Sewage Sludge to Energy and materials: advanced urban-mining H2020 Project To-Syn-Fuel

Liceo Galvani, Bologna 26 April 2018

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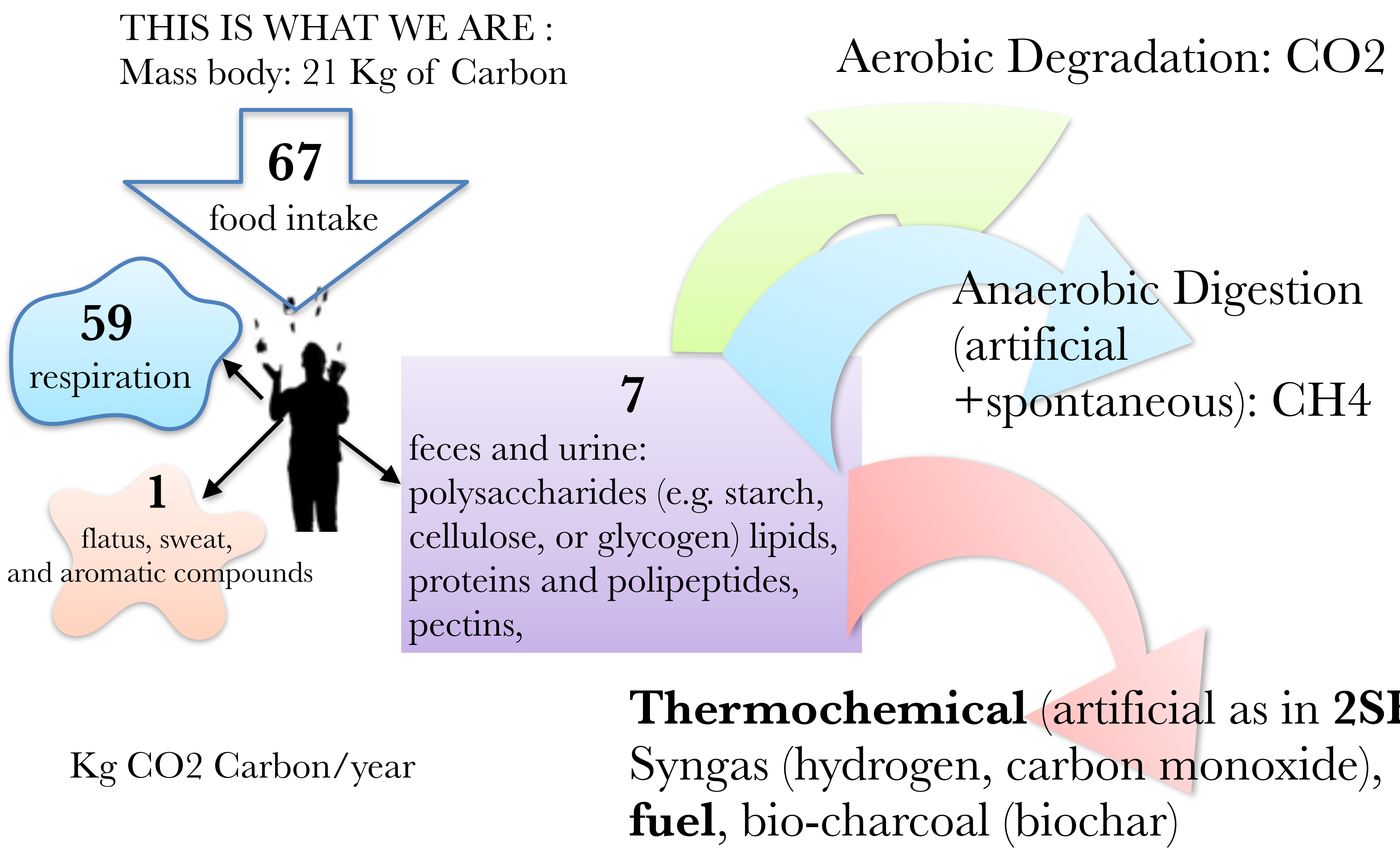
Sommario dei contenuti

1. il progetto To-Syn-Fuel (2SF): principi di funzionamento della tecnologia e applicazioni
2. la misura della sostenibilità del progetto
3. le sfide accettate da questo progetto
4. chi lo sta facendo e cosa possiamo fare insieme

1 il progetto

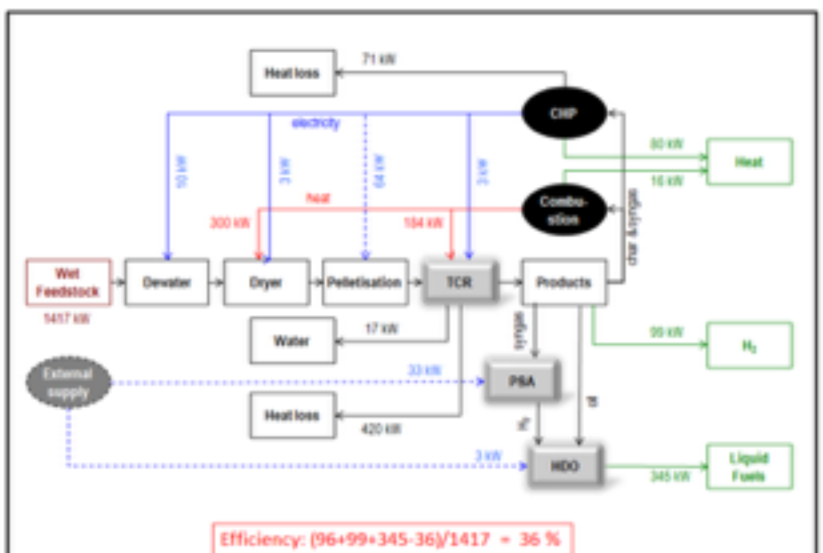
The general concept

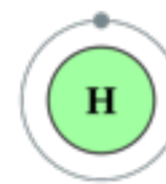


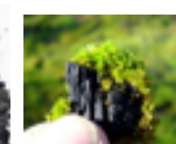
TO-SYN-FUEL

demonstrate the production of Synthetic Fuels and Green Hydrogen from organic waste biomass, mainly sewage sludge.

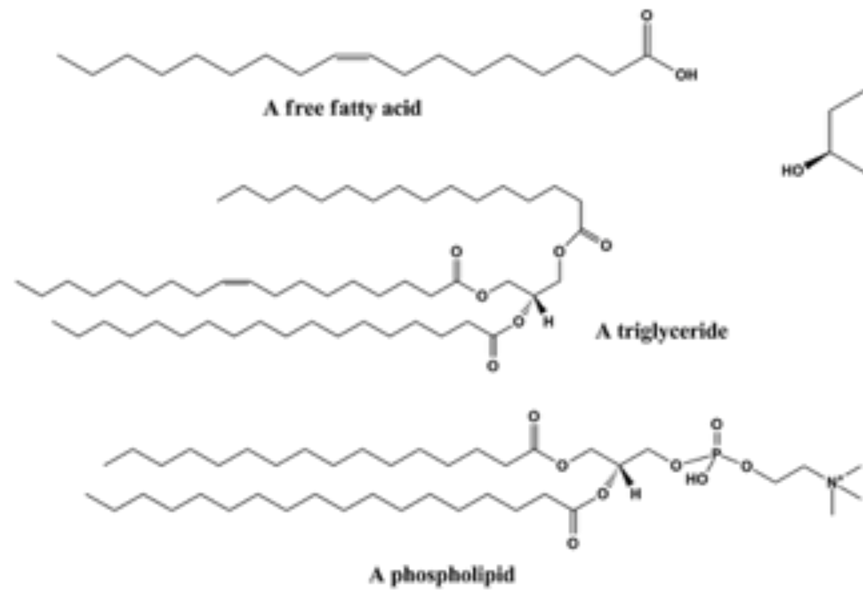
The project meets the European Commission proposal for the RED II, the Renewable Energy Directive for the post 2020 period. This proposal introduces a gradual phase-out of conventional biofuels and sets a minimum target for advanced biofuels for transports. Therefore, there is an urgent need to bring innovative biofuels from sustainable raw materials to the market.

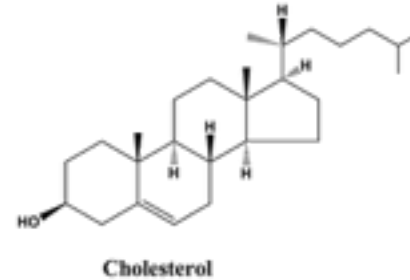


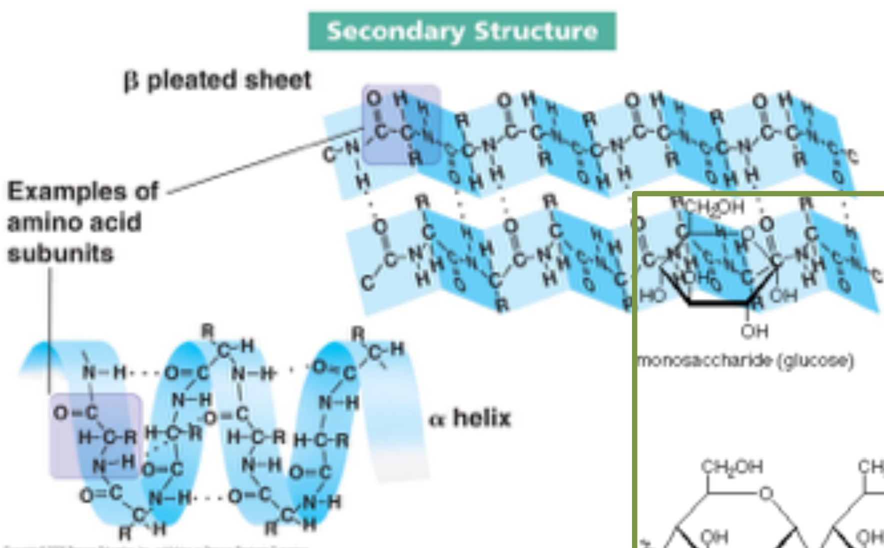


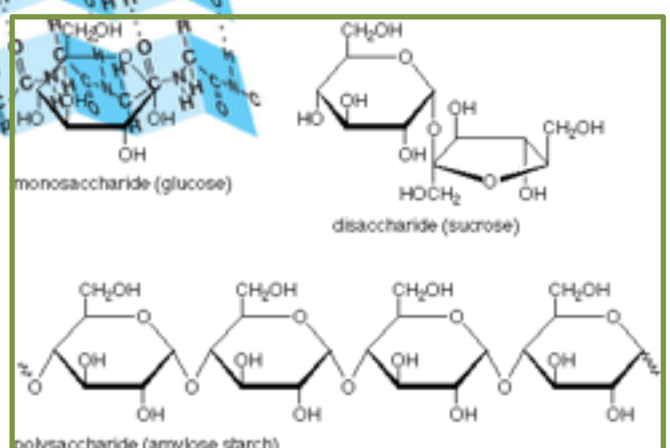


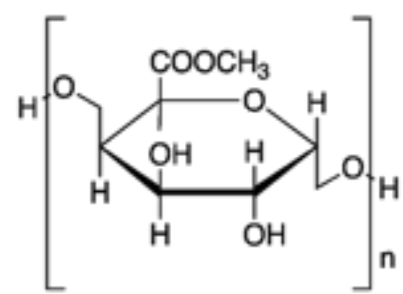
Feedstock carbon excreta (funny mix)





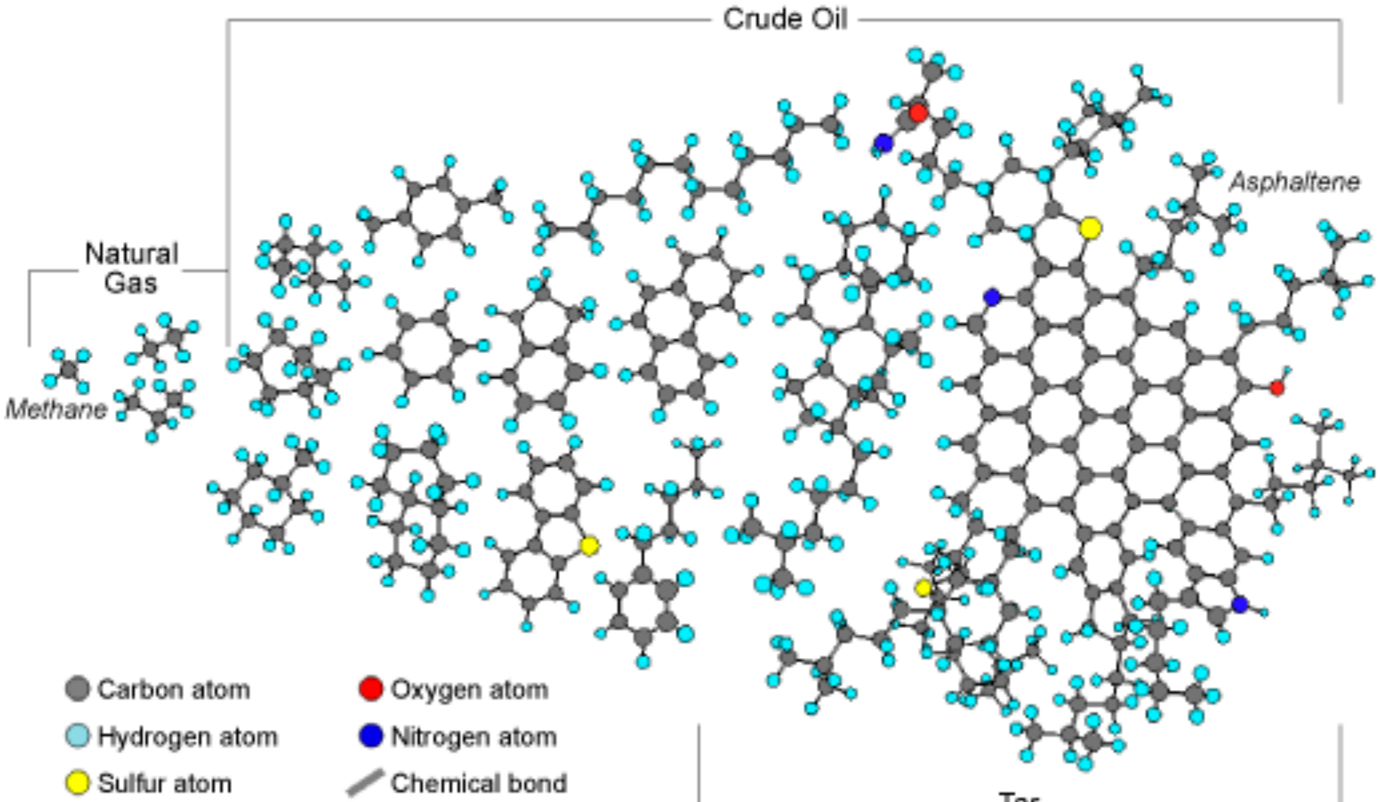






pectines

Examples of Some Organic Compounds in Petroleum

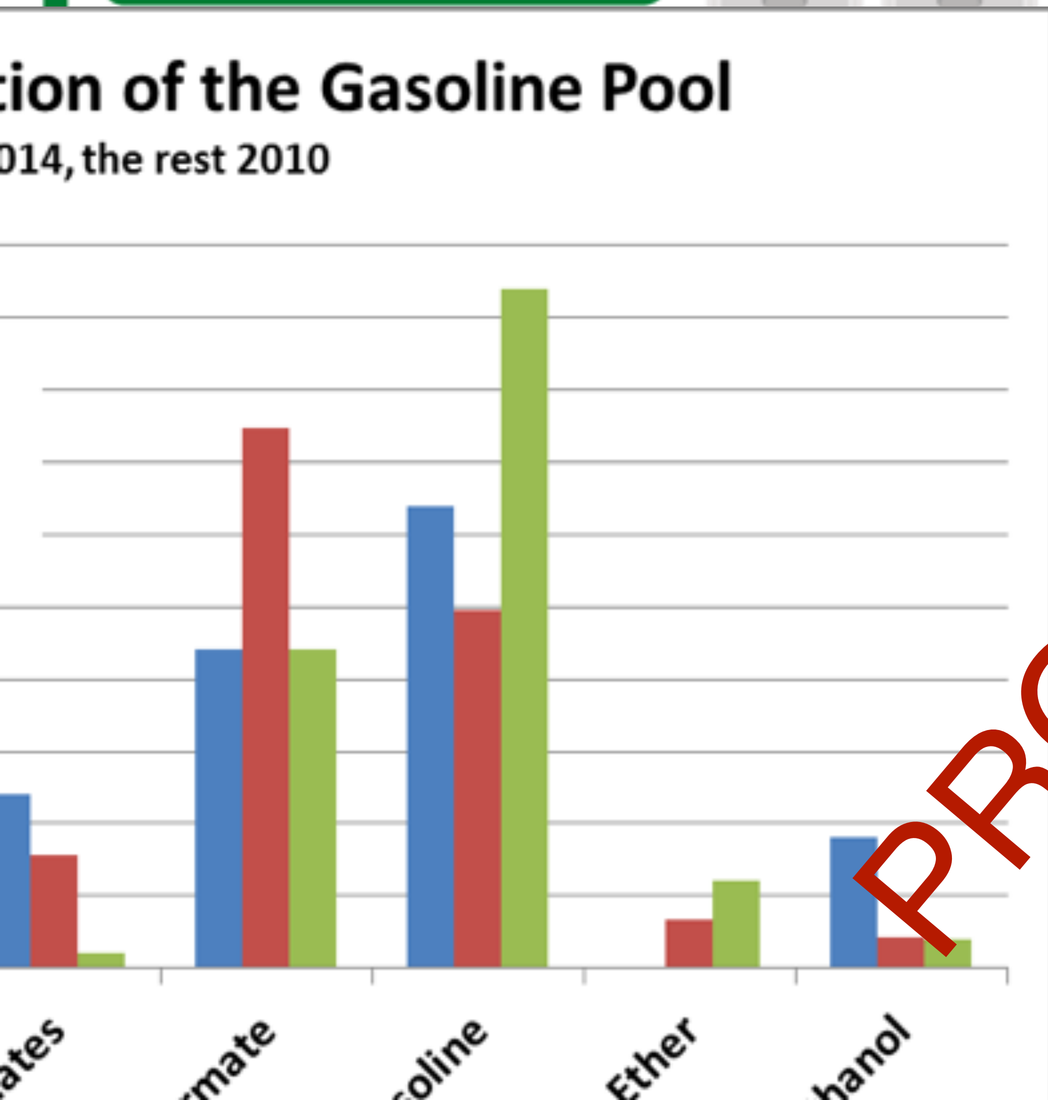


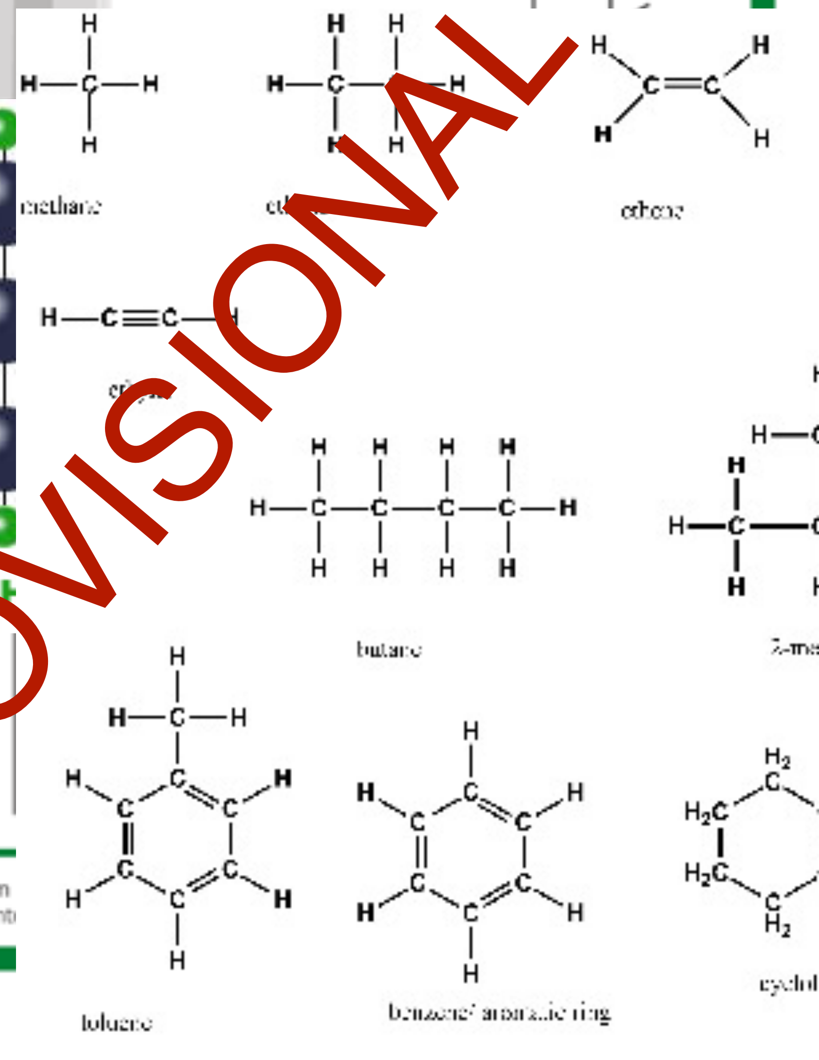
THE CHEMISTRY OF PETROL & DIESEL

There's a lot behind the fuel we put in our cars – in this graphic, we take a look at the differences between diesel, leaded petrol, and unleaded petrol.

PETROL & DIESEL – THE DIFFERENCE

OCTANE RATINGS & KNOCKING





The petrochemical way

Organic solid waste treatments

Thermochemical Pathway

Examples:

- Burning (after selection and purification)
- HydroThermal Conditioning (high temperature/high pressure water)
- …
- Thermo-Chemical Reactor (TCR)
- Pyrolysis coupled to anaerobic digestion

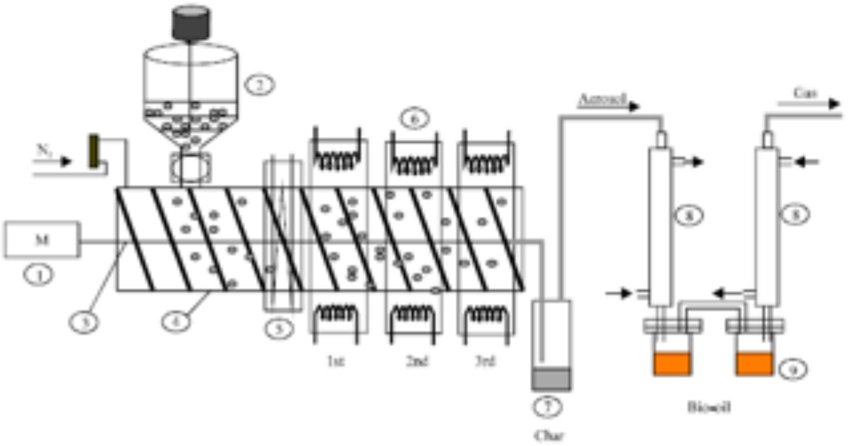
} based on pyrolysis

Pyrolysis

Thermochemical decomposition of organic material at elevated temperatures (200–300 °C to >1000 °C) in the absence of oxygen

Products: char + high temp. vapors
Vapors: condensate in liquid + gas

The feedstock can be inserted in the heated chamber by, e.g., an auger screw



Needs feedstock with low water content (excess water takes out heat from the process)

Feedstock form: depends on the system (e.g. for auger screw: pellets 5-10 cm)

Standard pyrolysis products

Char	decreases with temperature
Liquid: oil+water	decreases with temperature
(Syn)Gas	increases with temperature
Tar in the oil	increases with heating rate

Energy densities for intermediate pyrolysis:

feedstock: 15-20 MJ/kg

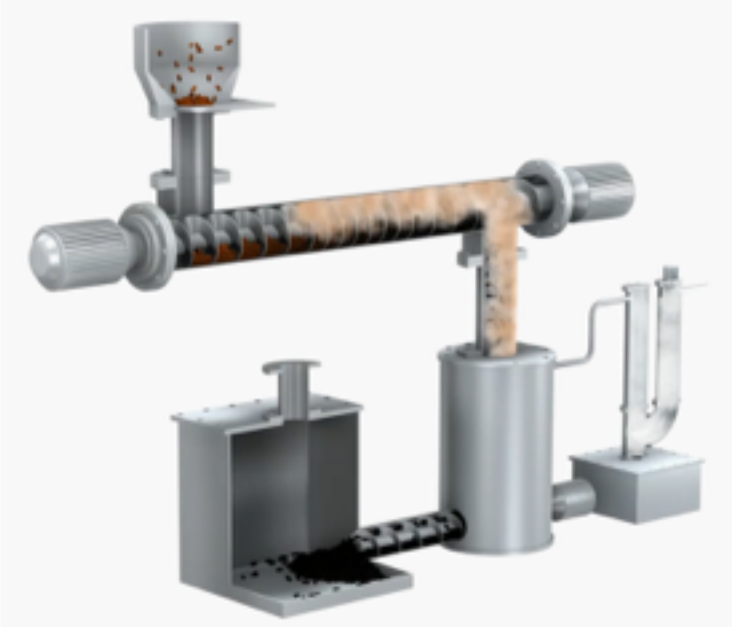
Char: 20-30 MJ/kg
Oil: 15-25 MJ/kg
Water: 1-5 MJ/kg
Gas: 5-15 MJ/kg

Problems:

- the liquid is a mix of water (~40%) and oil (~60%) which does not separate by gravity
- the oil contains a large quantity of oxygen and polymerize
- the tar in the oil makes it viscous and acid
- the hydrogen content in the syngas is low (~20%)

TCR: Pyrolysis + reforming

TCR: Thermo Catalytic Reforming



Very recent development (last 3 years)

Intermediate temperature pyrolysis (550-700 °C, heating time: minutes) so as to have sizable fractions of oil and char and low tar in the oil)

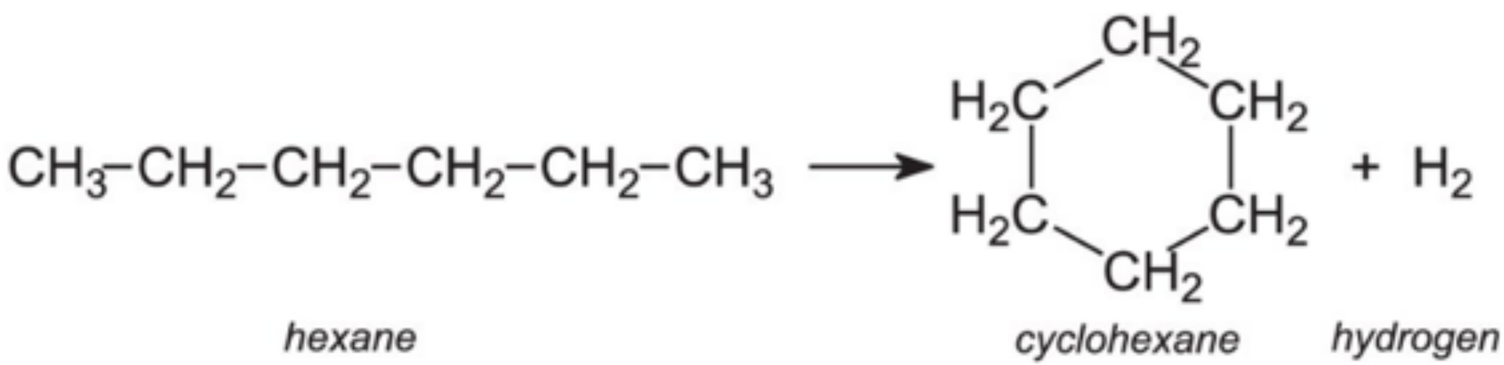
Hot char is used for vapor reforming at 700 °C

- The reforming produces smaller molecules in the oil and increases
- significantly the quantity of hydrogen in the syngas
- The water phase is easily separated from the oil by gravity
- The solid fraction is "activated" char

Tested on municipal wastes, anaerobic digestate, sewage sludge

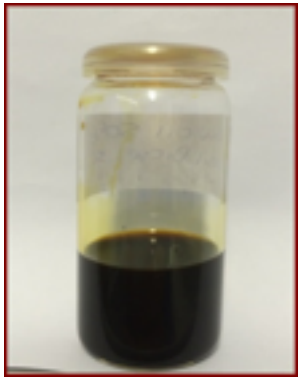
Reforming

Reforming is a process in which hydrocarbon molecules are rearranged into other molecules, usually with the loss of a small molecule such as hydrogen.



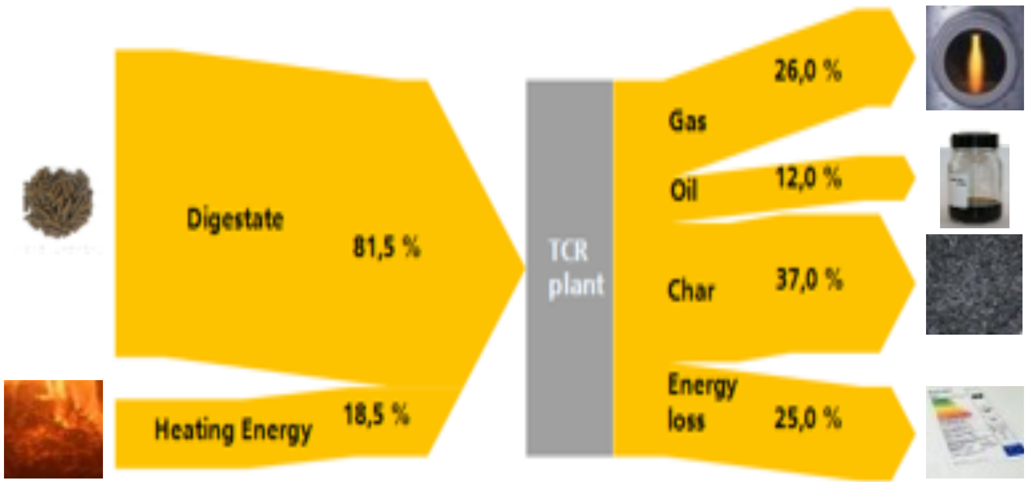
TCR: Pyrolysis + reforming

	Unit	Average TCR Oil	Fossil Diesel	Biodiesel	Fast Pyrolysis Oil
C	wt%	81.05	84.7	77.2	54.2
H	wt%	7.8	13.2	13.2	6.9
N	wt%	2.4	<0.1	0.1	0.1
S	wt%	0.44	<0.1	<0.1	0.1
O*	wt%	6.9	1.4	9.4	38.9
Water	wt%	1.4	0.06	0.4	35.6
Ash	wt%	<0.1	<0.01	<0.01	0.4
TAN	**mgKOH/g**	**3.2**	**0.02**	**0.5**	**>90**
HHV	MJ/Kg	37.3	44.7	39.3	24
LHV	**MJ/Kg**	**35.7**	**41.9**	**36.2**	**20**
Viscosity	**cSt**	**10.9**	**3.01**	**8.2**	**>100**



TCR oil directly blended with fossil Diesel at 50-50 volume ratio showing one phase

TCR: Pyrolysis + reforming



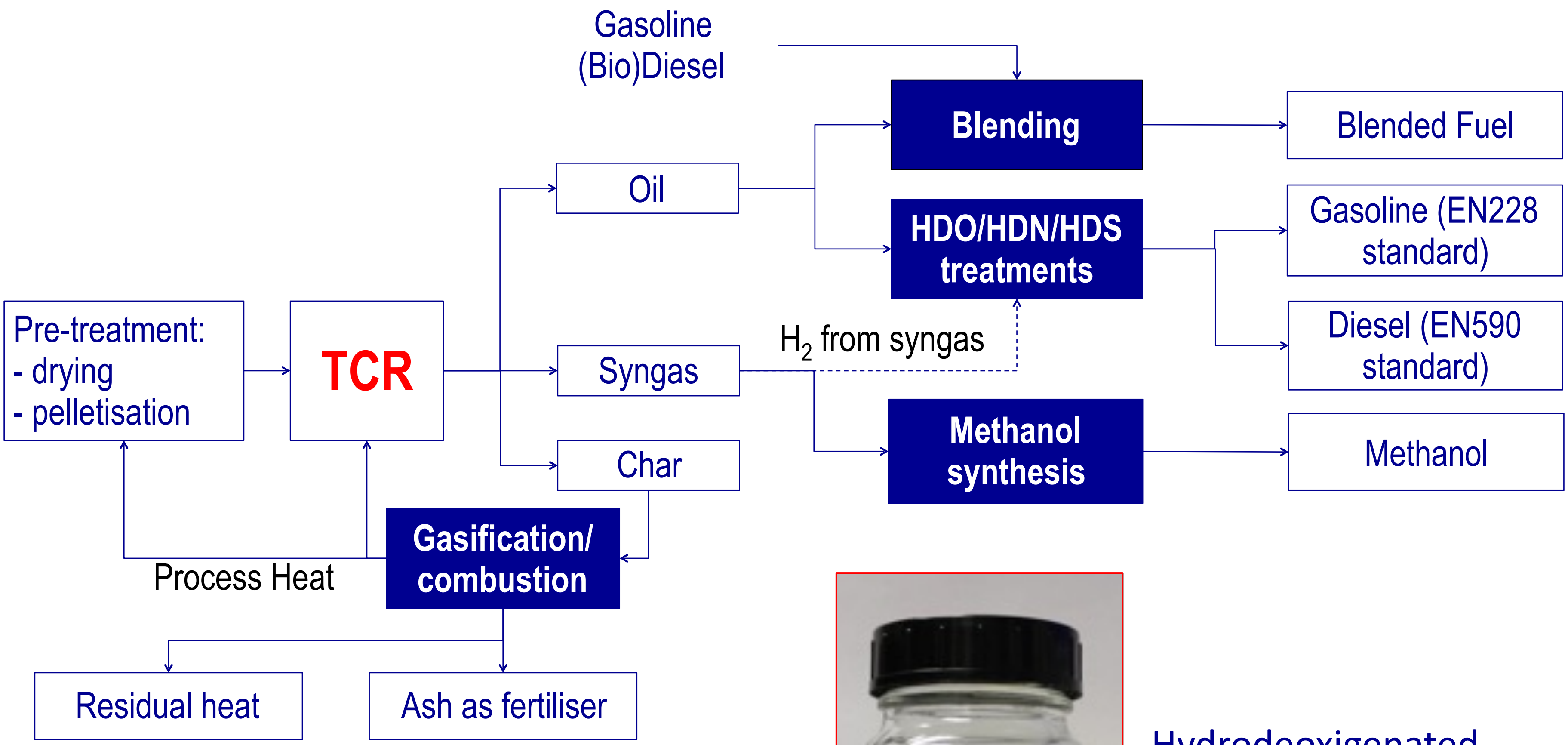
Energy balance using residues from anaerobic digestion as feedstock

Syngas: energy production in IC engines

Oil: engine applications in fuel blends

Char: energy production, agronomic applications (soil conditioner)

TCR: products upgrading to biofuels

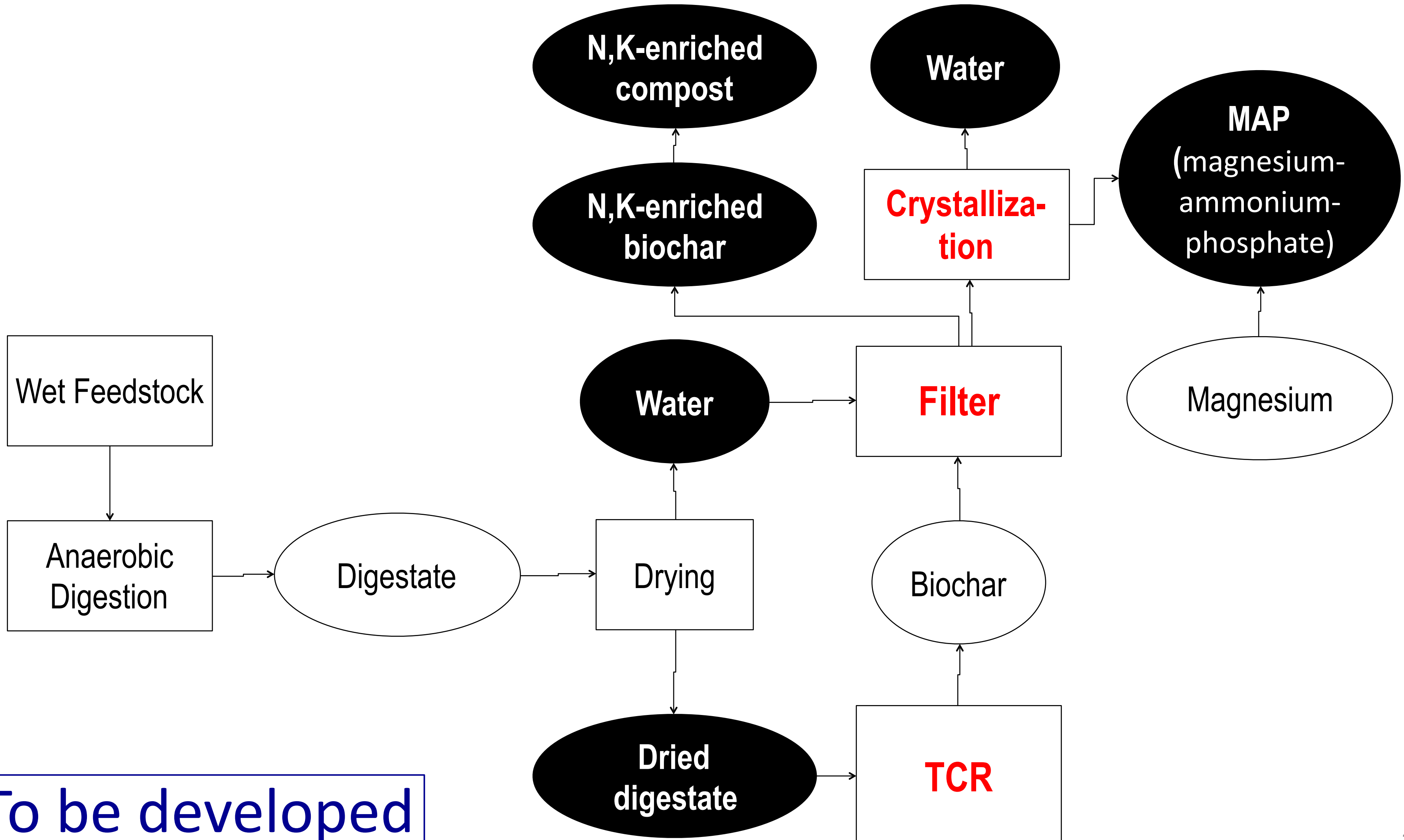


Hydrodeoxigenated TCR-oil from digestate

Small scale tests

TCR: nutrients recovery

N, P, K recovery through biochar

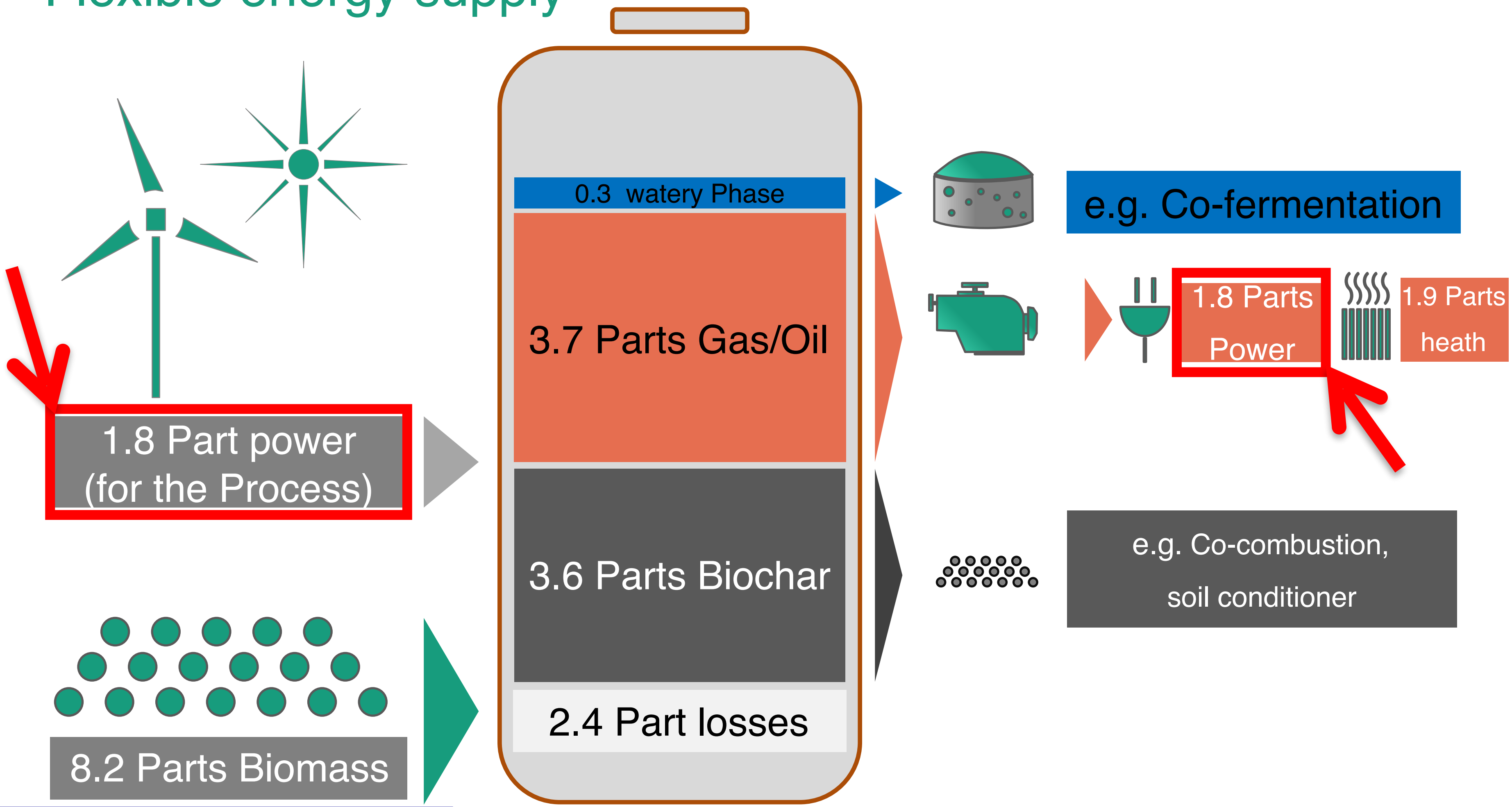


To be developed

TCR: energy storage

Biobattery application

Flexible energy supply



To be developed

TCR: Pyrolysis + reforming

TCR®: Thermo Catalytic Reforming

Very recent development (last 3 years)

Intermediate temperature pyrolysis
(550-700 °C, heating time: minutes)

Products: char + high temp. vapors
Hot char is used for vapor reforming at 700 °C

Vapors condensate in liquid + gas

- The reforming produces smaller molecules in the oil and increases the quantity of hydrogen in the syngas up to 40%
- The water phase is easily separated from the oil by gravity
- Oil can be blended with diesel or biodiesel

Tested on municipal wastes, anaerobic digestate, sewage sludge

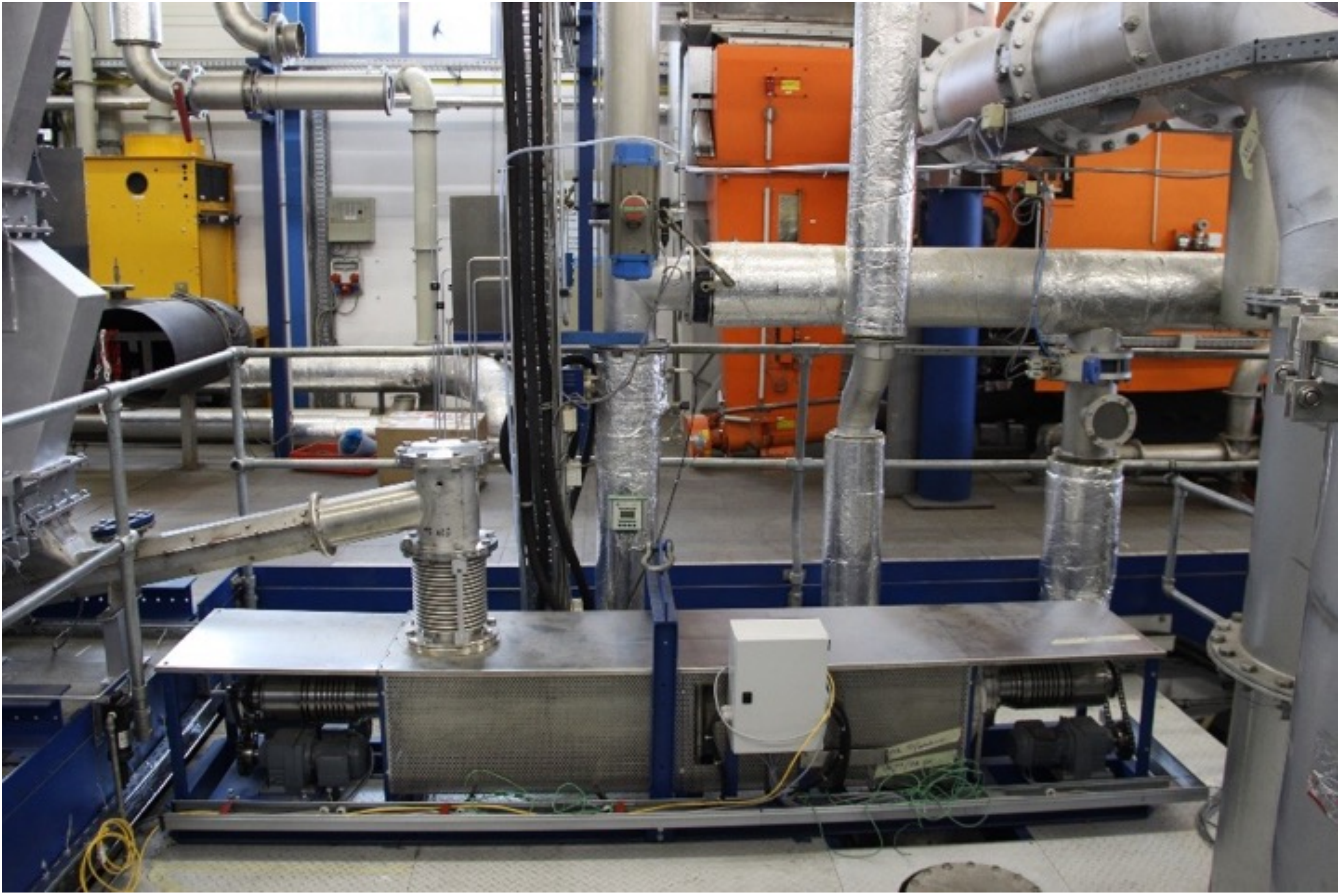
The process has been developed and patented by Fraunhofer Gesellschaft (UMSICHT Institute, Sulzbach-Rosenberg Branch)

TCR prototypes

2 kg/h lab-scale reactor

30 kg/h pilot plant at Fraunhofer UMSICHT

A TCR capable of treating 30 kg/h is now installed and operating at Fraunhofer UMSICHT



TCR industrial plant

300 kg/h Schwandorf - Germany 2018

Biorefinery

il concetto di bioraffineria

recupero di nutrienti: fosforo

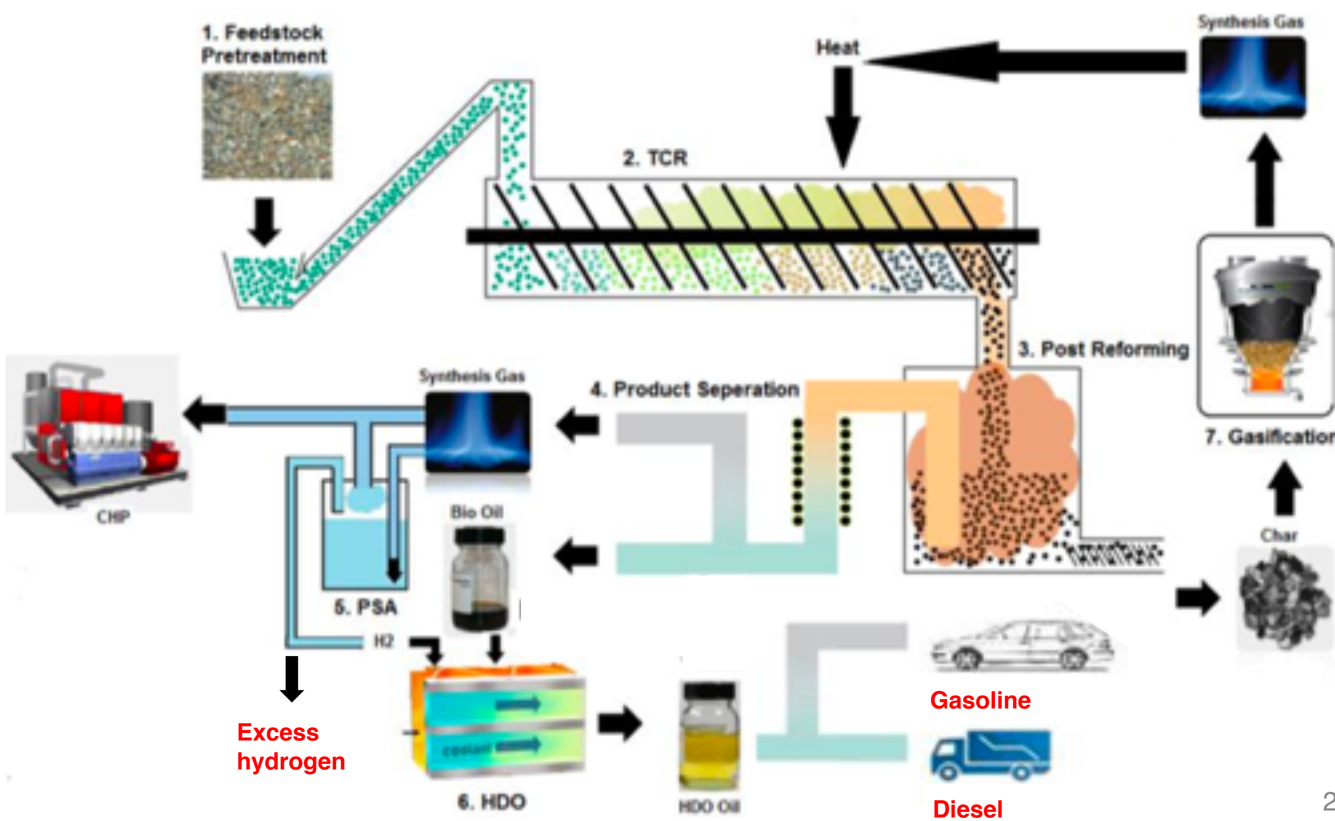
H2020 Project TO-SYN-FUEL

Demonstrate and validate the technical and commercial viability of a 300 kg/h plant of TCR®.

In order to have a drop-in fuel, further processing will be tested: Pressure Swing Adsorption (PSA) to get purified hydrogen out of syngas and hydrodeoxigenation (HDO), with a possible implementation into existing petroleum infrastructures.

Demonstrate the production of Synthetic Fuels and Green Hydrogen from organic waste biomass, mainly sewage sludge.

Total Budget: 14.5 M€
EU financing: 12.2 M€



Bio-oil + HDO

Hydrodeoxygenation:

$R_2O + 2\ H_2 \rightarrow H_2O + 2\ RH$

Catalysts: sulfided nickel-molybdenum or cobalt-molybdenum

Part of standard hydrotreating in oil refineries (HDS, HDN, HDO)

	Component	Mass balance in g/100 g feed
Feed	TCR bio-oil	100,00
	H_2	6,62
Products	HDO TCR oil	82,97
	Reaction water	13,50
	CO_x	0,00
	H_2S	0,16
	NH_3 (diff.)	4,53
	Methane	0,76
	Ethane	1,61
	Propane	1,50
	Butane	1,46
	Isobutane	0,13

Before HDO

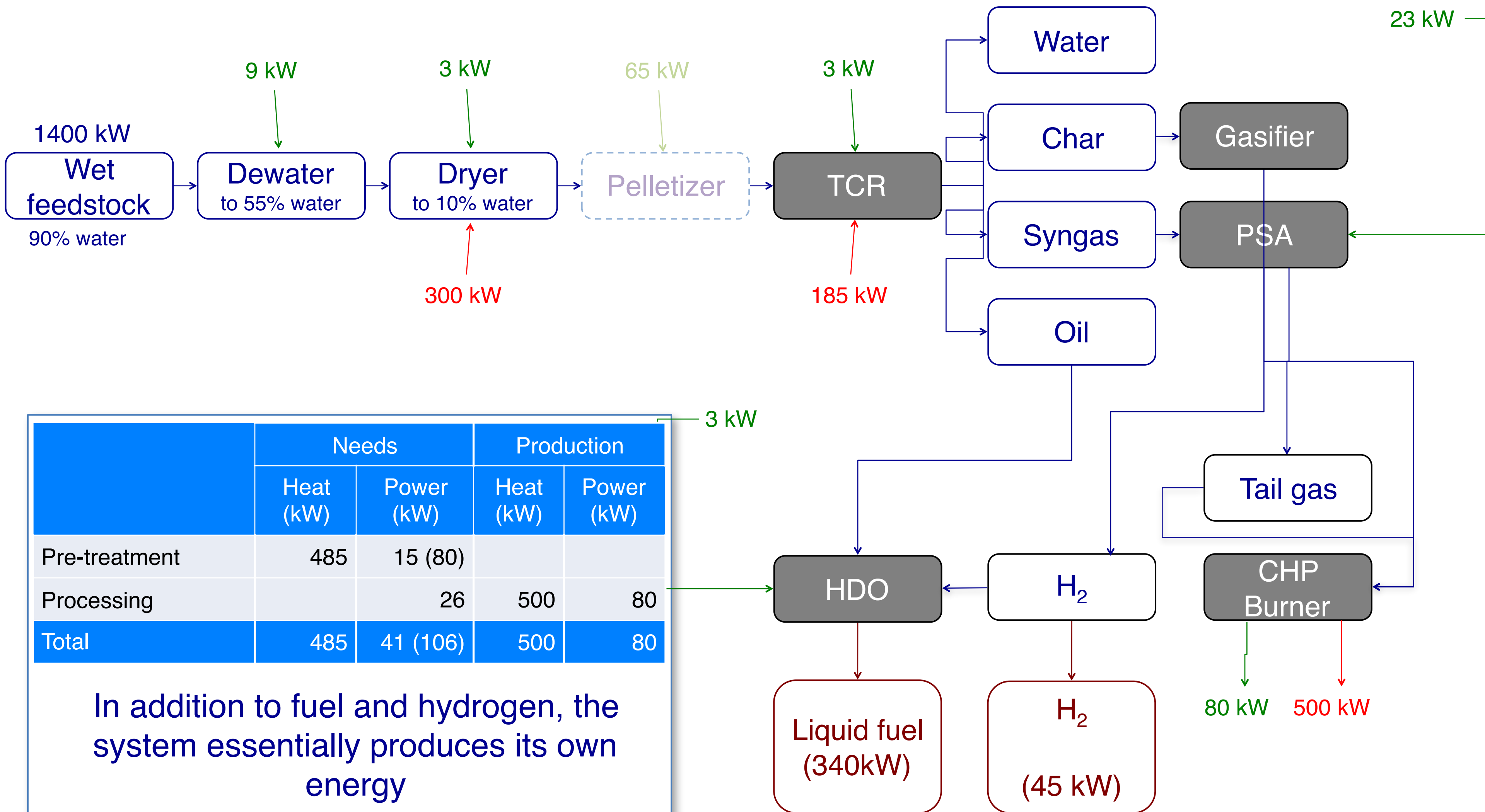
Physical Properties	Units	TCR-HDO oil	Fossil Diesel
Higher Heating Value	MJ/Kg	46	44.7
Lower Heating Value	MJ/Kg	43	41.9
Acid Number	Mg KOH/g	0.02	0.02
Viscosity	cSt	1.4	3.0
Water	Wt%	<0.1	<0.1
Ash	Wt%	<0.01	<0.01
Ultimate Analysis			
C	Wt%	86	84.7
H	Wt%	13.6	13.2
N	Wt%	0.5	<0.1
S	Wt%	<0.1	<0.1
O*	Wt%	0.7	1.4

Drop-in fuel: directly usable in cars

After HDO

Source: Johannes Neumann et al., Upgraded biofuel from residue biomass by Thermo-Catalytic Reforming and hydrodeoxygenation, Biomass and Bioenergy 89 (2016) 91-97

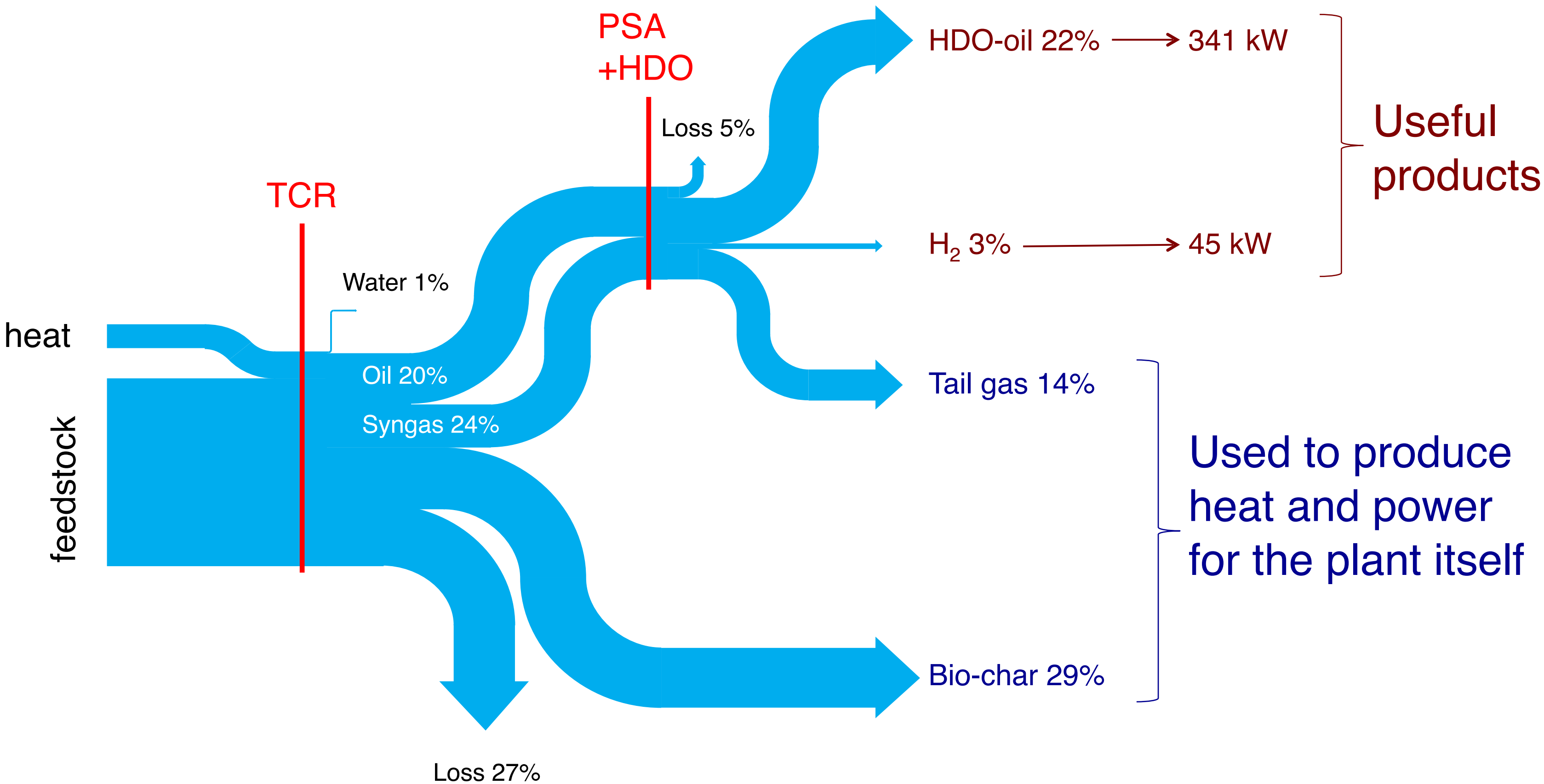
Process



	Needs		Production	
	Heat (kW)	Power (kW)	Heat (kW)	Power (kW)
Pre-treatment	485	15 (80)		
Processing		26	500	80
Total	485	41 (106)	500	80

In addition to fuel and hydrogen, the system essentially produces its own energy

Energy Balance



R&D needs

TCR

- go from lab-scale prototypes (2-30 kg/h) to industrial pilot scale (300 kg/h)
- test the uniformity of heating of feedstock
- scan the feedstock-pyrolysis temperature-reforming temperature-product quality parameter space
- apply to large scale feedstock treatment (uniformity checks)

Coupled pyrolysis/anaerobic digestion

- go from lab-scale prototypes (5 kg/h) to industrial pilot scale (50 kg/h)
- apply the method to different feedstocks

H2020 Project TO-SYN-FUEL

Plant design and installation

Fraunhofer UMSICHT

Susteen Technologies GmbH

engie

HYGEAR

Oil refinery operators

eni

VTS

Engine tests

UNIVERSITY OF BIRMINGHAM

Disseminations

GrantCraft

etaflorence renewableenergies

SNB

Feedstock provider

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

LEITAT Technological Center

Environmental and Social Life Cycle Assessment

2synfuel

Cost for a 3 tons/h Plant

Note: 3 tons/h is the maximum foreseeable size of a TCR/PSA/HDO plant

Capital costs		
Equipment purchase cost (PCE)	**7,200,000**	**€**
Construction costs	3,600,000	€
Physical Plant Cost (PPC)	**10,800,000**	**€**
Engineering, Contractors, Contingency	2,700,000	€
Full Cost (FC)	**13,500,000**	**€**
Working capital (3% of FC)	400,000	€
Total Capital Cost (TCC)	**13,900,000**	**€**
Operating costs		
Total Operating costs	**980,000**	**€**

Result		
Operation hours/year	**7,000**	**h/y**
Total products income	**1,434,000**	**€/y**
Avoided gate fees (10 €/ton)	**1,890,000**	**€/y**
Total income	**3,324,000**	**€/y**
Gross profit	**2,344,000**	**€/y**
Net profit	**1,641,000**	**€/y**
Payback time	**8.5**	**y**

Present cost of gasoline at the refinery gate	**0.58**	**€/kg**	[EIA, 2016]
Present cost of H2	**2.55**	**€/kg**	[DOE, 2012]

Delocalization

Production of sewage sludge: approx. 30 kg/inhabitant/y (dry matter)

3 t/h ➡ 21000 t/y ➡ 700,000 inhabitants

Delocalization is an advantage

How many plants?

Feedstock	Europe (million tons/year d.m.)	World (million tons/ year d.m.)
Sewage sludge	12	75
Anaerobic digestion digestate	100 (est.)	200 (est.)
Farming residues	120	500 (est.)
Municipal Organic Waste	450	2,200
Agro-food industry residues	2,000 (est.)	5,000 (est.)
TOTAL	~2,700	~ 8,000
Production upper limit HDO-oil	~ 250 (~ 10,000 PJ)	~ 700 (~ 30,000 PJ)
No. of plants (3 tons/h)	130,000	380,000

To be tested in follow-up projects

90 b€/y in 20 years

Note: crude oil imports in EU: 140 b€/y
http://ec.europa.eu/energy/en/data-analysis/eu-crude-oil-imports

2 sostenibilità

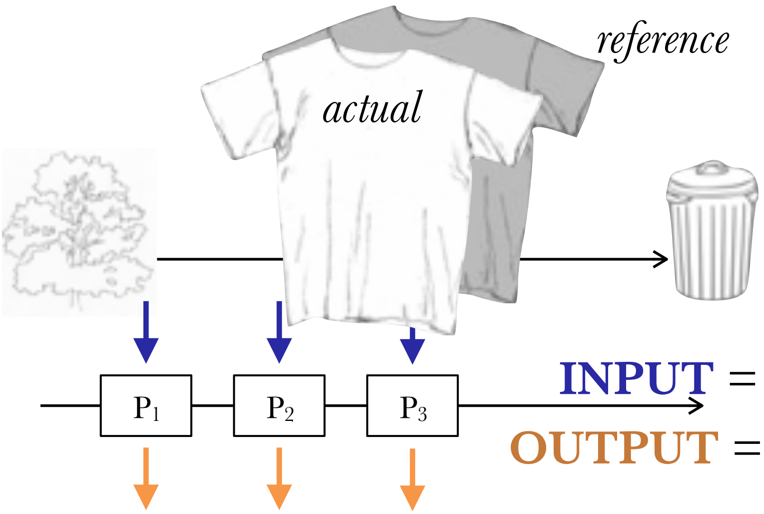
2synfuel

HOW did they get this?

HOW TO EVALUATE CHANGES? BETTER A COTTON MADE T-SHIRT OR SYNTHETIC ONE?

LCA

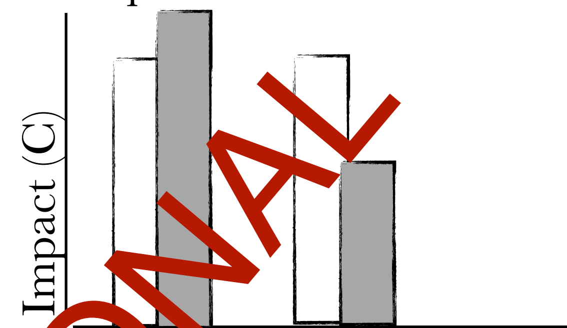
Functional Unit (**FU**) e.g. t-shirt dresnable 2000 times



Key words

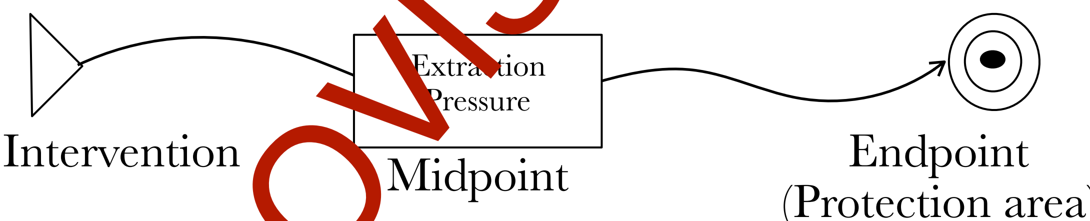
Goal
Scope
Inventory
Impact
Interpretation

Typical response with midpoint indicators



INPUT = Extraction factors (x) and impact on resource availability

OUTPUT = Pressure factors (x) and impact on health & environment



$$I_c = \sum_{x}^{n} CF_{x,c} \cdot m_x$$

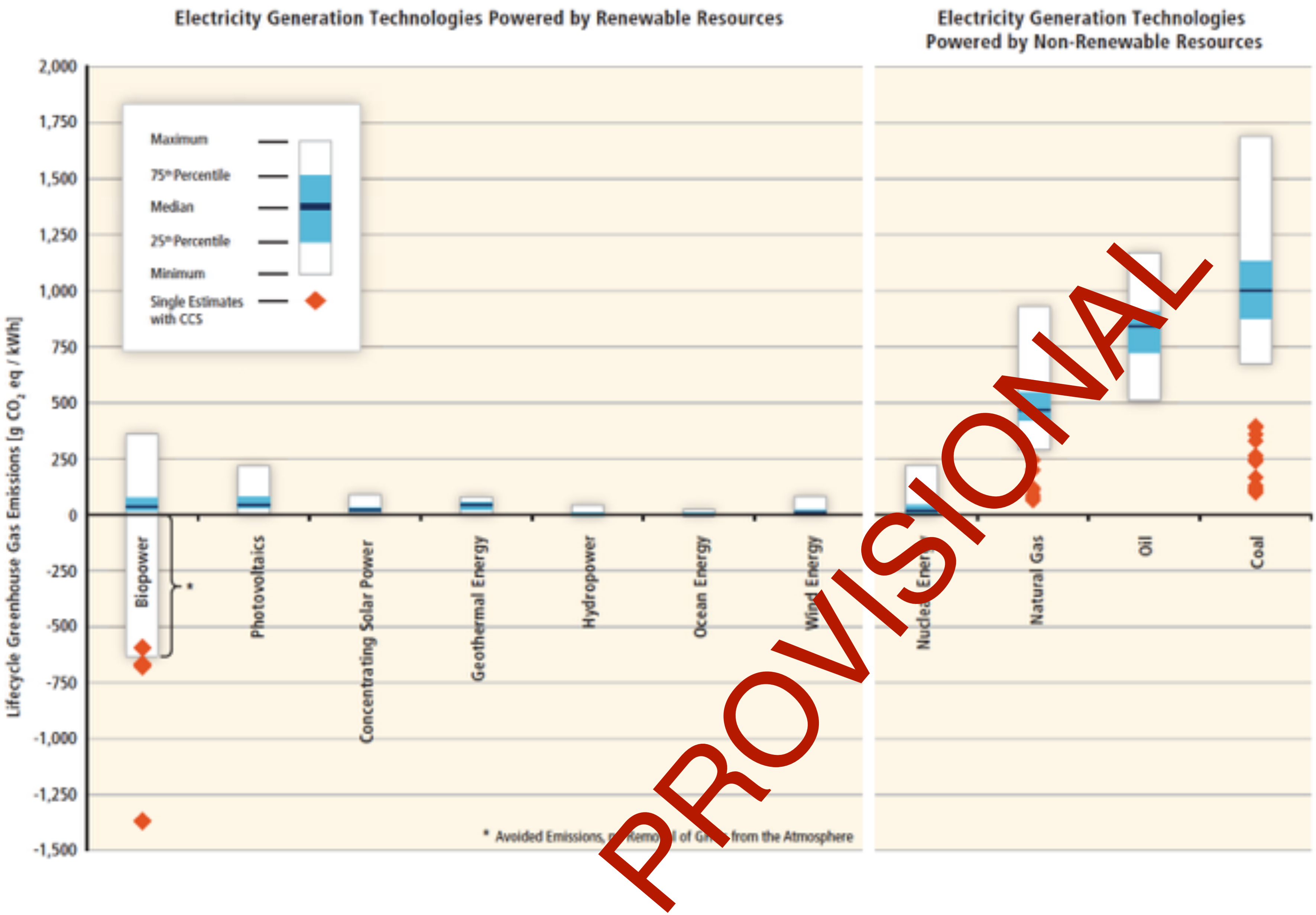
Characterisation factors CF for amount *m* of input or output can be get from inventories

Models describe and quantify impacts

Softwares provide to us CFs and allow modelling

thinkstep

Stepwise and standardised procedure (ISO 14040 + ILCD)



[IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation: Renewable Energy in the Context of Sustainable Development]

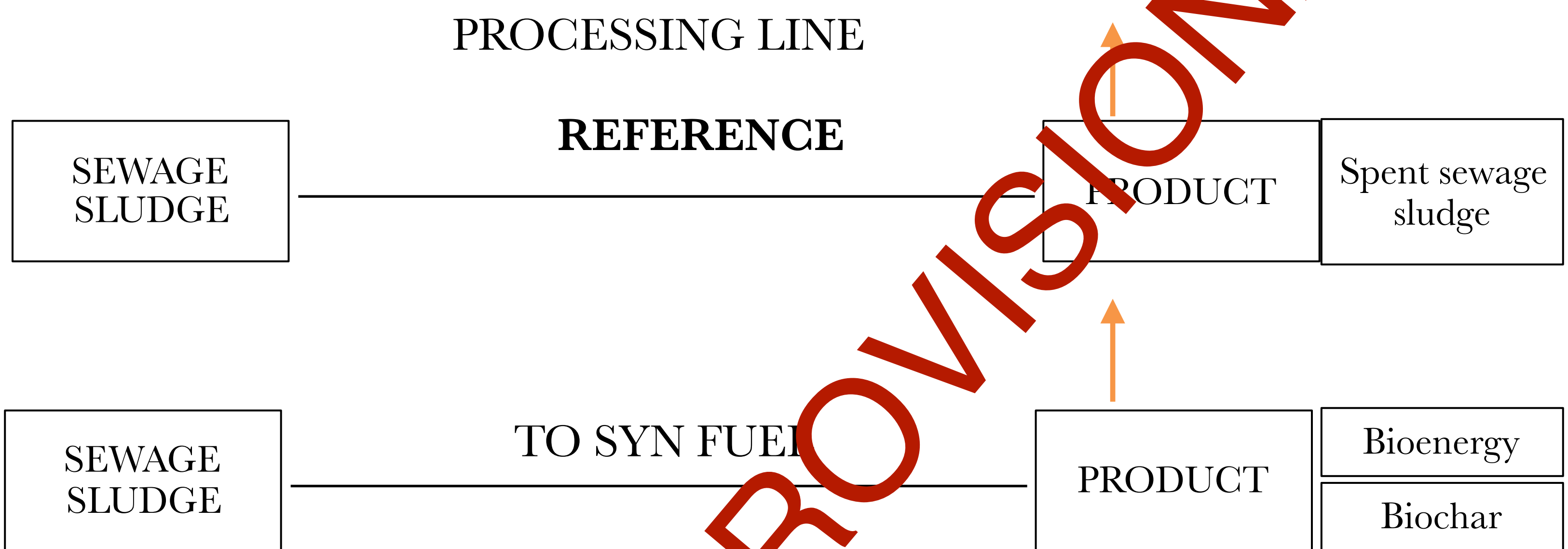
TO-SYN- FUEL - CARBON FOOTPRINT

supply chain: from sewage sludge to advanced biofuel and green hydrogen;

when considering LCA and the business as usual scenario (counterfactuals) we shall consider sewage sludge treatments, including anaerobic digestion.

FU = 1 TON
OF TREATED SLUDGE

g CO$_{eq}$/kg

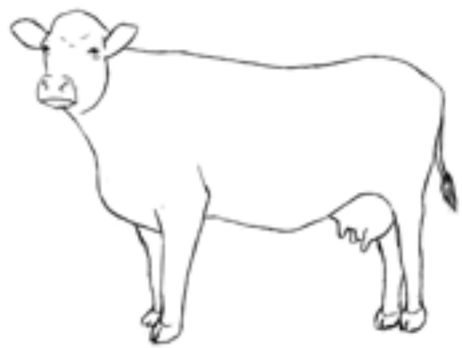


Focus is on the measure of biogenic emissions and storage (biochar) accountability

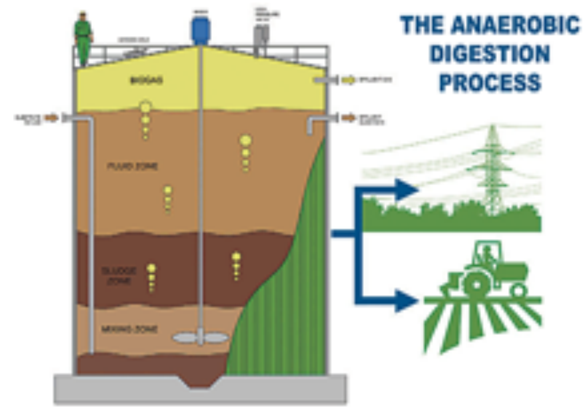
TYPICAL BIOGENIC EMISSIONS BROUGHT ON BY ANTHROPOGENIC ACTIVITIES

combustion

livestock enteric
emissions & cropland oxidation



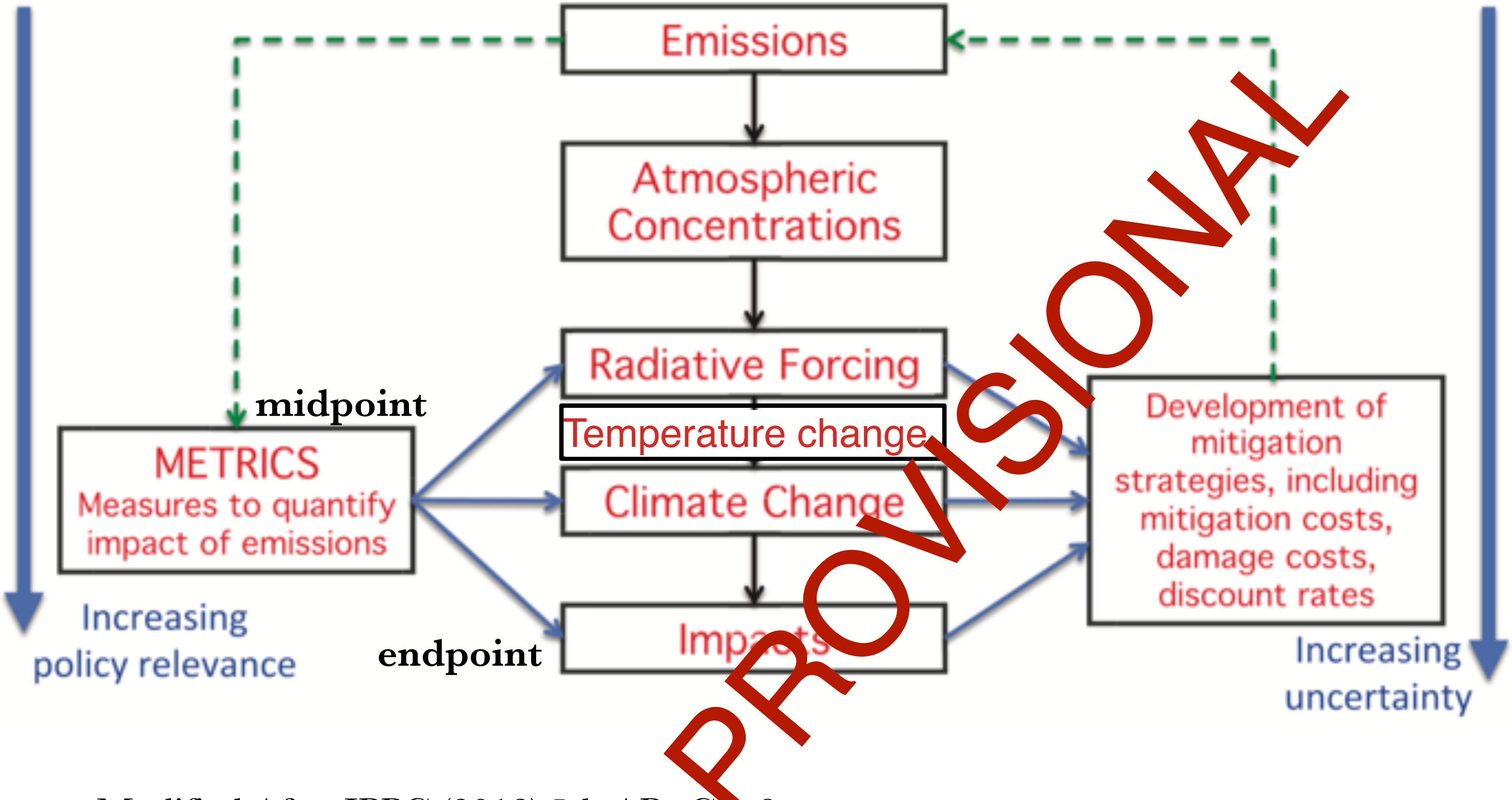
fugitive emissions of
biogas/biomethane for
transportation
and other fermentation
process along the supply
chain



TOPIC ISSUES

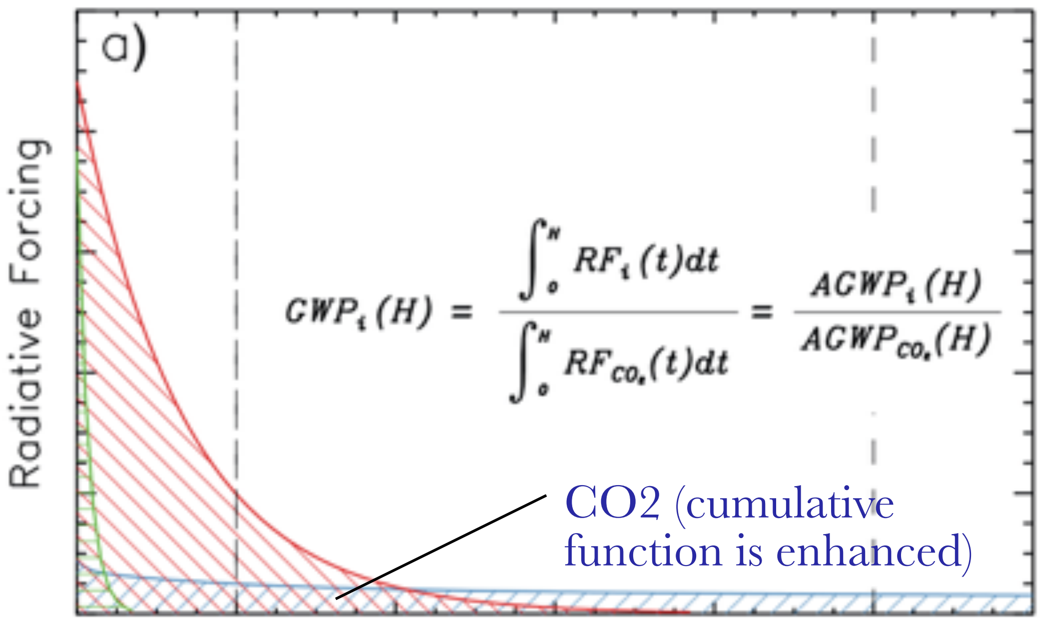
1. metrics (GWP, GTP)
2. carbon sequestration
3. baseline choice
   (counterfactuals scenarios)

METRICS



Modified After IPPC (2013) 5th AR, Ch. 8

Global warming potential (GWP) “relative cumulative forcing index” (IPCC 2013)



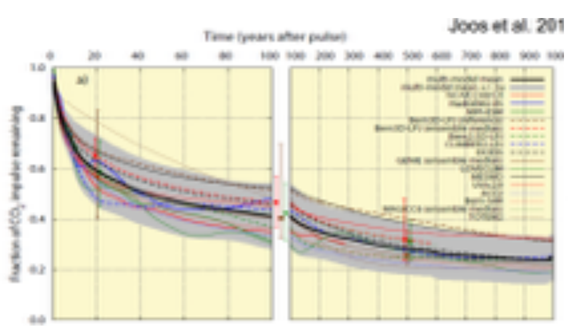
IPPC (2013) 5th AR, Ch. 8

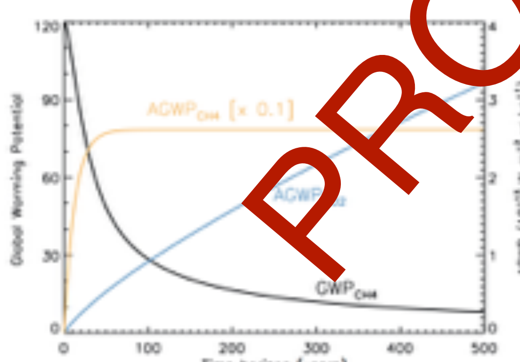
- $[kgCO2\text{ -eq } kg^{-1}]$ Index of total energy added to the atmosphere over a given time horizon
- Based on radiative forcing of greenhouse gases (GHG) in the atmosphere
- GWP measures the *relative* effect of the *i* GHG vs CO2

Relative cumulative forcing index’ would be more appropriate

$$RF_{CO_2}(t) = A_{CO_2}\left\{a_0 + \Sigma_{i=1}^{3} a_i e^{-t/\tau_i}\right\}$$

IRF = Impulse Response Function



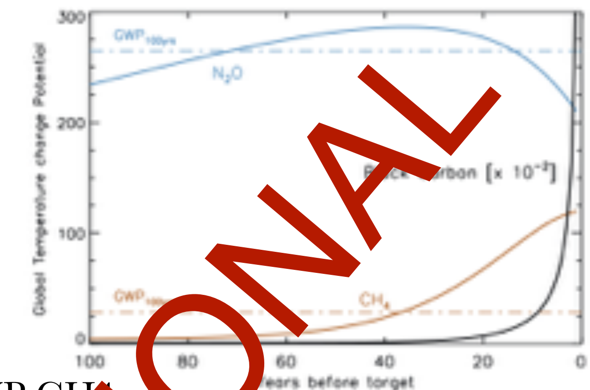


Substance	Lifetime (y)	GWP 20y	GWP 100y
Carbon dioxide (CO_2)		*1*	*1*
Methane (CH_4)	12.4	86	34
Nitrous oxide (N_2O)	121	268	298
Tetrafluoromethane (CF_4)	50’000	4950	7350

Global Temperature change potential (GTP)(IPCC 2013)

GTP(t)i = AGTP(t)i / AGTP(t)CO2 = ΔT((t)i /ΔT(t)CO2

CO2 compared



- $[kgCO_2\text{-}eqkg^{-1}]$

the change in global mean surface temperature at a chosen point in time in response to an emission pulse relative to that of CO2

- GWT measures the *relative* effect of the i GHG vs

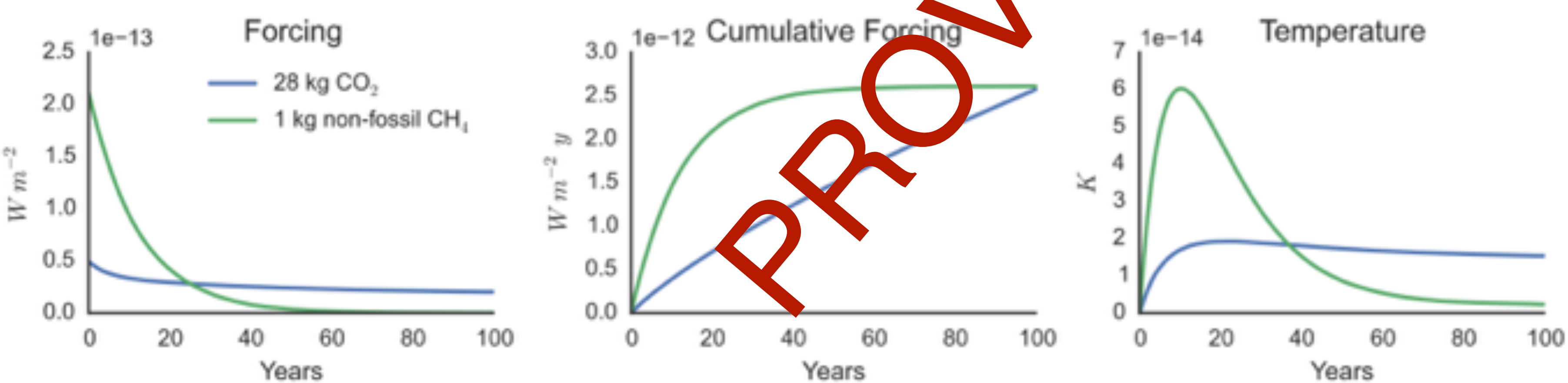
CO2 : likewise GWP, can be used for weighting the emissions to obtain 'CO2 equivalents' ; time horizon has a strong effect on the metric values

- similar to GWP, yet may be more relevant for

determining environmental consequences of emissions; relevant as for black carbon (**BC**)

GWP CH4

Metric	Time horizon = 20 years	Time horizon = 100 years
GWP (without feedbacks)	84	28
GWP (with feedbacks)	86	34
GTP (without feedbacks)	67	4
GTP (with feedbacks)	70	11



A. Levasseur et al. / Ecological Indicators 71 (2016) 163–174

GWP$_{bio}$ indicator based on Impulse Response Function(IRF) aka Cherubini method (2011): convolution between atmospheric CO2 decay and carbon sequestration in biomass (Accepted by IPPC 5th AR)

$$f(t)_i = \int_0^t e(t')_i \, y_{CO_2}(t-t') \, dt' - \int_0^t NEP(t')_i \, y_{CO_2}(t-t') \, dt'$$

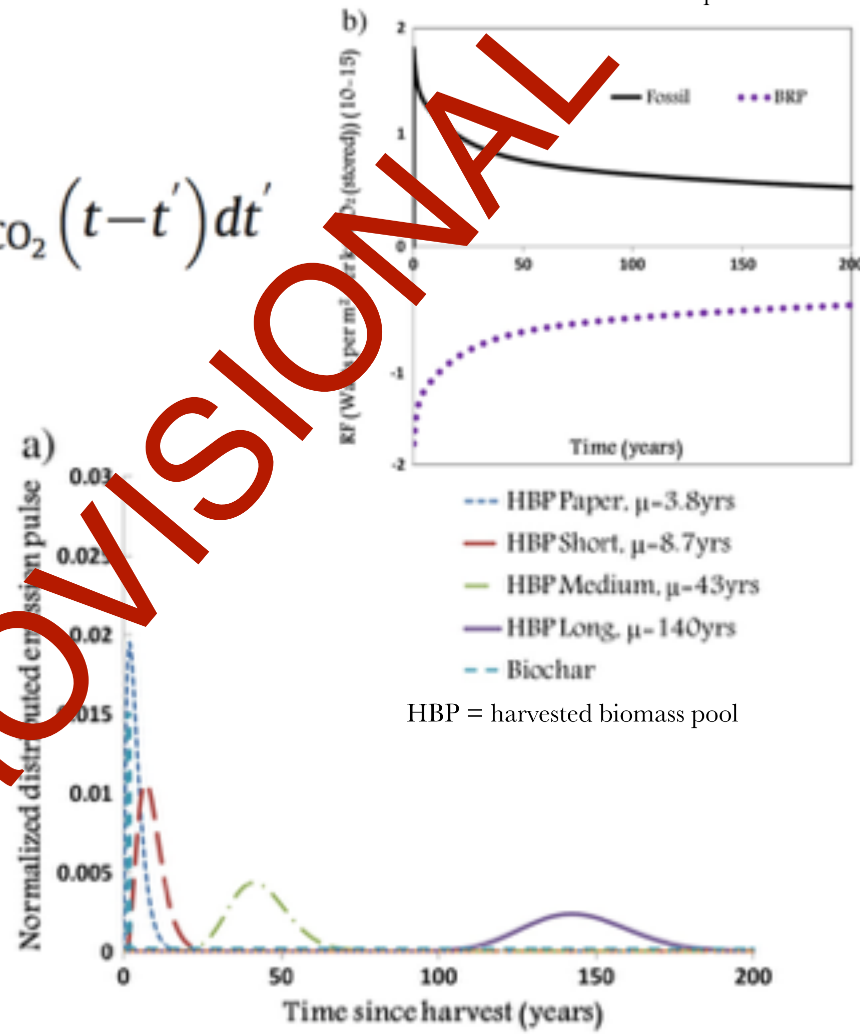
decay IRF

e(t) is the unit distributed emission profile of the carbon that oxidizes to the atmosphere

$$GWP = \frac{\int_0^{TH} RF_{bio-CO_2}(t)dt}{\int_0^{TH} RF_{CO_2}(t)dt} = \frac{\int_0^{TH} k_{CO_2} \cdot f(t)dt}{\int_0^{TH} k_{CO_2} \cdot y_{CO_2}(t)dt}.$$

NEP(t) is the net ecosystem productivity normalized to the biomass yield that is extracted and utilized as a product (i.e. normalized to the unit emission profile e(t)).

RBP = biomass resource pool



HBP = harvested biomass pool

G. Guest et al. / Environmental Impact Assessment Review 43 (2013) 21–30

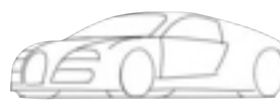
Baseline choice and counterfactuals (reference scenarios)

Problem: how to account biogenic emissions deriving from C stocks of a **new technology** meeting these conditions:

1) they are in scope (meaning also that the baseline flow is diverted and modified for industrial purposes
2) they are biogenic meaning that carbon is deriving from renewable sources

new technology route

SEWAGE SLUDGE → PROCESSING →



What are counterfactual thoughts?

- "Counterfactual thoughts are mental representations of alternatives to past events, actions, or states. They are epitomized by the phrase "**what might have been**," which implicates a juxtaposition of an imagined versus factual state of affairs" (Epstude & Roese, 2008).

Counterfactual in Emilia Romagna 2015

SEWAGE SLUDGE → PROCESSING → LAND APPLICATION

Same stock -- comparable emissions yet different **RF.** Both pathways are artificial.
Shall we account BIO-CH4 fugitive emissions likewise fossil CH4?

Baseline definitions for bioenergy from wood-fired biomass; modified from Johnson and Tschudi 2012.

Baseline type	Description
No baseline	All biomass is carbon neutral
Reference point	Net carbon stock of a defined piece of land is compared between the start and finish of the measurement period.
Marginal fossil fuel	The footprint of wood power equals net carbon emissions from a forest minus avoided emissions from a fossil-fuel-fired alternative.
Biomass opportunity cost	The footprint of wood power equals the carbon stock intentionally harvested to generate electricity.

Wood-fired electricity footprints, by baseline type.

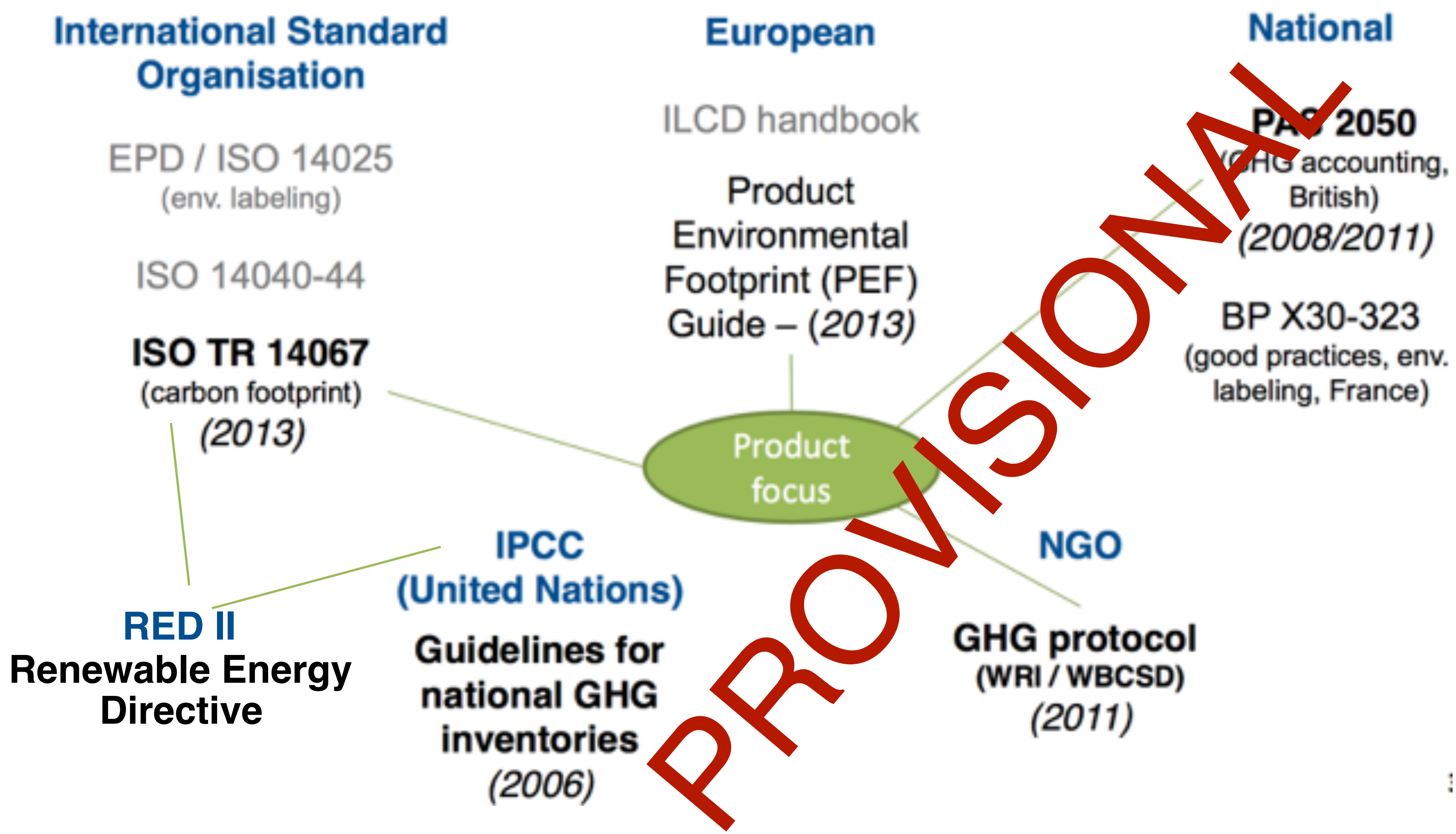
Baseline	Absolute footprint ($g\ CO_2/kWh$)	Relative footprint (as a multiple of 'no baseline')
No baseline	39	1.0
Reference point	266	6.9
Marginal fossil fuel[a]		
Natural gas, average	−107	−2.8
Natural gas, state-of-the-art	135	3.5
Coal, average	−544	−14.0
Biomass opportunity cost	536	13.9

a.k.a 'carbon debt': see Cherubini method.n.a

The footprint of biogenic emissions are the net emissions due to the technology route minus avoided emissions of the *counterfactual* scenario.

Depends on the choice of the counterfactual

n.a.


International Standard Organisation
EPD / ISO 14025
(env. labeling)
ISO 14040-44
ISO TR 14067
(carbon footprint)
(2013)
European
ILCD handbook
Product Environmental Footprint (PEF) Guide – (2013)
National
PAS 2050
(GHG accounting, British)
(2008/2011)
BP X30-323
(good practices, env. labeling, France)
Product focus
RED II
Renewable Energy Directive
IPCC
(United Nations)
Guidelines for national GHG inventories
(2006)
NGO
GHG protocol
(WRI / WBCSD)
(2011)

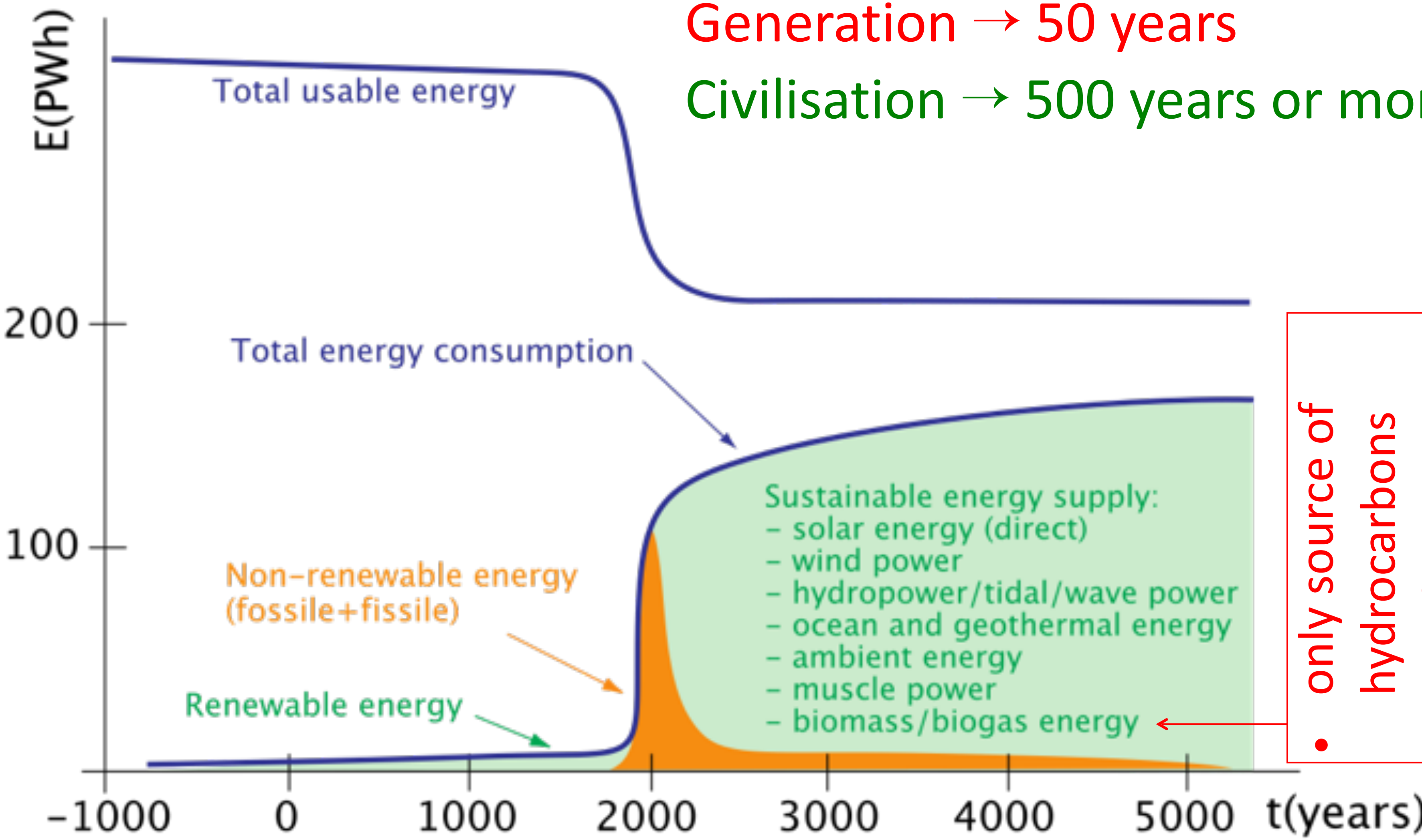
3 LE SFIDE

A civilisation point of view

Politics → 5 years

Generation → 50 years

Civilisation → 500 years or more



- only source of hydrocarbons
- circular economy

source CMDC/WSEC

The problem

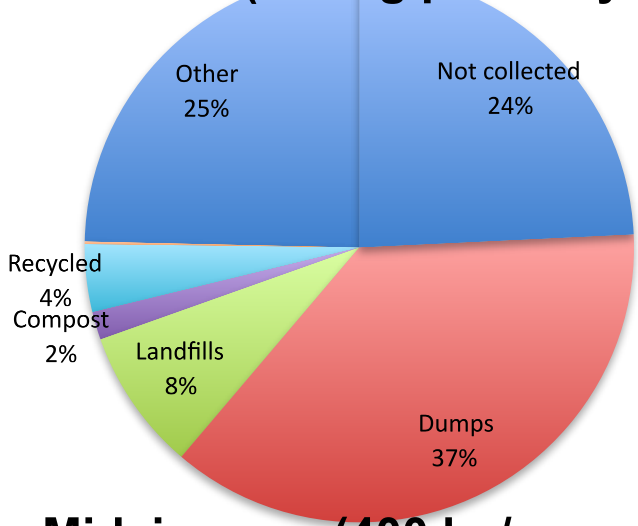
World solid waste production by **urban** population:
1.3 billion tons/year ⇨ 440 kg/capita/year, out of which nearly half is organic.

Very large stock of secondary material to be managed in the best possible way

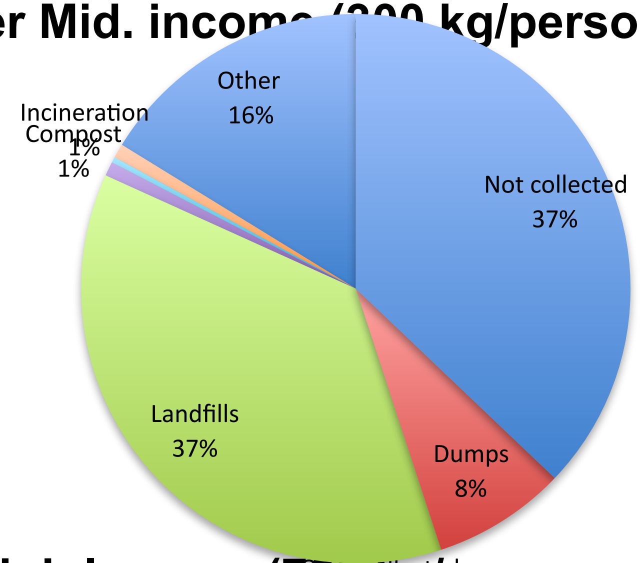
Source: The World Bank, WHAT A WASTE **-** A Global Review of Solid Waste Management (2012)

Solid waste production and disposal

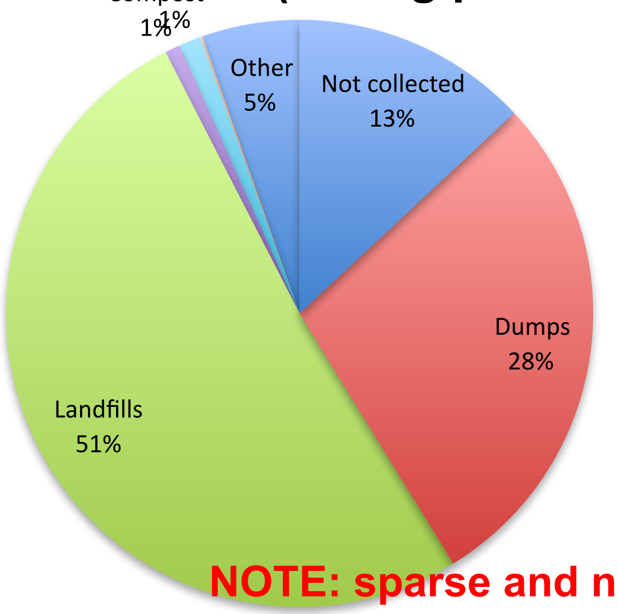
Low income (200 kg/person-year)



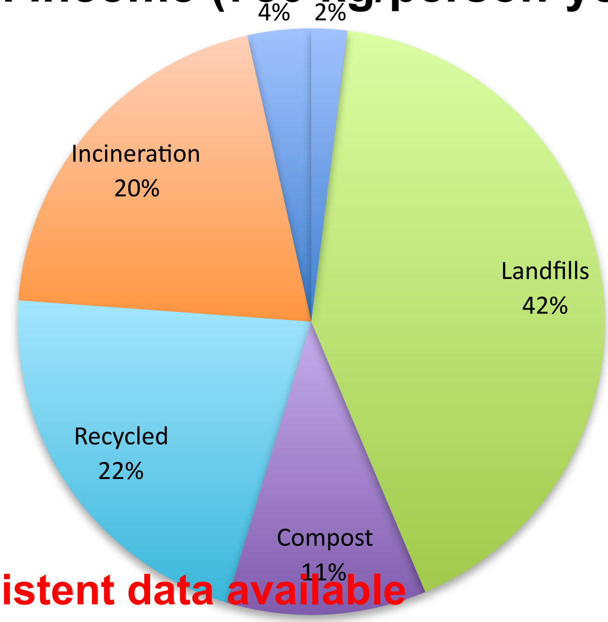
Lower Mid. income (300 kg/person-year)



Upper Mid. income (400 kg/person-year)



High Income (750 kg/person-year)



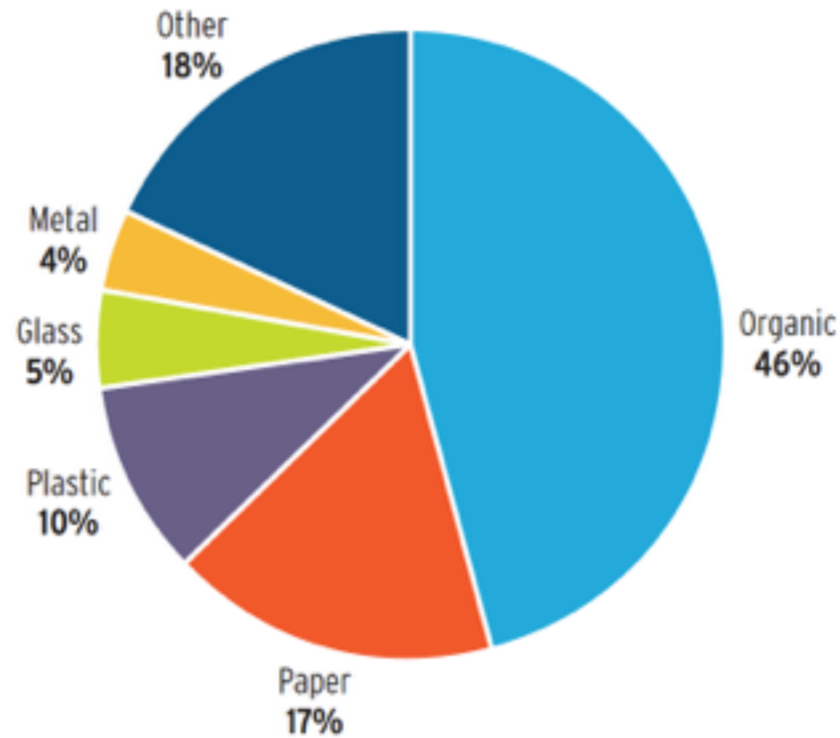
NOTE: sparse and not always consistent data available

Source: The World Bank, WHAT A WASTE - A Global Review of Solid Waste Management (2012)

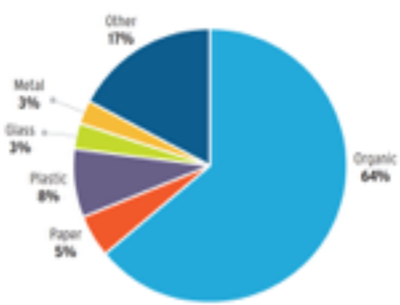
Solid waste composition

Residential
Commercial
Institutional
Construction and Demolition
Municipal Services
Industrial and Process
Medical
Agricultural

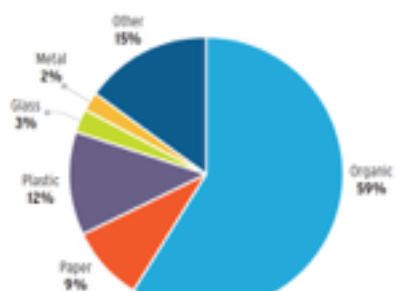
} if the municipality oversees their collection and disposal



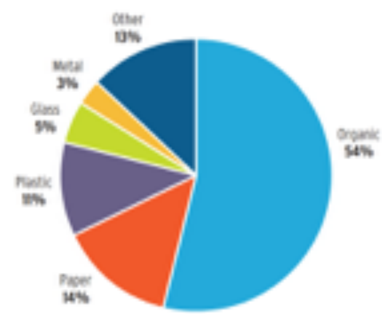
Low Income



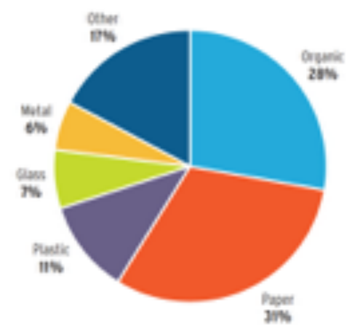
Lower Mid. Income



Higher Mid Income



High Income



Source: The World Bank, WHAT A WASTE - A Global Review of Solid Waste Management (2012)

Projection to 2025

	2010	2025
Urban population	2.9	4.3 billion
Solid waste production	434 1.3	511 kg/capita/year 2.2 billion tons/year

total organic	1	billion tons/year
energetic content	3000	kcal/kg
total energy content	1.3×10^{19}	J/year
	303	Mtoe/year
	2.2×10^{9}	barrels/year
total oil production	3×10^{10}	barrels/year

Percent of oil production = 7.5%

Source: The World Bank, WHAT A WASTE - A Global Review of Solid Waste Management (2012)

Other feedstock: agriculture residues

Europe:
Average grain production: 5.7 t/ha/year
Average straw production (40% collection, 20% wet): 2.9 t/ha/year
Total straw production: 120 million tons/year (to be compared with 300 million tons of solid waste)

USA:
Total straw production (dry, below 60 $/t): 200 million tons/year

There is probably as much ligno-cellulosic feedstock available as organic solid waste

Source for Europe: http://bisyplan.bioenarea.eu/ The Bioenergy System Planners Handbook (2012)
Source for USA: DOE: 2011 Billion-Ton Update,

The Project

Large scale pilot pyrolyser with reforming

- capacity: 300 kg/h (2,100 t/year, dried biomass)
- dealing with organic solid wastes, agricultural residues, forestry management products, residues from wood manufacture industries

Small scale pilot pyrolyser without reforming coupled to an anaerobic digestor

- capacity: 50 kg/h (400 t/year)
- fitting in a 20" standard container, dealing with all kinds of food production wastes from farms and industrial manufacturers (canning, juice and wine production, etc.)

Present financing from European Regional Funds (test TCR 2kg/h): Thermo-chemical treatment for zero waste (product upgrading – small scale) – budget 1 M€ total

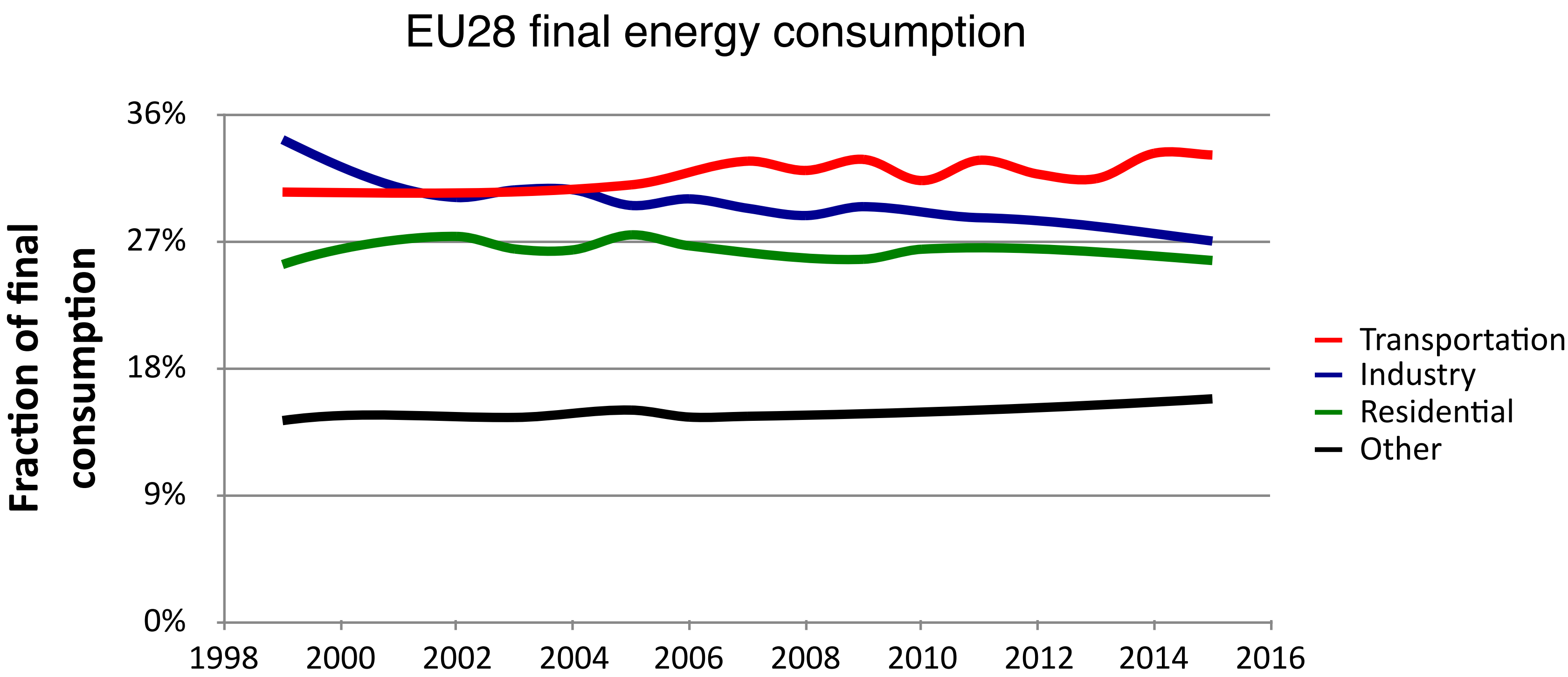
Larger co-financing looked at through three EU H2020 Proposals (deadlines September 8th, 13th and 16th):

- Products and Chemicals from low value agricultural residues – (ProChem) – budget 11 M€
- Advanced biofuel pathways (TO-SYN-FUEL) – budget 12.5 M€
- Sustainability Transition Assessment and Research of Bio-based Products (STAR-ProBio) – budget 5 M€

Conclusions

- Pyrolysis is a way to treat all kind of organic residues
- Avoidance of gate fees makes the system economically viable
- De-localization is an important advantage

Transportation



We are asked for solutions by the European Commission
(every year, one or two projects on biofuels financed by H2020 program)

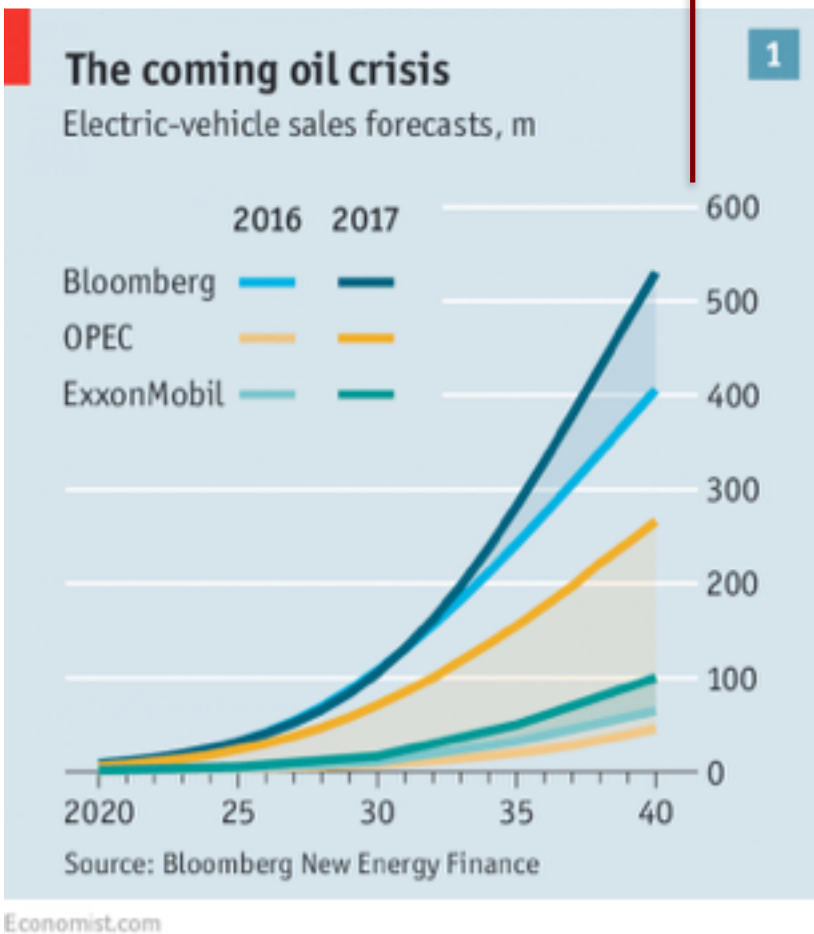
Main drivers:

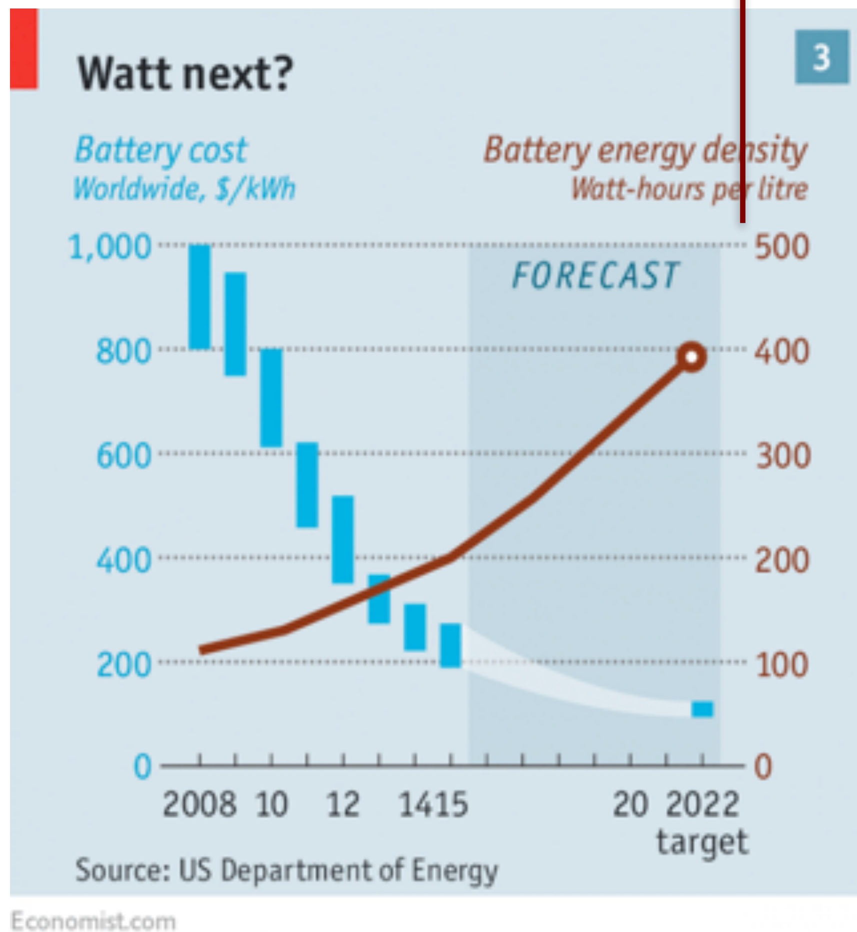
- reduction of the energy dependence from abroad
- technological development and jobs

Fuel or electricity for cars?

cars:
1.5 billion

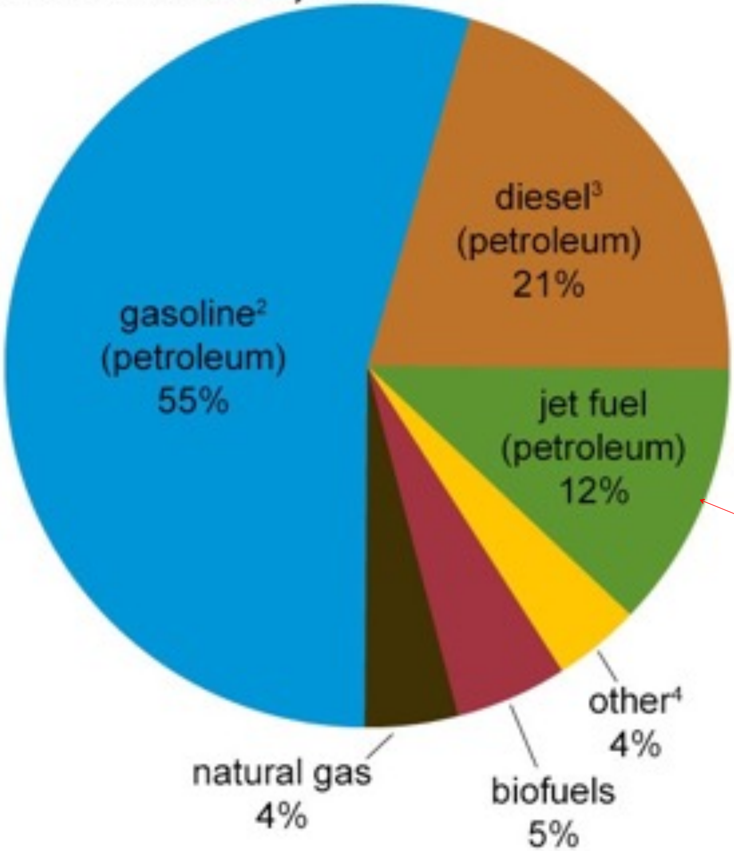
Gasoline:
3,500 Wh/liter
(including IC
engines
efficiency)





Aviation

U.S. transportation energy sources/fuels, 2016[1]



Jet Fuel accounts for 12% of consumption in USA

[1] Based on energy content
[2] Motor gasoline and aviation gas; excludes ethanol
[3] Excludes biodiesel
[4] Electricity, liquefied petroleum gas, lubricants, residual fuel oil, and other fuels

Note: Sum of individual components may not equal 100% because of independent rounding.

Source: U.S. Energy Information Administration, *Monthly Energy Review*, Tables 2.5 and 3.8c, April 2017, preliminary data

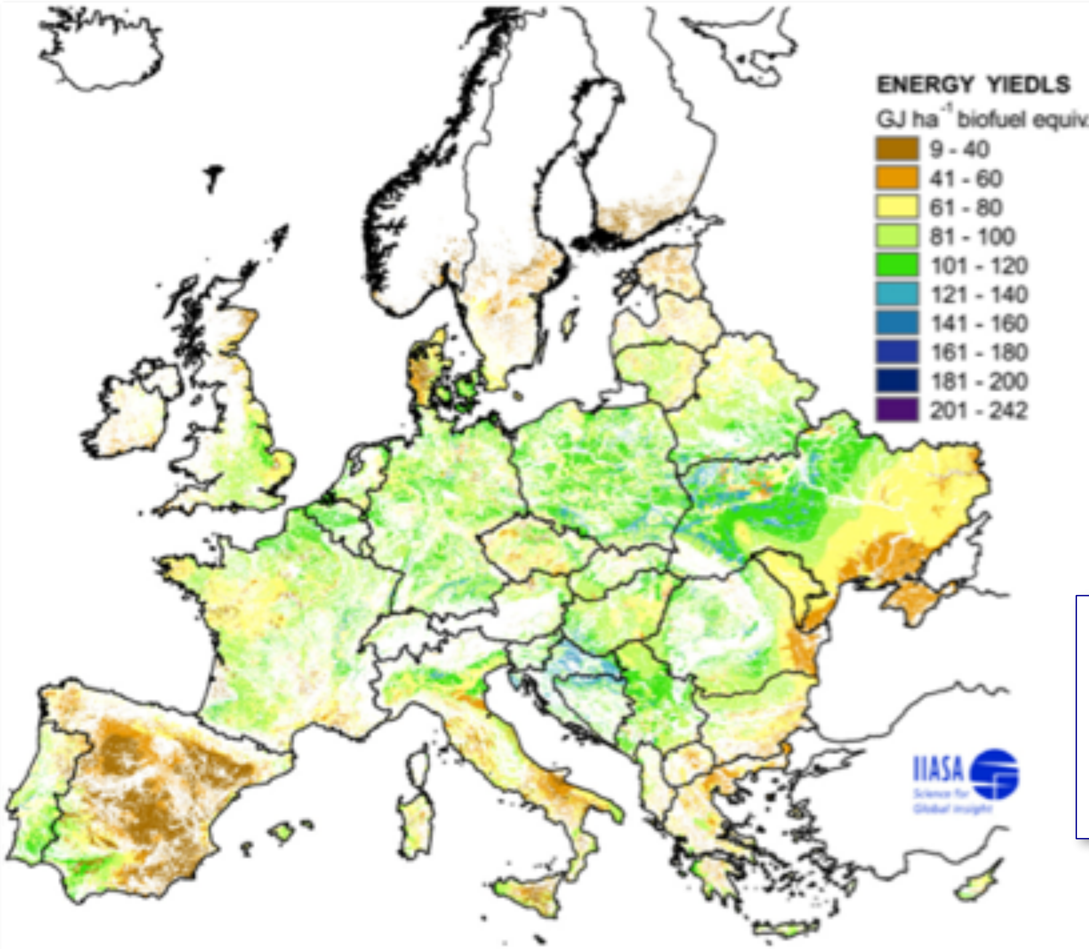
Which biomass? And which kind of technology for biomass?

Cultivated crops, agricultural waste and forest residues	➠	Combustion
Oil seed crops (esterification)	➠	Bio-diesel (esterified oil)
Starch or glucose-producing plants (fermentation)	➠	Bio-ethanol
Wet biomass (anaerobic digestion)	➠	Bio-methane
Any residual biomass (pyrolysis)	➠	Bio-oils for fuel or as substitute for oil in the chemical industry

Combustion	➠	low efficiency for electricity (25-30%), particulate emissions – essentially dedicated to heat production
Bio-diesel	➠	Needs dedicated crops (with low productivity), marginal production from used cooking oil and animal grease
Bio-ethanol	➠	Needs dedicated crops, no commercial plant yet for enzyme destruction of lignin to treat ligno-cellulosic material
Bio-methane	➠	Relatively low production (about 60% of organic input material is transformed), digestate may be used as fertilizer
Pyrolysis	➠	Treat all kind of biomass, need of pretreatment (drying and maybe pellettisation)

1st generation biomass: dedicated crops

Energy yield with 1st generation biofuels



Strong competition with food

Total yield: 2,000 ÷ 4,000 PJ

IEA - International Energy Outlook 2016
Europe consumption

gasoline+diesel	13,500 PJ
jet fuel	2,200 PJ
total	15,700 PJ

G. Fischer, S. Prieler, H.van Velthuizen, G. Berndes, A. Faaij, M. Londo, M. de Wit, Biofuel production potentials in Europe: Sustainable use of cultivated land and pastures. Part II: Land use scenarios, Biomass and Bioenergy, 34 (2010) 173-187 (REFUEL FP7 project)

Focus on 2nd generation feedstock

World solid waste production by **urban** population:
1.3 billion tons/year ⇨ 440 kg/capita/year, out of which nearly half is organic.

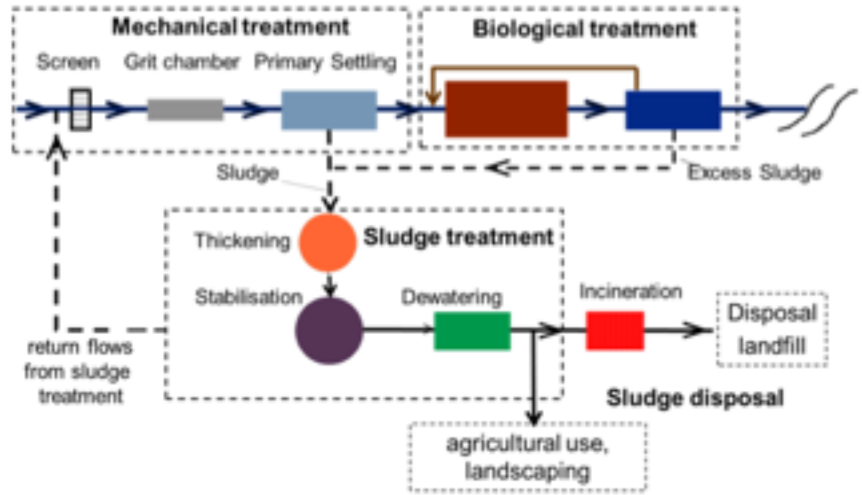
Very large stock of secondary material to be managed in the best possible way

Source: The World Bank, WHAT A WASTE - A Global Review of Solid Waste Management (2012)

Another 2nd generation feedstock

World sewage sludge production from wastewater treatment: 75 million tons/year (dry matter)

Wastewater treated: less than 10%



Source: A. Vaccani & Partner, International Market Developments in the Sewage Sludge Treatment Industry, May 2017

Yet another 2nd generation feedstock

Europe:
Average grain production: 5.7 t/ha/year
Average straw production (40% collection, 20% wet): 2.9 t/ha/year
Total straw production: 120 million tons/year (to be compared with 300 million tons of solid waste)

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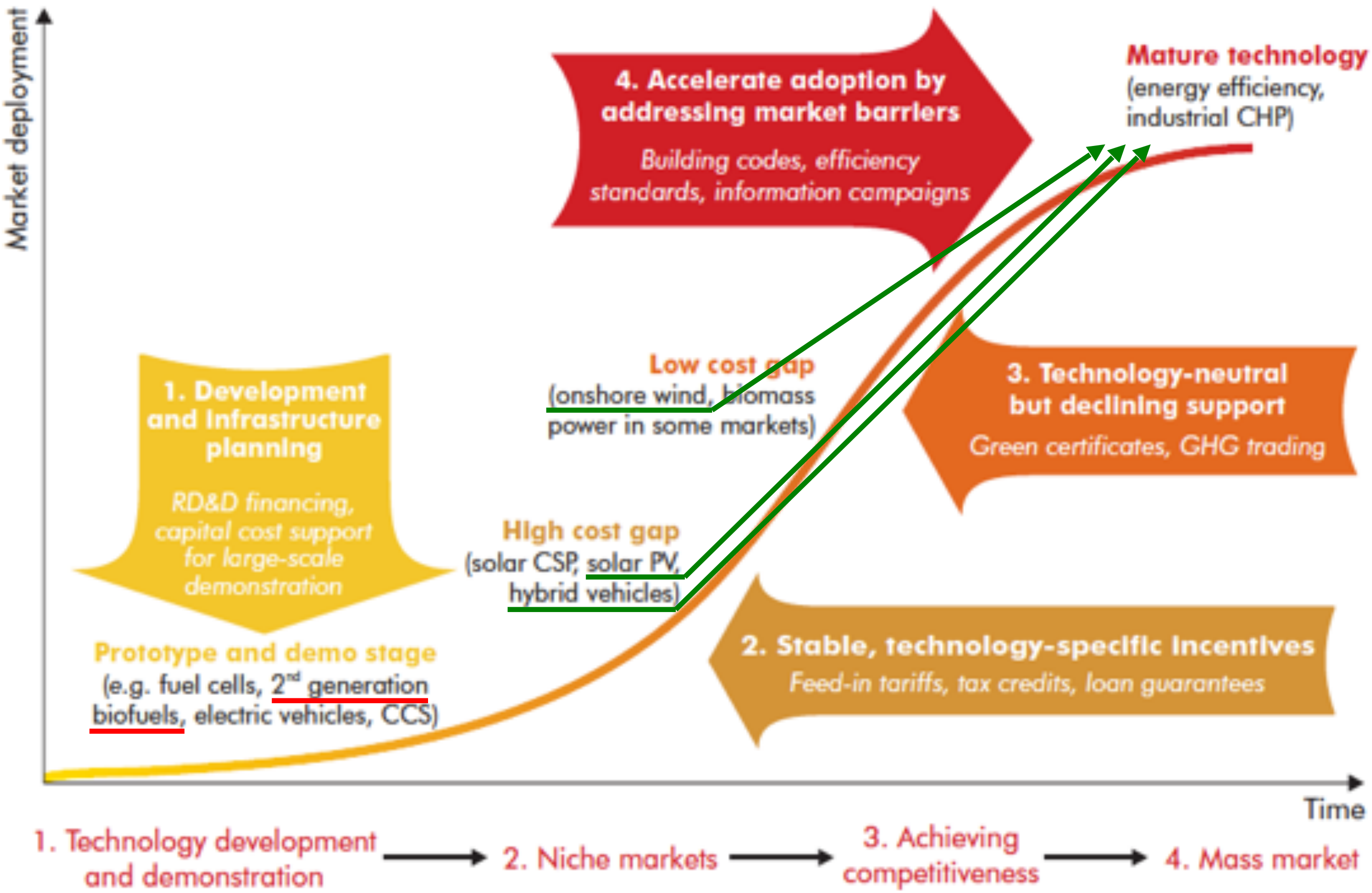
Source for Europe: http://bisyplan.bioenarea.eu/ The Bioenergy System Planners Handbook (2012)
Source for USA: DOE: 2011 Billion-Ton Update,

Technology readiness level

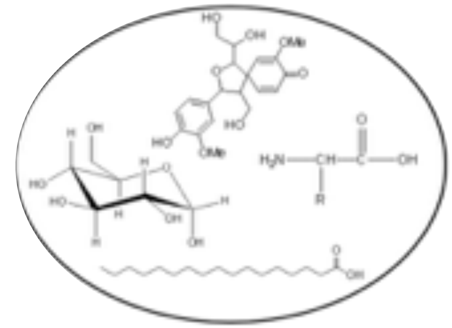
International Energy Agency

Energy Technology Perspectives 2010



WHY TO GO FOR BIOBASED PRODUCTS

The unique selling point of materials from renewable biomass is chemical functionality. The same functionality can be achieved by processing virgin naphtha (fossil oil) at price of higher energy expenditure.



Optimal array of 1 t of intermediate biobased product from petrochemical route and from biomass (grass) and related cumulative energy demand (CED)

58 GJ/ton

Styrene
Phenol
Toluene
Ethylene
Ammonia
Ammine
Fertilisers

7.13 GJ/ton

POTENTIAL ADVANTAGES

- diminished GWP, acidification potential, eutrophication and persistent pollutants
- some biobased products are biodegradable

Brehmer et al. doi:10.1016/j.cherd.2009.07.010

…a step back in history…

Nineteenth century salt works considered the foul smelling petroleum a real nuisance-.

Samuel Kier of Pittsburgh in the latter 1840's was the first to give crude petroleum a sustained market value when in 1848 he packaged pure crude oil from Tarentum area salt wells in half-pint bottles for sale as a medicine. A half-pint bottle of Kier's Petroleum, or Kier's Rock Oil, sold for 50 cents. (2 USD/lt)

About 1849, at the suggestion of a Professor Booth – a Philadelphia chemist, Kier began manufacturing in Pittsburgh an illuminating oil for lamps, called carbon oil, by distilling small batches of crude petroleum twice and then allowing the distillate to sit out in the air in shallow metal pans for clarifying. This distilled and treated petroleum lamp oil found a market around Pittsburgh and, later, New York.

By 1853, Kier's carbon oil was selling for a $1.50 a gallon, or $60.00 /bl.

...a step back in history...

biochemtex

1859 -Edwin Drake -
The First Oil Well Was Known as "Drake's Folly"

Once Drake began working in the oil business he became motivated to increase production at the oil seeps.
The solution seemed to be to dig into the ground to get to the oil. Drake reasoned that he could drill for oil, using a technique similar to that used by men who had drilled into the ground for salt. He experimented and discovered iron "drive pipes" could be forced through the shale and down to where oil deposits should be.

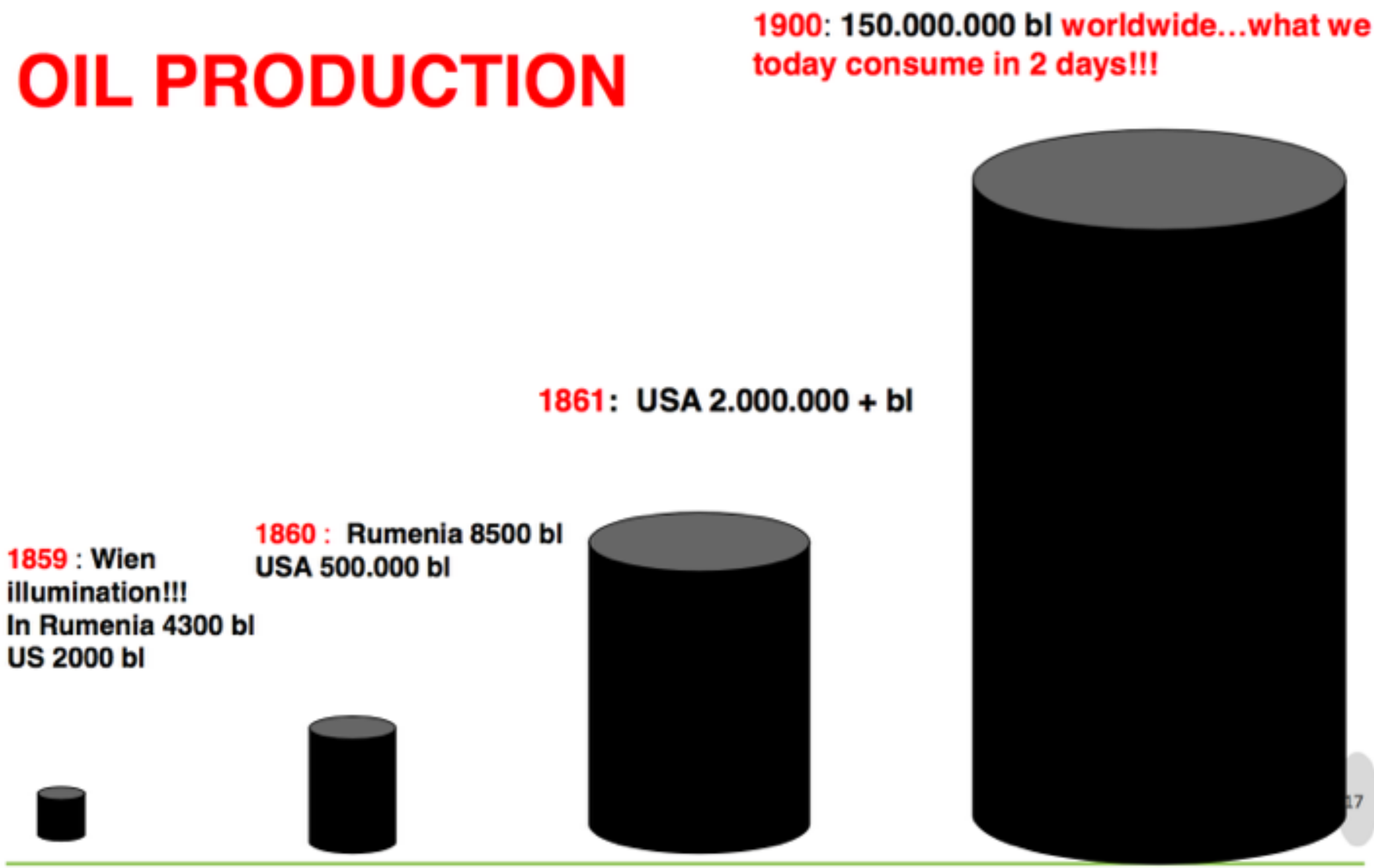
The oil well Drake constructed was called "Drake's Folly" by some of the locals, who doubted it could ever be successful.
But Drake persisted, with the help of a local blacksmith he had hired.

At a slow progress, three feet a day, the well kept going deeper, until, on August 27, 1859, it reached a depth of 69 feet (21 mt…the first oil well)

Few numbers...

biochemtex

OIL PRODUCTION



The inventions

biochemtex

- **The electric bulb** December 31, **1879**, in Menlo Park **Edison**
- made the first public demonstration of his incandescent light
- bulb. It was during this time that he said: "*We will make electricity so*
- *cheap that only the rich will burn candles....”*
- **Internal combustion engine** - **1876** - **Nikolaus August Otto** - inventor of the first engine to efficiently burn fuel directly in a piston chamber. Although other internal combustion engines had been invented, Otto was the first to make it practical and was immediately successful.
- **Karl Benz** **1886** - Benz designed and built his own **four stroke engine** that was used in the first automobiles in production.
- **Wilhelm Maybach - 1893 -** technical director of Daimler Motor Company, invented the **float-feed carburetor**, which made it possible to use gasoline to power internal combustion engines.
- **Rudolf Diesel (DIESEL MOTOR)** -1892 -patents for "Method of and Apparatus for Converting Heat into Work". At Ausburg, on August 10, **1893,** Rudolf Diesel's prime model, a single 10-foot (3.0 m) iron cylinder with a flywheel fat its base, ran on its own power for the first time. **In 1896** Diesel demonstrated another model with a theoretical efficiency of 75%, in contrast to the 10% efficiency of the steam engine. By 1898, Diesel had become a millionaire.

Barrel of oil

biochemtex

OIL COMPOSITION

Carbon - 83 to 87%
Hydrogen - 10 to 14%

Mixture of compounds up to 350!!!

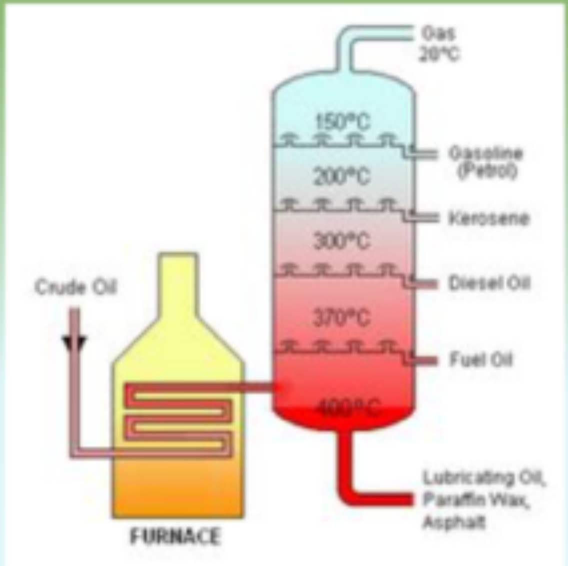
C1-C2-C3 - Gas form
From C4 on liquids…

C4 to C10 -Gasoline

Above C40 – Asphalt

Between C10 and C40 everything!!!

OIL FRACTIONATION



Crude oil is separated into fractions by fractional distillation. All of the fractions are processed further in other refining units

Use and limits

biochemtex

The *problem*:

Only 11% is usable as fuel…all the rest have to be used elsewhere (illumination).

In 1913 the fuel consumption is higher then the request for illumination…

A *solution* is needed.

The next inventions:

Burton and Houdry

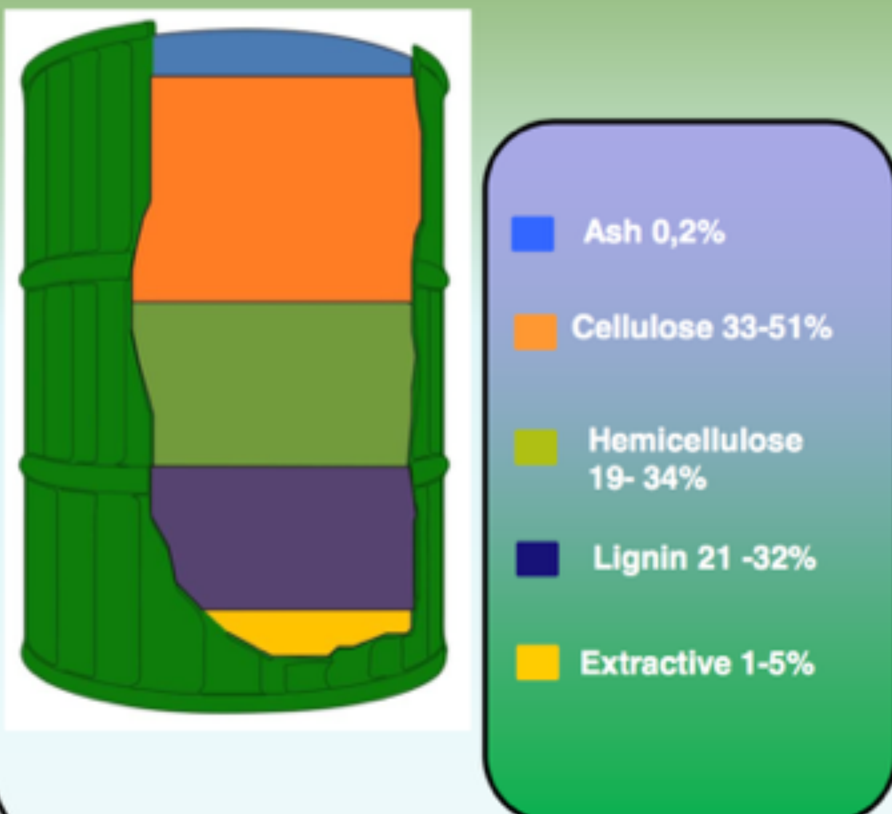
Heavy fraction - Asphalts…Not a wast but a RESOURCE

With the advent of the automobile, road engineers needed to find a road that didn't self-destruct.
Some states and independent labs had already experimented with mixing asphalt or road oils and different sized stones.

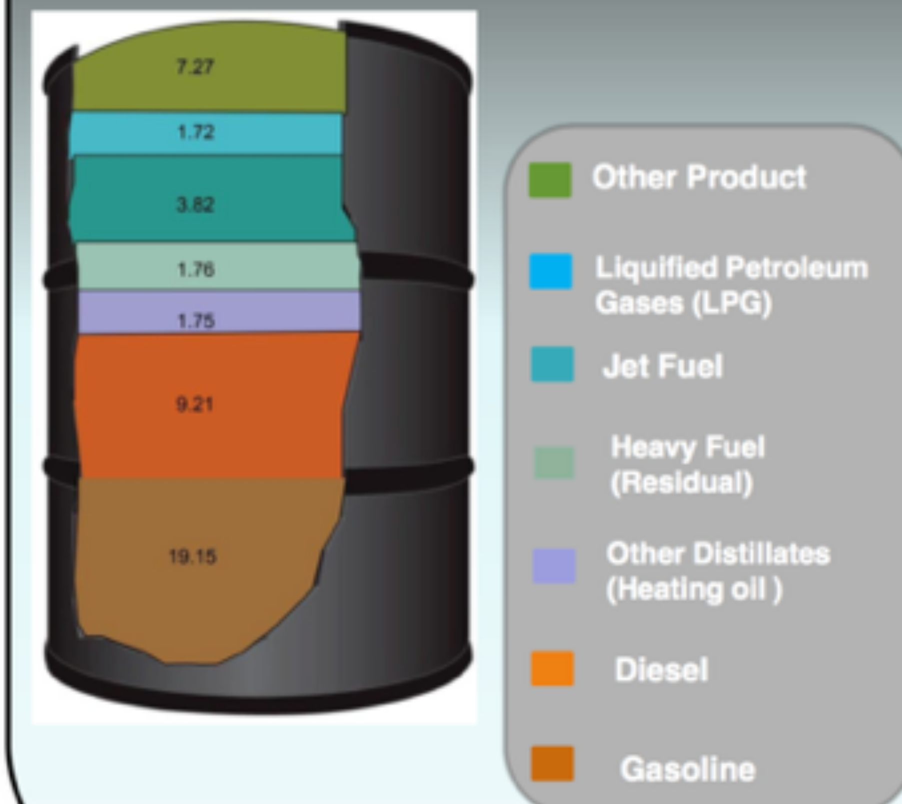
By 1902, Gulf Refining and Texas Refining in Texas, and Sun Oil in Pennsylvania, started producing asphalt. Asphalt producers began making asphalt mixes, to be used for building inter-city highways.

By 1910, refined petroleum asphalt had gained its permanent market supremacy over the producers of rock, natural and sheet asphalt. The oil companies could manufacture asphalt cheaper to that mined from the natural deposits in Trinidad Lake and Bermudez Lake.

Barrel of biomass



Barrel of oil



4 NOI

slide di presentazione del gruppo:

chi sono io e cosa faccio nella vita

cosa fa il nostro gruppo

dove siamo collocati

Cosa possiamo fare insieme:

impianto da 2 kg/h da noi da settembre:

visite

newsletter del progetto

1 progetto alternanza scuola lavoro?

Thanks for your attention

Prof. Andrea Contin
Director
Research Center for Environmental Sciences
University of Bologna
Ravenna Campus, Italy

andrea.contin@unibo.it
http://www.cirsa.unibo.it/en/research/environmental-management-research-group-emrg