ENEA activities on Biofuels and Biorefineries for Renewable Energy

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Bioenergy, Biorefinery and Green Chemistry Division

20th Sede Boqer Symposium on Solar Electricity Production

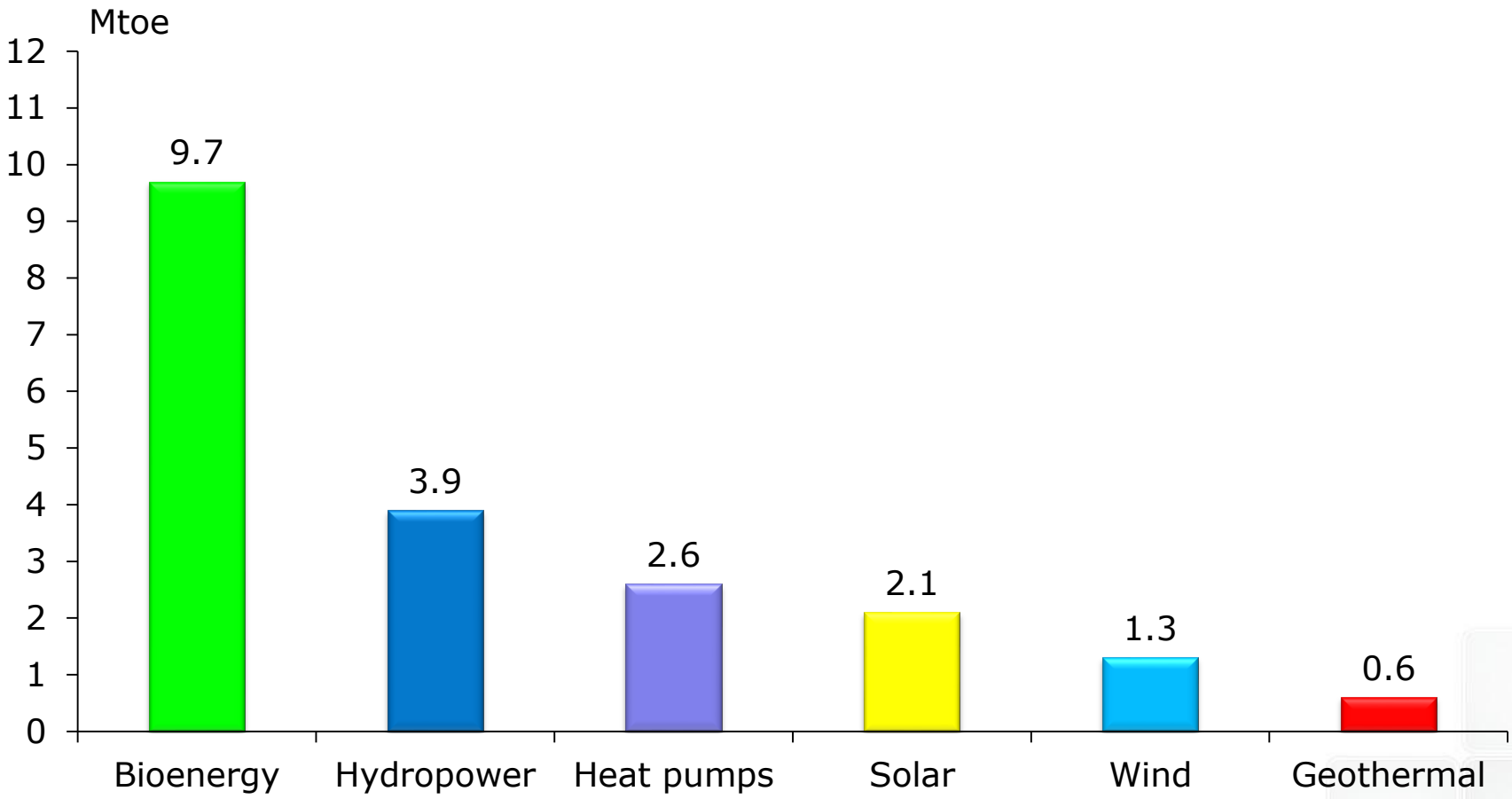
Beer-Sheva, Israel - September 27, 2016

Bioenergy in Italy

- Domestic and district heating (wood and wood residues)
- Process heat and/or CHP at agro-industrial factories (wood industries, distilleries etc.)
- Electricity production and/or CHP at power plants (lignocellulosic biomass, vegetable oils, biogas)
- Liquid biofuels for transport (biodiesel, bioethanol, ETBE)

CAVIRO distillery CHP and biogas plant (Faenza, Italy)

Contribution to gross energy consumption from renewable energy sources in Italy in 2014



Source: GSE, 2015

ENEA activities and research groups on bioenergy and green chemistry

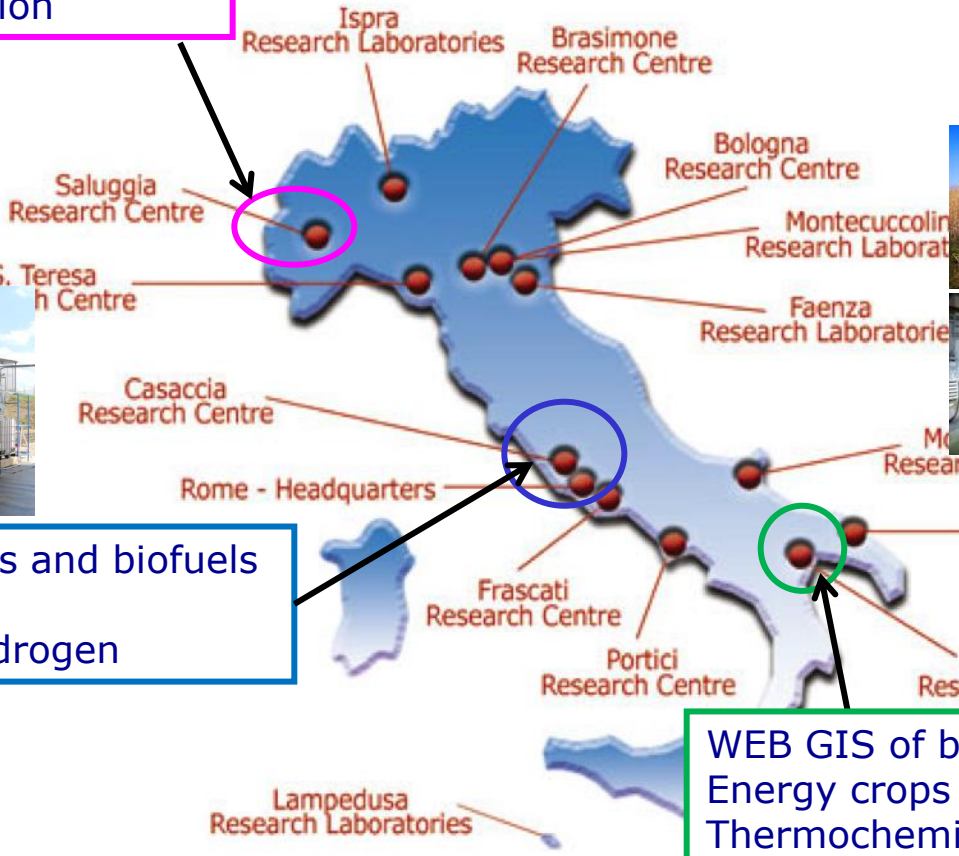
Saluggia

Biomass to energy pathways
Biomass combustion

Casaccia

Microalgae for biogas and biofuels
Energy crops
Biomethane / Biohydrogen

Trisaia



WEB GIS of biomass availability
Energy crops
Thermochemical processes
2nd generation biofuels

Bioenergy, Biorefinery and Green Chemistry Division
(G. Braccio)

Laboratories:

- **Biomass and Biotechnology for Energy** *(V. Pignatelli)*
- **Technologies and Processes for Biorefineries and Green Chemistry** *(I. De Bari)*
- **Thermochemical Processes for Biomass and Waste Valorization** *(G. Cornacchia)*

ENEA interest in "2nd generation" biofuels

- Biofuels are today the only direct substitute for oil in transport that is available on a significant scale
- The proposed target concerning with 10% renewable energy included in the total fossil fuels consumed within EU by 2020 could be fulfilled only if a significant amount of "second generation" biofuels will be produced and sell on the market, in order to avoiding possible competition with food crops
- 2nd generation biofuels can be produced without environmentally harmful impacts because of:
  - use of no-food feedstock, as cellulose (forestry / agriculture residues, grasses) and other non-conventional raw material (glycerol, organic wastes, algae etc.)
  - higher potential to reduce GHG
  - New processes and technological approaches, including biotechnological ones

Current ENEA RTD activities on new technologies for bioenergy and/or "2nd generation" biofuels production

BIOLOGICAL PROCESSES FOR ENERGY, BIOFUEL AND OTHER VALUABLE PRODUCTS FROM BIOMASS

- Advanced processes for biogas clean-up and upgrading to produce biomethane suitable both for injection into the natural gas delivering grid as well as for transport biofuel
- Production of hydrogen-rich biogas (hydromethane) by advanced anaerobic fermentation processes of waste biomass
- Ethanol and hydrogen production from raw glycerol arising from biodiesel industry by anaerobic fermentation with mixed bacteria cultures
- Ethanol from lignocellulosic biomass by cellulose enzymatic hydrolysis and fermentation, suitable as renewable transportation fuels directly by mixing with gasoline or via conversion to ETBE, TAEE etc.
- Production of biofuels (biogas and/or bio-oil) from CO_2 & sunlight through micro-organism based production (algae, bacteria etc.) and further upgrading into transportation fuels and valuable bio-products

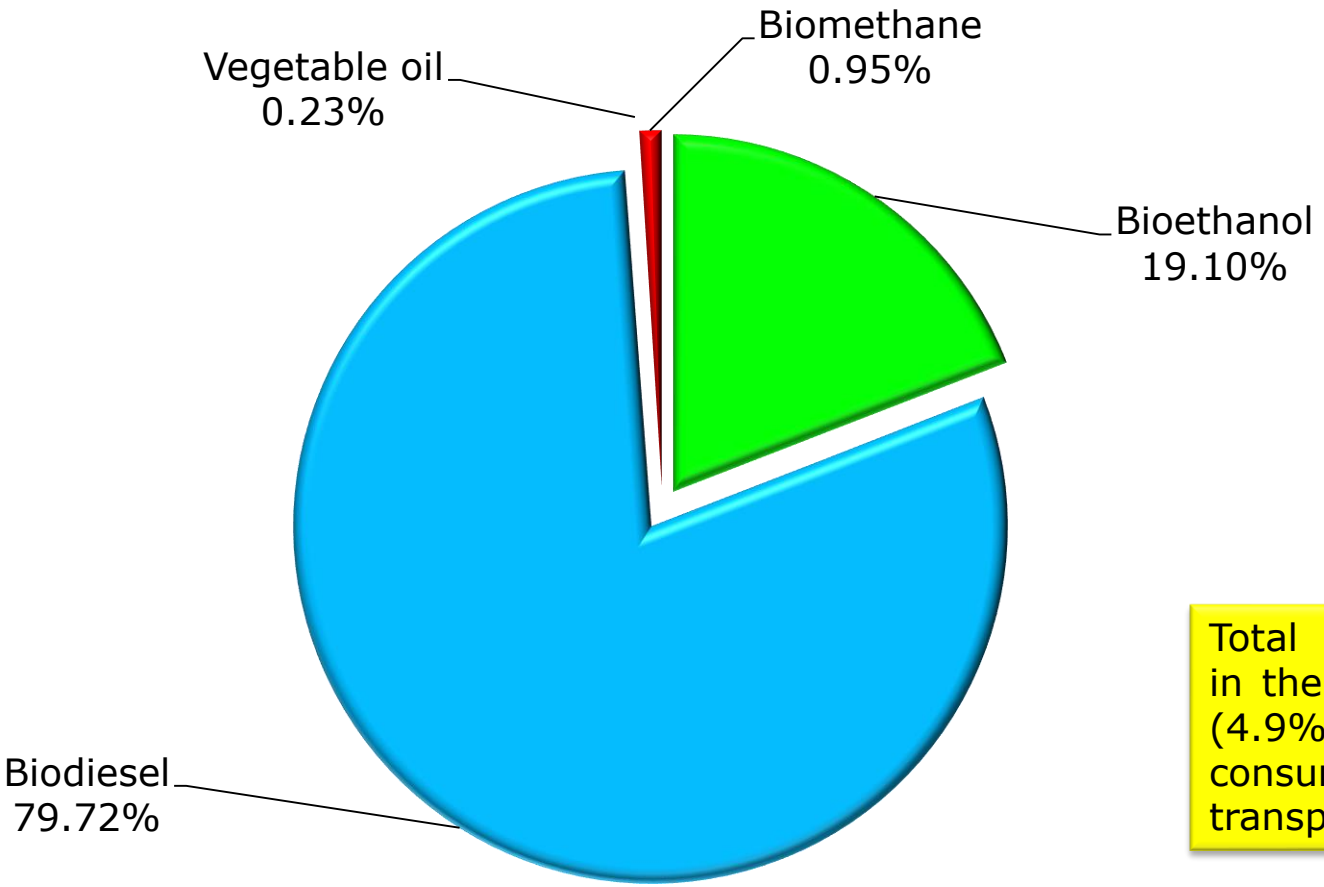
Research activities on biogas production

- Experimental cultivation of Jerusalem Artichoke for biogas production at ENEA Casaccia Research Centre

- Pilot anaerobic digester (6 m3) for testing innovative biogas production processes at ENEA Casaccia Research Centre

- Experimental cultivation of microalgae for biogas or liquid biofuels production at ENEA Casaccia Research Centre

Biofuel consumption (%) in the EU 27 in 2014



Total biofuel consumption in the EU (2014): 13 Mtoe (4.9% of total energy consumption in the EU transport sector)

Elaboration on data from EurObserv'ER - Biofuels Barometer 2015

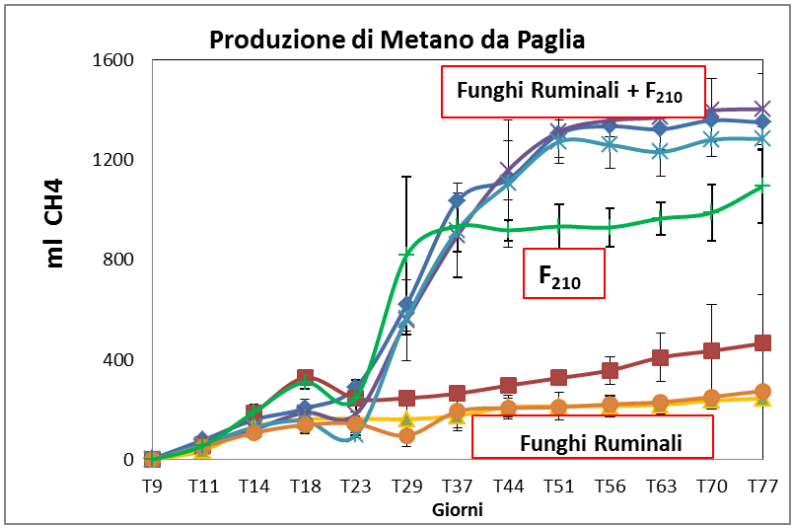
ENEA research activities on biogas and biomethane

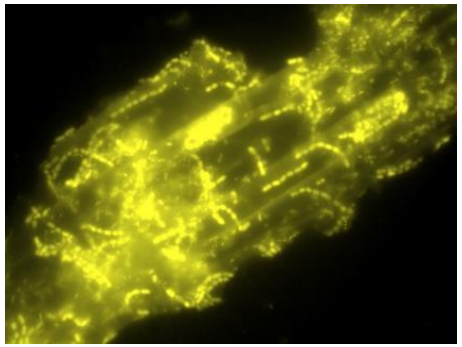
Experimental photo-bioreactor for H_2S removal from biogas by means of a biological clean-up process based on the anoxygenic photosynthesis reaction at ENEA Casaccia Research Centre

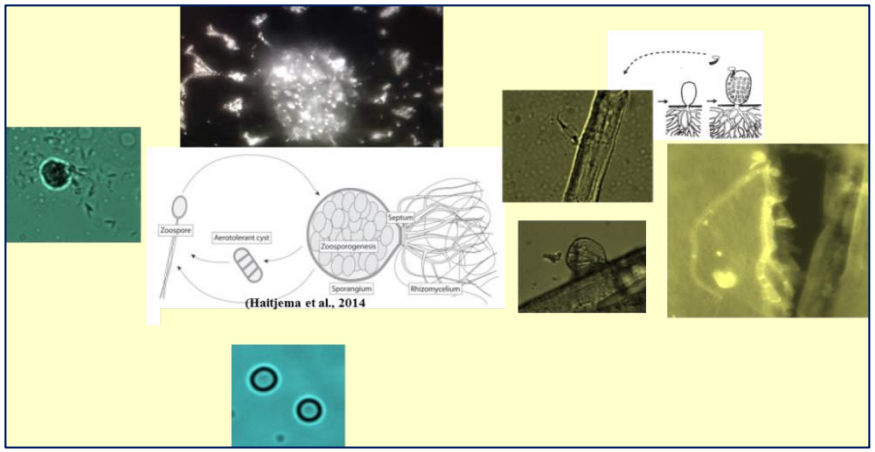
Membrane separation pilot plant for biomethane production, able to treat up to 350 m^3 biogas / h, at ENEA Trisaia Research Centre

Bioconversion of lignocellulosic biomass to fuels and chemicals

- Development of microbial processes for hydrolysis of lignocellulosic materials by Anaerobic Ruminal Fungi



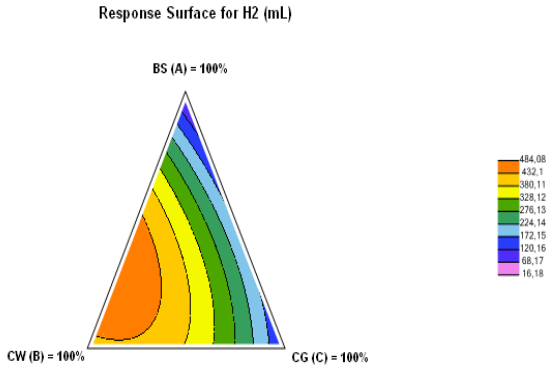




- Isolation and characterization of hydrolytic and hydrogen-producing bacterial strains
- Bacterial hydrolysis and saccharification of cellulose and hemicelluloses to fermentable monosaccharides

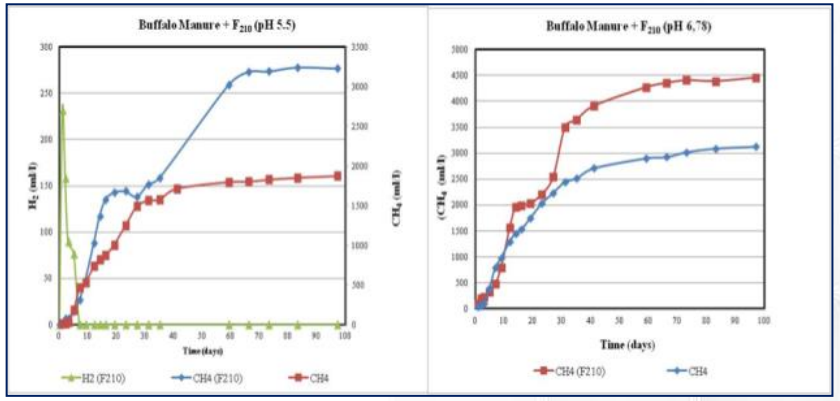
Processes optimization: fermentation and anaerobic digestion

- Statistical optimization of substrate composition



- Scaling up activities: Two Stage AD plant
  ENEA-CRA Patent number PCT/IB2014/059942

- Enrichment of suitable inocula for methane production by bioaugmentation of hydrogen producer communities



Characterization of microbial communities by molecular techniques

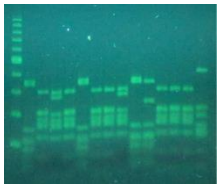
- Selection of suitable inocula for the hydrogen production stage, exploring the microbial diversity in natural ecosystems
- Investigating and monitoring the structure and functionality of the microbial communities during fermentation, AD and clean up processes

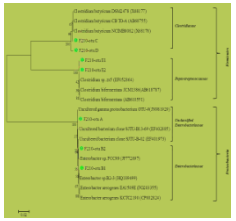
No. Clone	Abundance (%)	Closest relative	no. Accession	Similarity (%)
10	11.11	*Klebsiella* sp. ANctcri2	HQ286642	99-100
3	3.33	Uncultured *Klebsiella* sp. clone F5feb.43	GQ416012	99
3	3.33	Uncultured *Klebsiella* sp. clone SL08	HQ264068	99
5	5.56	*klebsiella pneumoniae* KCTC2242	CP002910	99
17	18.89	Uncultured bacterium clone 16slpB7-10f02.w2k	GQ158955	99-100
1	1.11	*klebsiella* sp.A18-1 strain A18-1	AB244431	100
1	1.11	*Klebsiella pneumoniae* strain SF5	JF489150	99
4	4.44	Uncultured *Klebsiella* sp. Clone F5feb.60	GQ416029	99-100
2	2.22	*Klebsiella pneumoniae* subsp. pneumoniae NTUH-K2044	AP006725	99
2	2.22	Uncultured bacterium clone ncd1468d11c1	JF118845	99
1	1.11	Uncultered bacterium clone ncd1413a11c1	JF122956	99
1	1.11	*Klebsiella* sp. VITPGP5AA	HM462444	100
2	2.22	Uncultured bacterium clone 16slpB7-10d05.p1k	GQ158941	99
5	5.56	*Escherichia coli* O7:K1 str. CE10	CP003034	99
9	10.00	*Escherichia coli* UMNK88	CP002729	99
2	2.22	*Escherichia coli* O111:H	AP010960	99-100
6	6.67	*Escherichia coli* W	CP002185	99-100
1	1.11	*Escherichia coli* UM146	CP002167	99
6	6.67	*Shigella sonnei* strain FBD025	EU009199	99
9	10.00	*Cupriavidus metallidurans* NBRC-101272	AB681431	99-100

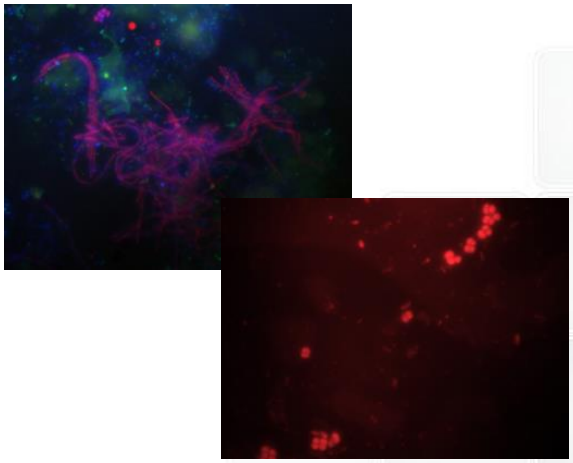
58% *Klebsiella*

32% *Escherichia/Shigella*

10% *Cupriavidus*





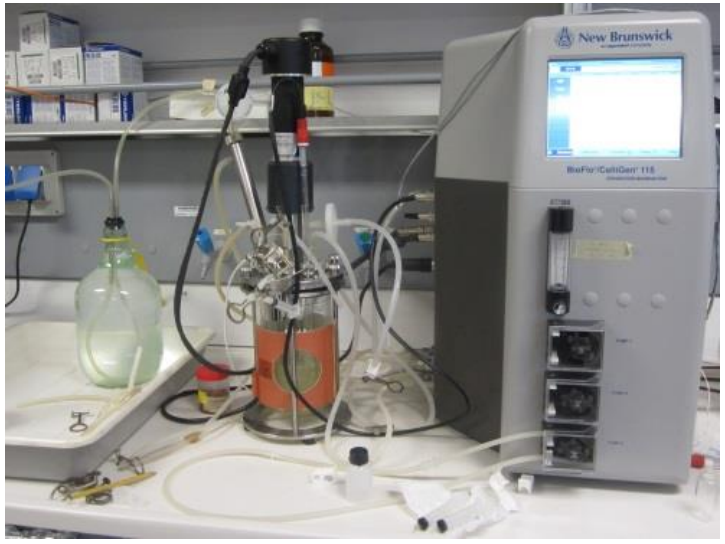


- Construction of 16S rDNA libraries
- Denaturing gradient gel electrophoresis (DGGE)
- Amplified ribosomal DNA restriction analysis (ARDRA)
- Fluorescence In Situ Hybridization (FISH)

Bioconversion of crude glycerol into ethanol, hydrogen and biochemical compounds

- The aim of the activities is to increase the glycerol consumption, maximizing production of hydrogen and ethanol

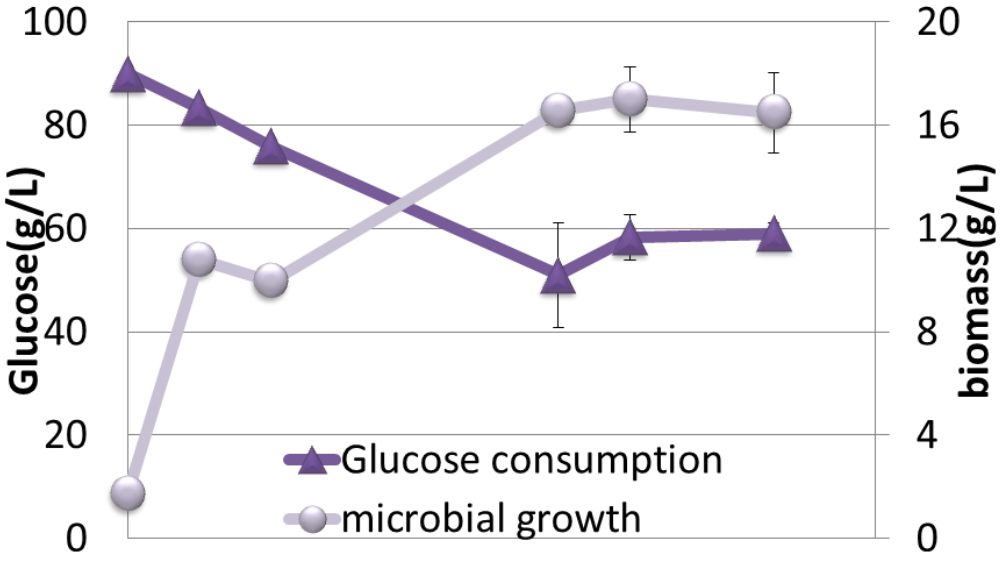
- Lab scale fed-batch experiments in non-sterile conditions by using increasing glycerol concentration to enhance substrate degradation ability

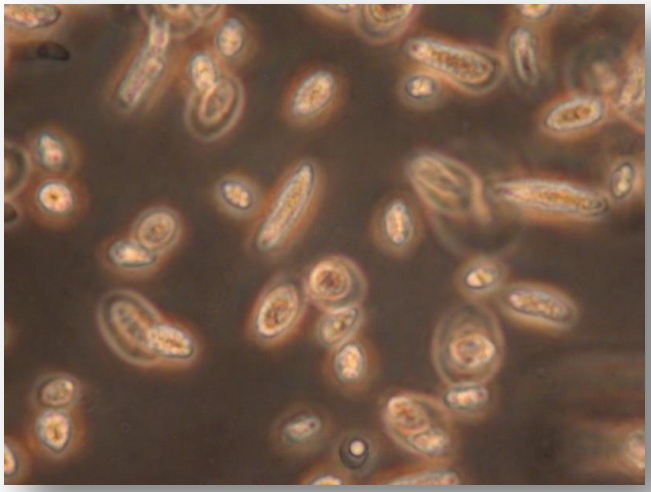


GRAIL

Glycerol Biorefinery Approach for the Production of High Quality Products of Industrial Value

Microbial production of lipids





- ✓ Depending on the microorganism, the lipid yield could reach ~70% of the microorganism biomass
- ✓ Co-utilizzazion of C& and C5 is possible

but…

Fermentation strategies ensuring an optimized C/N ratio can improve the process yields

Biorefinery and Green Chemistry: conversion of biomass into liquid fuels and chemicals

cereals
sugar

grain

straw

hydrolysis
fermentation

Bio-chemical process

Steam explosion

bioethanol

gassification

H_2 CO

F. Tropsch

pyrolisys

Thermal process

Bio oil

sundiesel

oleaginous plant

pressing

vegetable oil

transesterification

biodiesel

Key actions on Biorefinery

ENEA involvement in the "Cluster" projects (sustainable biochemicals and bioproducts)

Project ALBE
Project leader: VERSALIS
Sustainable technologies for the production of new **elastomers** and **lubricant oils**

Project BIT3G
Project leader: NOVAMONT
Third generation biorefineries (oils to **bioplastics, biolubricants, bioherbicides** etc.)

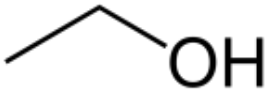
Project REBIOCHEM
Project leader: MATER-BIOTECH
Chemicals from biomass (i.e. **BDO, 5HMF** etc.)

Dedicated crops for biofuels and biobased products

BIOFUELS DRIVEN BIOREFINERIES

	Arundo donax
Glucan	34.75
Xylan	20.10
Galactan	0.27
Arabinan	2.12
Mannan	0
Lignin	22.0

BIOLYFE 2nd gen bioethanol



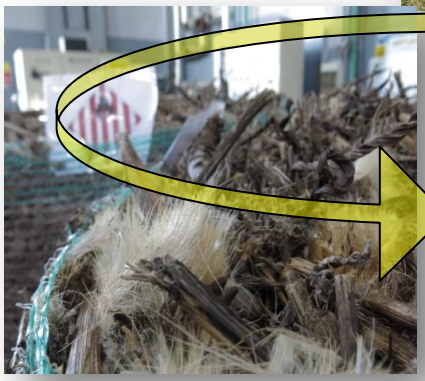
BIOLYFE "Second **Bioethanol** process: **demonstration scale** for the step of lignocellulosic hydrolysis and fermentation

SPRING
Sustainable Processes and Resources for Innovation and National Growth
Italian Cluster of Green Chemistry

BIOCHEMICALS DRIVEN BIOREFINERIES

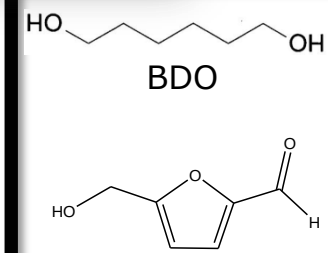
SEEDS

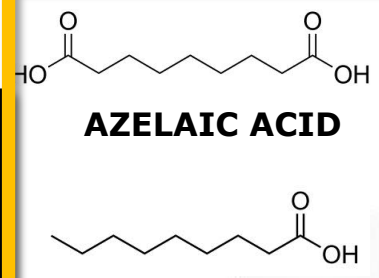
VEGETABLE OILS



lignocellulosic derived sugars

	Residue from Cardoon
Glucan	35
Xylan	14
Galactan	1,7
Arabinan	2,2
Mannan	1,1
Lignin	25



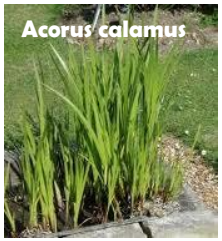


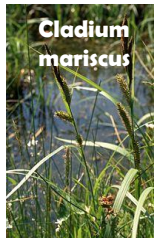
polyesters

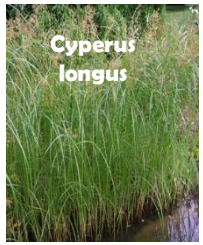
Bioplastics, Biolubricants.....

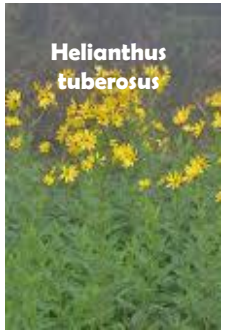
Production of 2G bioethanol from crops suitable for phytoremediation of contaminated soils

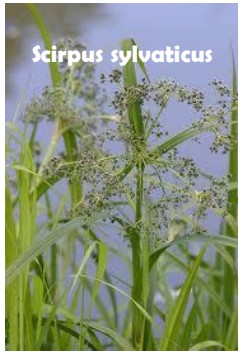
ENEA
AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE





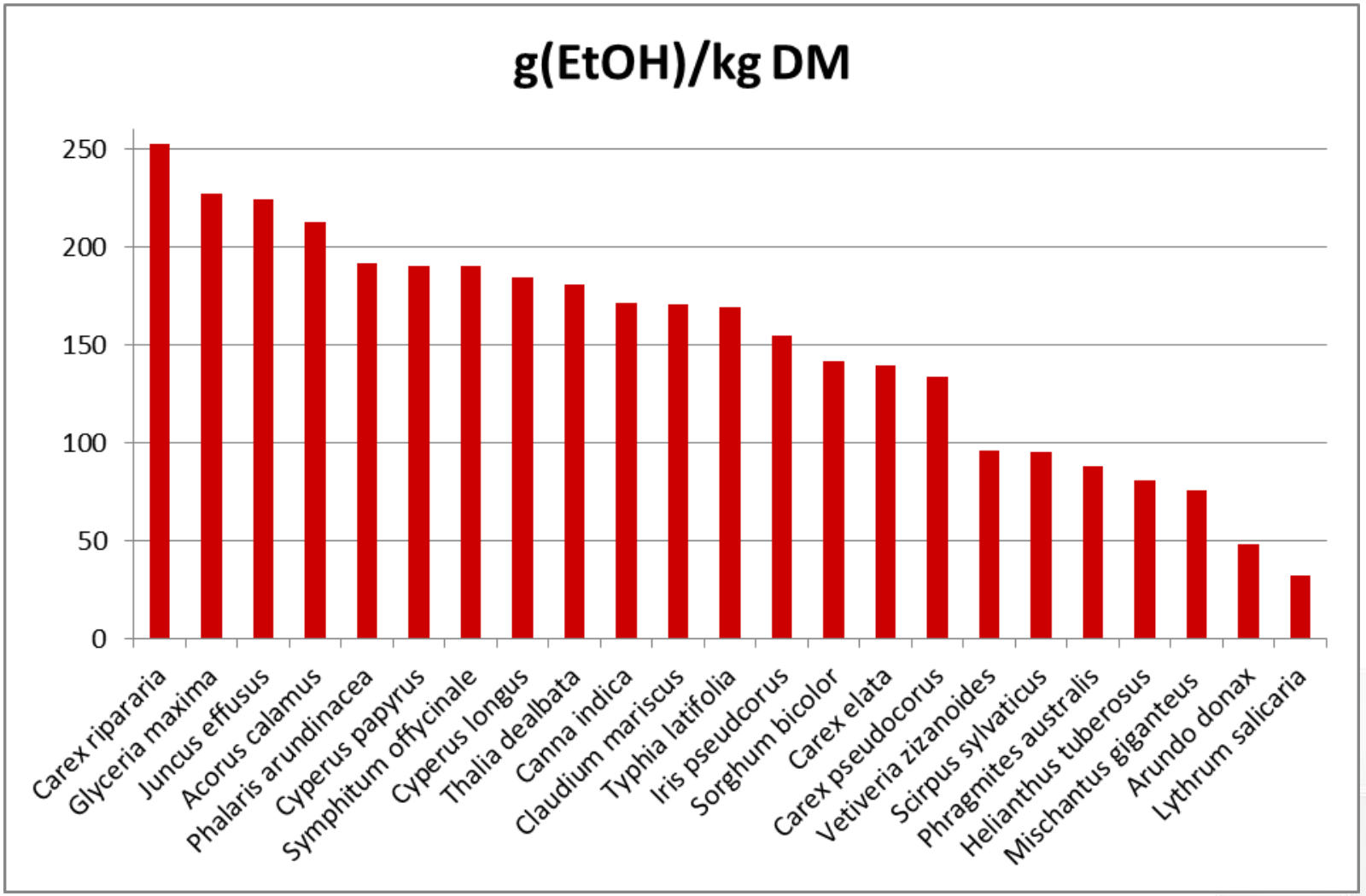






23 SPECIES

Bench scale tests for the production of EtOH



Data from FITOPROBIO Project (MIPAAF)

2nd generation bioethanol production at industrial scale

Partnership:
Mossi & Ghisolfi - ENEA

Pilot Size: 40.000 tonnes/years
Industrial Size: 200.000 t/a

Targets:

- **EtOH yield ≥ 0.25 g/$g_{BIOMASS}$**
- **yield per hectare EtOH ≥ 100 hl/ha**
- **Production Cost < 0.6-0.7 €/l**

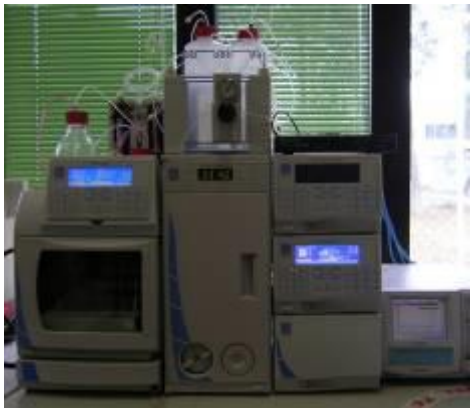
CO-Products

- **Probiotics & sweeteners**
- **Fibers**
- **Biodegradable materials**

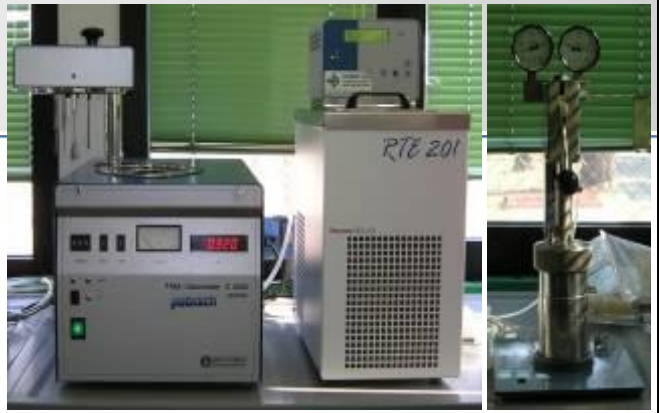
ENEA facilities for biorefining

- Pretreatment and fractionation at pilot scale (300 kg/h)
- Production of second generation sugars
- Process scale-up
- Downstream processing
- Technological platforms for thermal valorization of biomass residues (pyro-gasification
- Identification of new proteins and key enzymes involved in biomass degradation (proteomics)
- Fully equipped analytical labs for materials characterization and process analysis

Chemical Analytical Laboratory: Instruments & Equipments

		
GC-MS & TDS/DIP	**ICP-OES**	**ICP-MS**
		
HPIC-PED	**HPIC-RI**	**HPLC-UV**
		
UV-Vis	**FTIR**	**AAS**

Chemical Analytical Laboratory: Instruments & Equipments

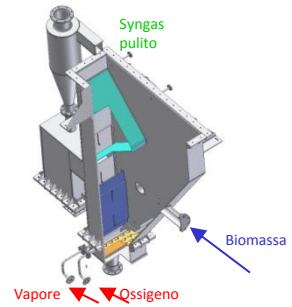
		
Elemental Analyser	**Calorimeter System & Mahler Bomb**	**TGA**
		
Soxhlet System	**Rotavapor**	**Microwave Digester**
		
Oven	**Muffle**	**Grinder**

Current ENEA RTD activities on new technologies for bioenergy and/or "2nd generation" biofuels production

TERMOCHEMICAL PROCESSES FOR ENERGY AND BIOFUEL PRODUCTION FROM LIGNOCELLULOSIC BIOMASS

- Liquid biofuels (BTL, biomethanol) and/or hydrocarbons from biomass via gasification, gas cleaning and upgrading and catalytic synthesis (main markets: renewable transportation fuels for jet and diesel engines)
- Substitute natural gas (bio-SNG) and other gaseous fuels (DME) from biomass via gasification
- High-efficiency thermal and power generation via gasification of biomass at a local level (farm, wood processing or agro-industrial factory)
- Bioenergy carriers from biomass (charcoal, bioliquids) via other thermochemical processes like pyrolysis, torrefaction etc.

Pilot plants for biomass gasification at ENEA Trisaia

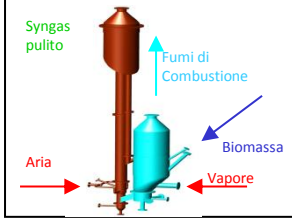


Fluidized bed –Internally recirculating

enriched air/steam 1MWth

Coupled with ICE for power generation

SYNGAS COMPOSITION	
	%Vol.
H_2	32
CO	17
CH_4	6.2
N_2	0.9
CO_2	20.9
H_2O	32



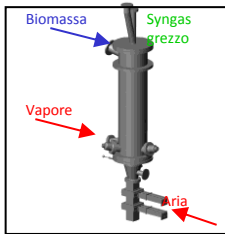
Fluidized catalitic bed –Internally recirculating

Air/steam 550kWth

Coupled with ICE or FC for power generation,

Fisher Tropsch

SYNGAS COMPOSITION	
	%Vol.
H_2	34.1
CO	25.1
CH_4	10.4
N_2	9.6
CO_2	20.8



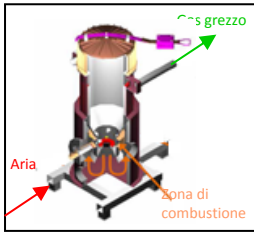
UPDRAFT fixed bed

Air/steam 200kWth

Coupled with ICE for power generation,

Fisher Tropsch

SYNGAS COMPOSITION	
	%Vol.
H_2	20
CO	21
CH_4	4
N_2	40
CO_2	6
H_2O	9



DOWNDRAFT fixed bed

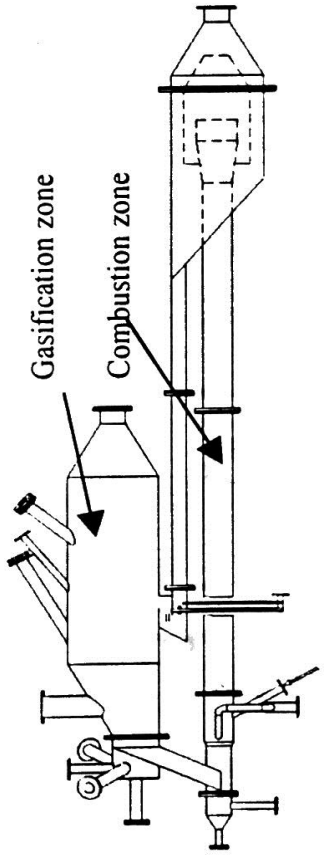
Air/steam 150-450kWth

Coupled with ICE for power generation

SYNGAS COMPOSITION	
	%Vol.
H_2	15
CO	22
CH_4	3
N_2	40
CO_2	20

Steam gasification FICFB plant

- Steam gasifier 500 kWth
- Fast Internally Circulating Fluidized Bed
- "Nitrogen free" Syngas
- Catalytic bed



Syngas, Vol %	
H_2	34 - 32
CO	21 - 25
CH_4	9 - 10
CO_2	19 - 22
C_2-C_3	2-3
N_2	9 - 13

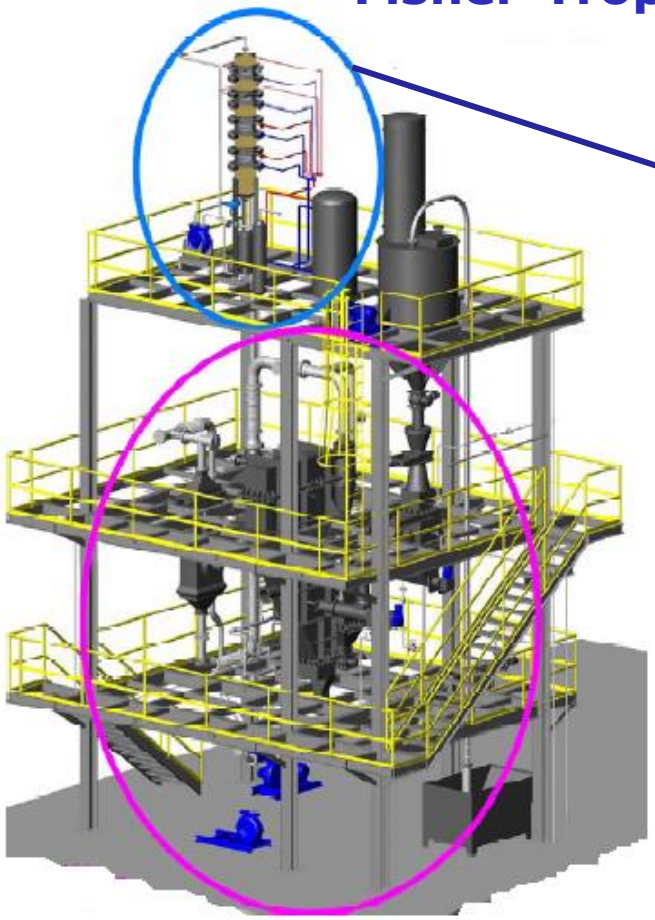
Tar raw gas ~ 9 g/Nm^3 $_{secco}$

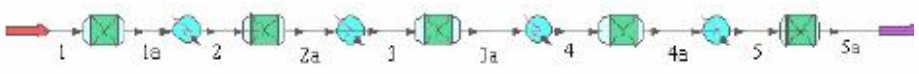
Raw gas yield 1-1.4 Nm^3/kg $_{daf}$

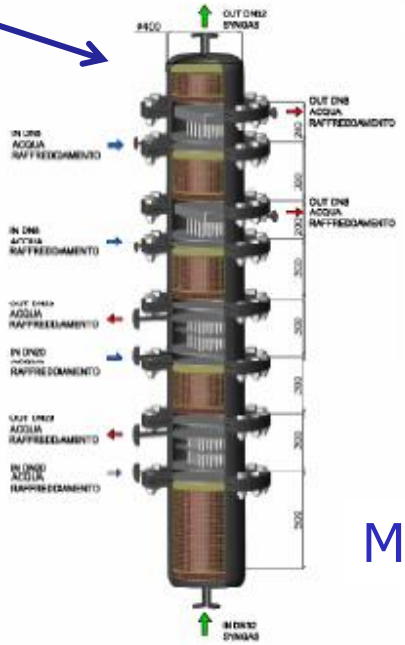
LHV raw gas 11-13 MJ/Nm^3$_{dry}$

Combined plant: gasification + Fisher-Tropsch process

Fisher-Tropsch reactor (adiabatic stages)







Products

Methanol and chemicals

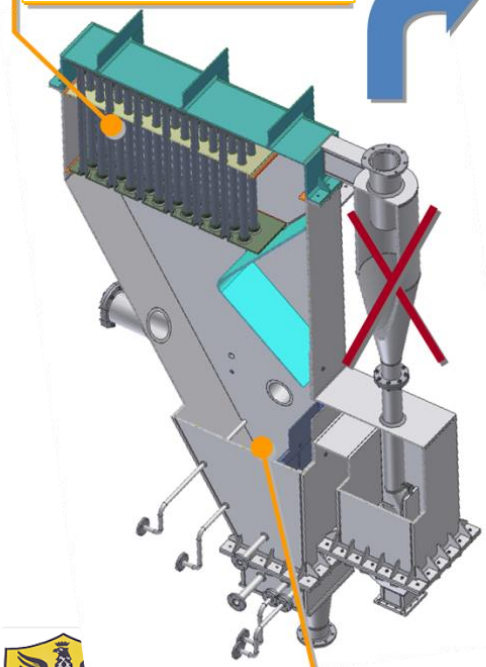
"Hydrosin" gasification plant

Internally Circulating Bubbling Fludized Bed 1 MWth

Integrated cleaning & conditioning of rawgas inside of the reactor

Cost reduction for cleaning is estimated about 20 -30 %. Compact plant with reduced heat loss

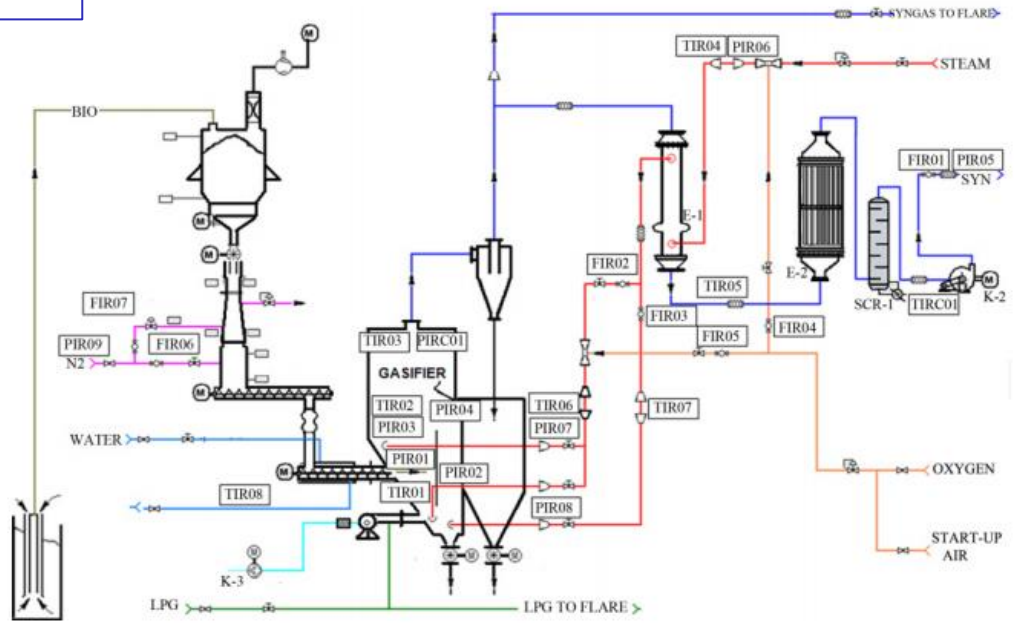
Ceramic catalytic candles



In bed additives for tar conversion

High temperature purified syngas

Advanced application (i.e. HTFC)



Gasifier under patent ENEA-UNIVAQ (1MWth ICBFB)

Thanks for your kind attention

Vito Pignatelli

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