatives

Lignocellulosic biomass conversion

Conversion of lignocellulosic biomass to bioethanol from celluloses and hemicelluloses and electricity and other products from lignin



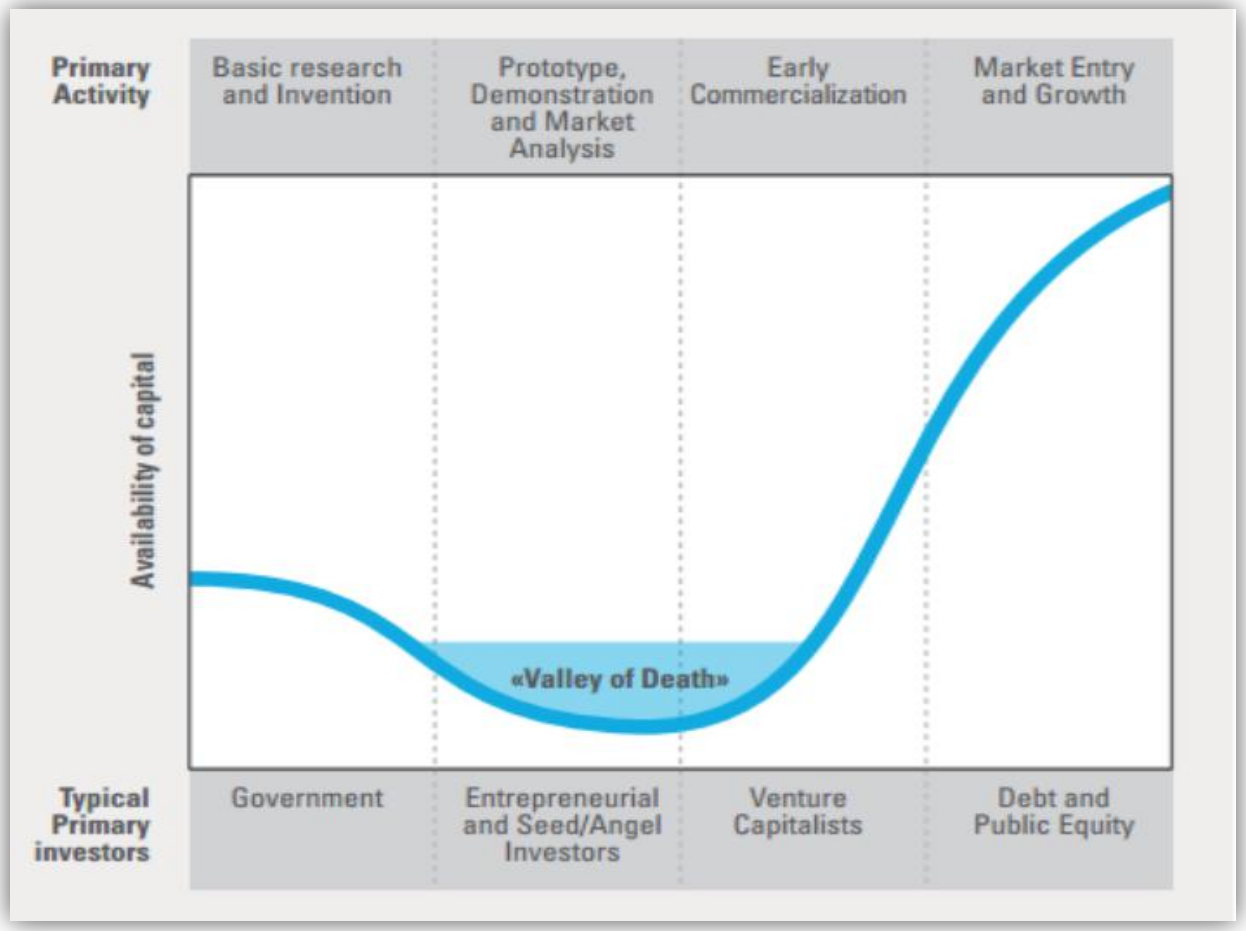
Although the potential end uses of perennial grasses are high the commercial marketplace still face several barriers



- Competitiveness with fossil fuels
- Technical (both physical and chemical)
- constraints of feedstocks and low energy density
- Logistics issues
- lack of certification and regulation criteria
- Land use conflict with food and feed crops
- Uncertain and undefined environmental and social benefits, etc.

Valley of death for innovation

Source: Star Colibri project, (www.star-colibri.eu)



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LIGNOFOS (www.lignofos.gr)

FAIR CT97 3701 (www.switchgrass.nl)

ENK CT2001 Bioenergy Chains (www.cres.gr/bioenergy_chains)

Thank you very much for your attention

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