Sustainable energy

Prof. Andrea Contin – University of Bologna, Ravenna Campus

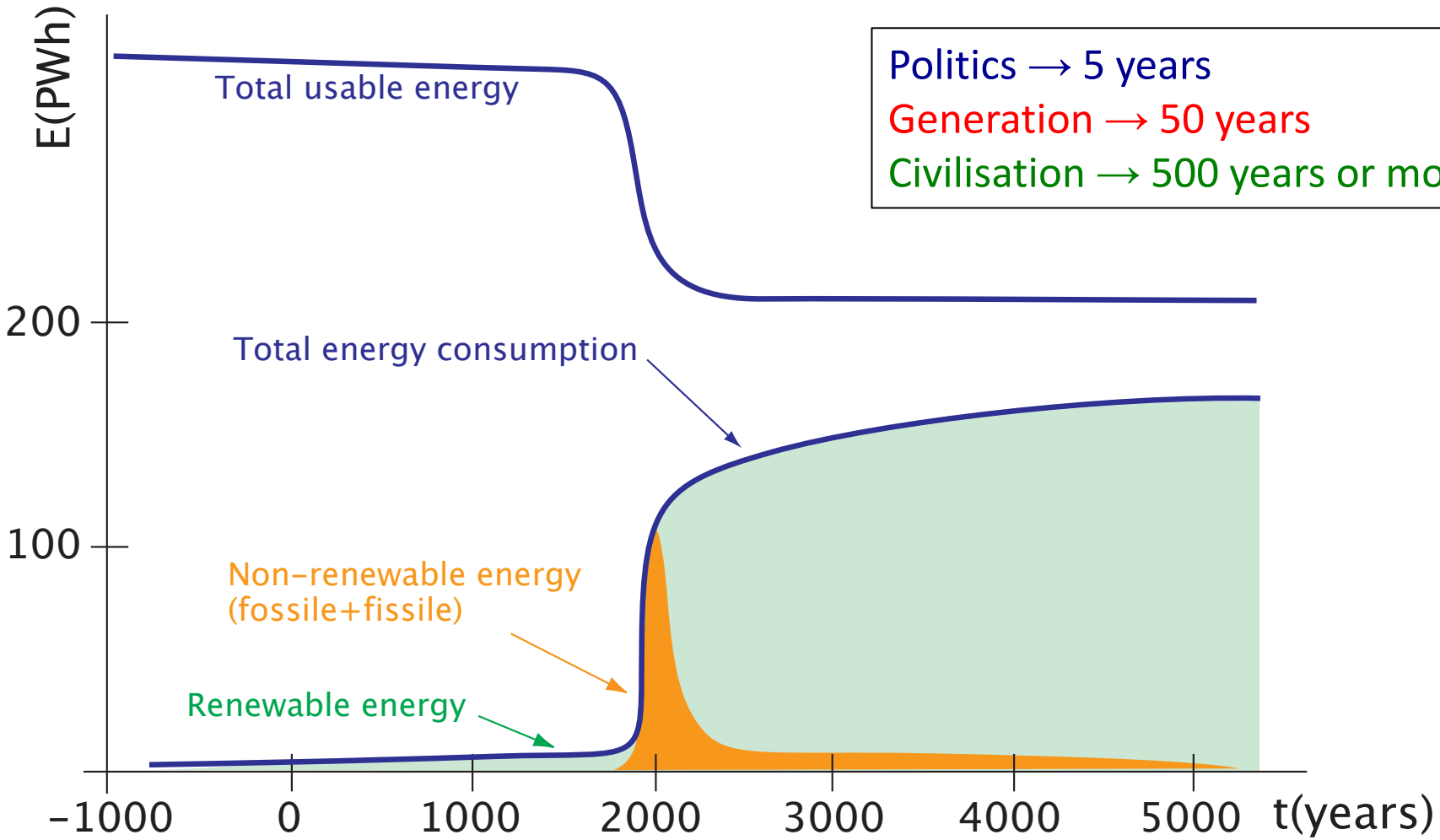
Joint EPS-SIF International School on Energy 2019

RETE ALTA TECNOLOGIA
EMILIA-ROMAGNA
HIGH TECHNOLOGY NETWORK
TECNOPOLO RAVENNA

Outline

1. Why sustainable energy?
2. Principles of sustainability
3. How much energy do we need?
4. How to substitute crude oil

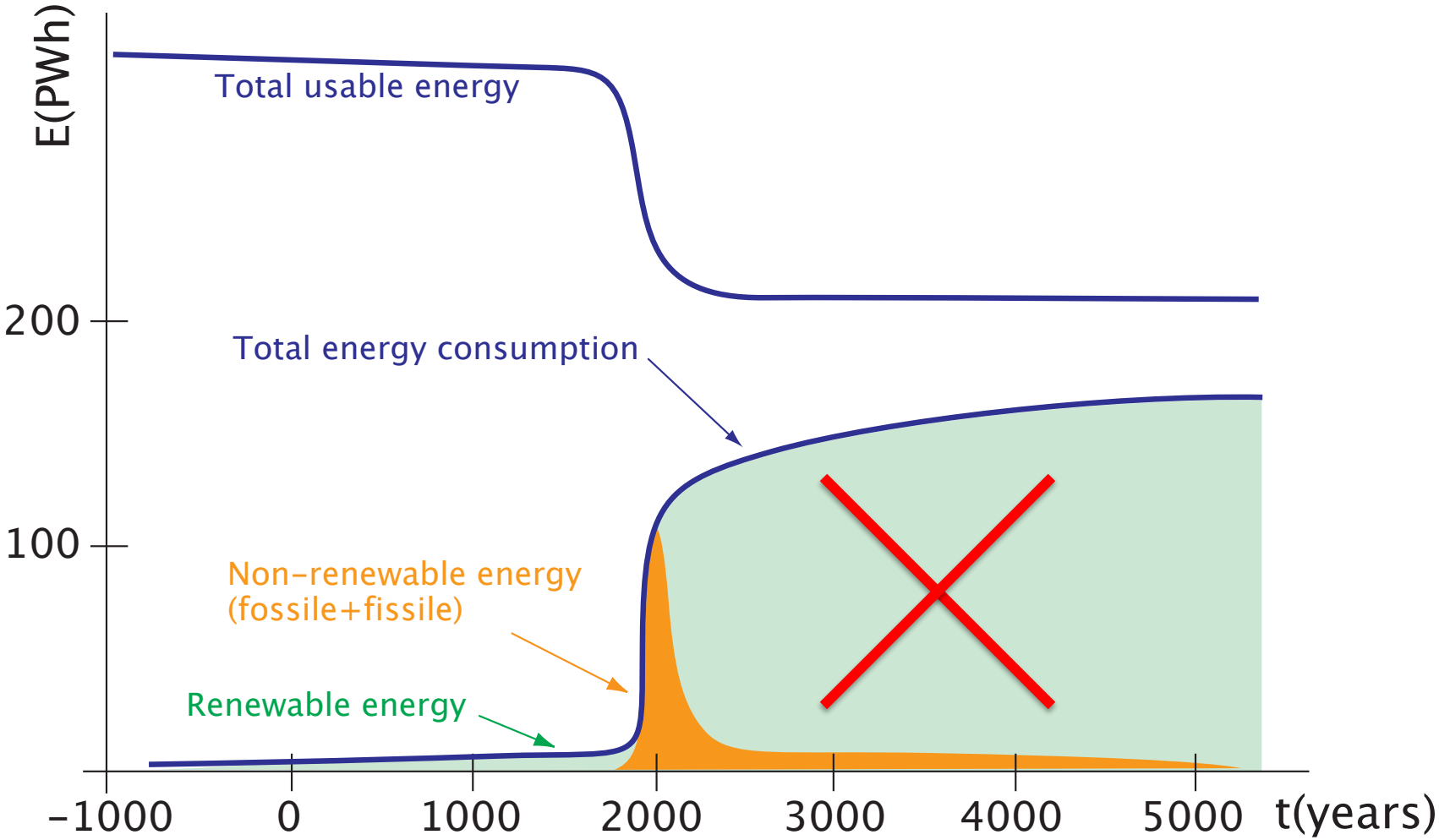
A civilisation point of view



Politics → 5 years
Generation → 50 years
Civilisation → 500 years or more

source CMDC/WSEC

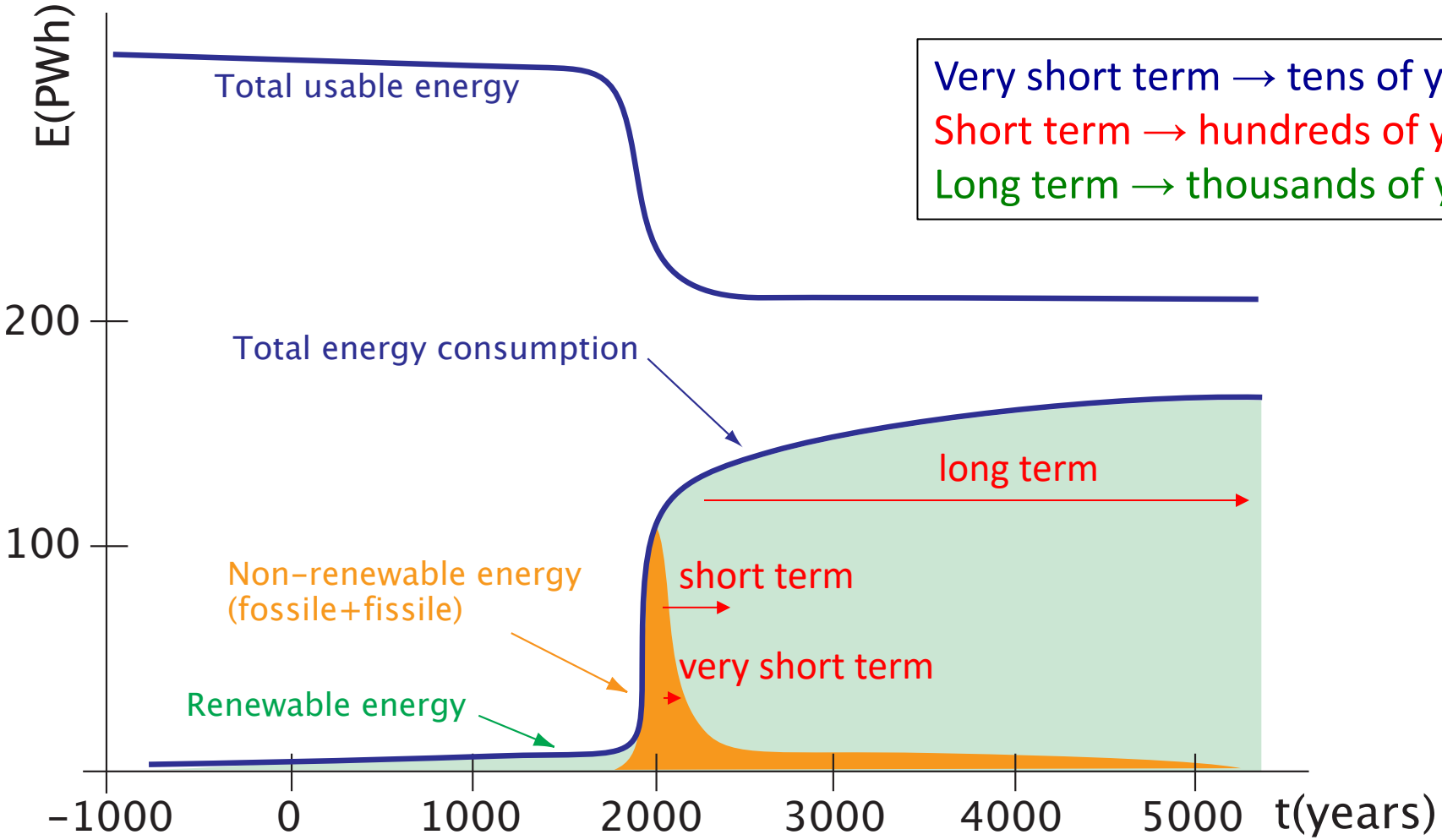
What if?



source CMDC/WSEC

What if?

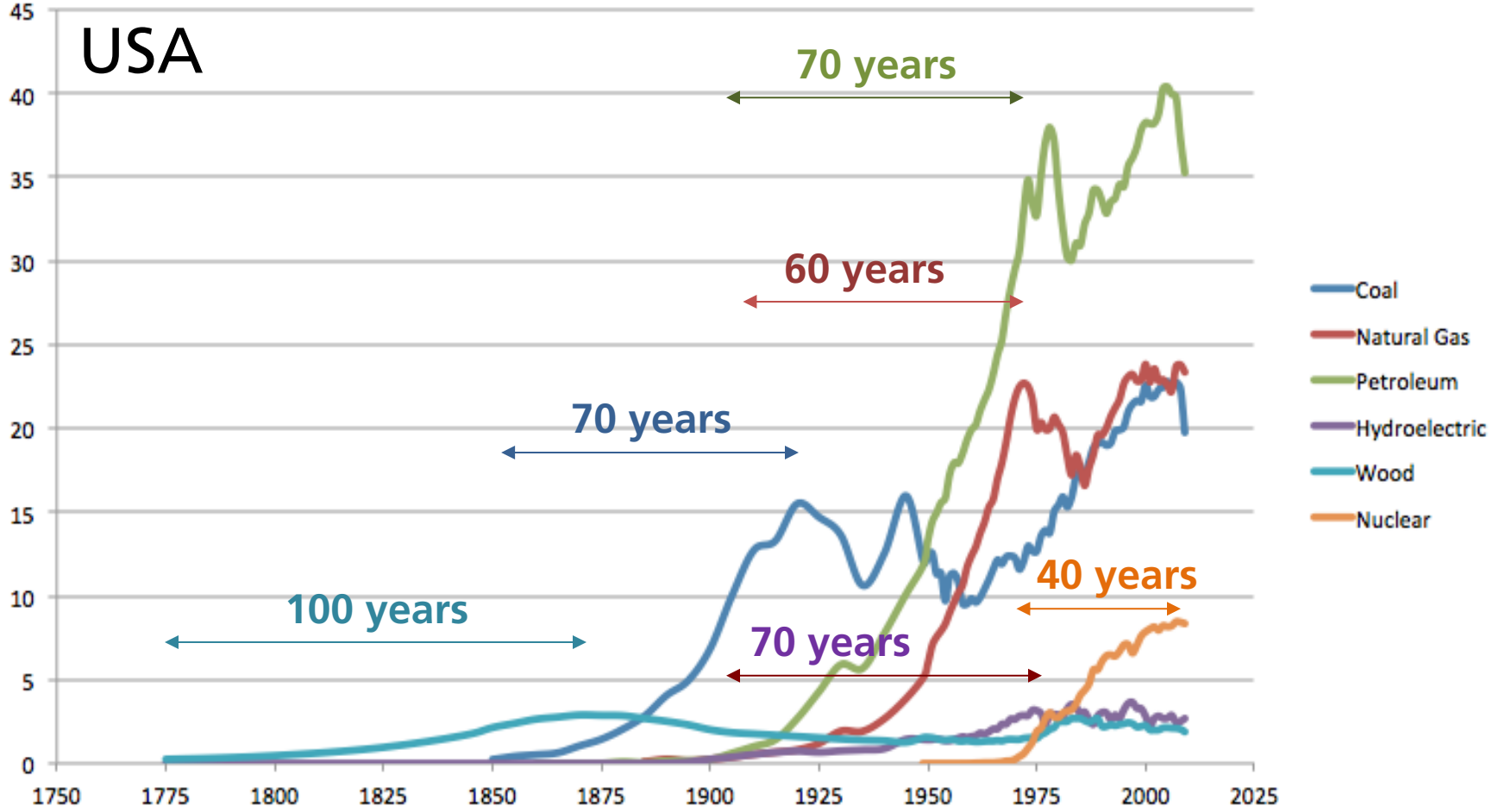
How can we fill the gap?



Very short term → tens of years
Short term → hundreds of years
Long term → thousands of years

source CMDC/WSEC

Time needed to bring new technologies to full maturity



Ethical considerations

Two general questions:

1) Should all members of mankind have equal opportunities?

YES: equality must be pursued

NO: developed countries must prevent others the access to resources
However:
- in the long run, much more costly then answering YES
- sooner or later we will anyway run out of resources

2) Should next generations have the same opportunities as we have today?

YES: resources must be preserved for future generations

NO: avoid investing in new technologies
our life span is short ⇒ enough resources to keep our standard of living

My answers

My personal answers:

1) Should all members of mankind have equal opportunities? YES
2) Should next generations have the same opportunities as we have today? YES

⇒ SUSTAINABLE DEVELOPMENT

From Common to Public Goods

FROM: Common goods (or common-pool resources)

non-excludable – shared, accessible to all
rivalrous – if consumption by one consumer prevents simultaneous consumption by other consumers

Common goods (non-excludable rivalrous resources) become subject to over-use and over-consumption, which destroys the resource in the process

TO: Public goods

non-excludable – shared, accessible to all
non-rivalrous – if consumption by one consumer does not prevent simultaneous consumption by other consumers

Ethical considerations - sustainability

Principles:

- Public Environmental Order
- Sustainability
- Carrying Capacity
- Obligatory Restoration of Disturbed Ecosystems
- Biodiversity
- Common Natural Heritage
- Sustainable Urban Environment
- Aestetic Value of Nature
- Environmental Awareness

All the members of society, the Administration, groups, organisations, businesses and citizens are called upon to collaborate in sustainable development, but under the strategic control and supervision of the state

Sustainable development is a long-term choice at constitutional level

Michael Decleris, The law of sustainable development – general principles, Report to the European Commission, 2000

Ethical considerations - sustainability

Principles:

- Public Environmental Order
- Sustainability
- Carrying Capacity
- Obligatory Restoration of Disturbed Ecosystems
- Biodiversity
- Common Natural Heritage
- Sustainable Urban Environment
- Aestetic Value of Nature
- Environmental Awareness

If there is complete identity between the interests of man and nature, sustainability is the self-evident term for the dynamic equilibrium between man and nature and for the co-evolution of both within the Earth mega-system

The deeper meaning of sustainability is the harmonisation of all public policies and social practices and their convergence towards ensuring the co-evolution of man-made systems and ecosystems

Michael Decleris, The law of sustainable development – general principles, Report to the European Commission, 2000

Ethical considerations - sustainability

Principles:

- Public Environmental Order
- Sustainability
- Carrying Capacity
- Obligatory Restoration of Disturbed Ecosystems
- Biodiversity
- Common Natural Heritage
- Sustainable Urban Environment
- Aestetic Value of Nature
- Environmental Awareness

All man-made systems are constructed and developed at the cost of ecosystems, but together with the latter they constitute greater composite systems within the Earth mega-system

Carrying capoacity is the optimum size which will maintain the equilibrium of the whole (greater) system

Michael Decleris, The law of sustainable development – general principles, Report to the European Commission, 2000

Ethical considerations - sustainability

Principles:

- Public Environmental Order
- Sustainability
- Carrying Capacity
- Obligatory Restoration of Disturbed Ecosystems
- Biodiversity
- Common Natural Heritage
- Sustainable Urban Environment
- Aestetic Value of Nature
- Environmental Awareness

During the ruthless development so far, many ecosystems have been destroyed owing to ignorance of their value

Thus, today it is futile to strive for balance between man-made systems and ecosystems unless, in parallel, immediate action is taken to restore ecosystems destroyed illegally and also all those which may be deemed essential for the full re- establishment of the disturbed equilibrium, provided of course that such restoration is still physically possible.

Michael Decleris, The law of sustainable development – general principles, Report to the European Commission, 2000

Ethical considerations - sustainability

Principles:

- Public Environmental Order
- Sustainability
- Carrying Capacity
- Obligatory Restoration of Disturbed Ecosystems
- Biodiversity
- Common Natural Heritage
- Sustainable Urban Environment
- Aestetic Value of Nature
- Environmental Awareness

Inherent value of all wild flora and fauna species and protection for all the variety of these species and for their habitats

The value of species is that they are biogenetic reserves and constituents of the ecosystems

The stability and vigour of ecosystems follow from the rationale that the greater an ecosystem's biodiversity, the greater is its stability.

Michael Decleris, The law of sustainable development – general principles, Report to the European Commission, 2000

Ethical considerations - sustainability

Principles:

- Public Environmental Order
- Sustainability
- Carrying Capacity
- Obligatory Restoration of Disturbed Ecosystems
- Biodiversity
- Common Natural Heritage
- Sustainable Urban Environment
- Aestetic Value of Nature
- Environmental Awareness

Areas of nature in the wild, with exceptionally sensitive ecosystems, of great ecological or biological value, with a rich biodiversity, untouched by human activity, with special ecological or aesthetic value, i.e. the "common property of all" to be preserved and protected

Michael Decleris, The law of sustainable development – general principles, Report to the European Commission, 2000

Ethical considerations - sustainability

Principles:

- Public Environmental Order
- Sustainability
- Carrying Capacity
- Obligatory Restoration of Disturbed Ecosystems
- Biodiversity
- Common Natural Heritage
- Sustainable Urban Environment
- Aestetic Value of Nature
- Environmental Awareness

In settlements, the way people live must be sustainable, the settlements themselves must be sustainable, and the ecosystems that support them must also be sustainable

Priority must be given to improving degraded areas in cities

Michael Decleris, The law of sustainable development – general principles, Report to the European Commission, 2000

Ethical considerations - sustainability

Principles:

- Public Environmental Order
- Sustainability
- Carrying Capacity
- Obligatory Restoration of Disturbed Ecosystems
- Biodiversity
- Common Natural Heritage
- Sustainable Urban Environment
- Aestetic Value of Nature
- Environmental Awareness

The "landscape" is an aesthetic system whose element are certain geomorphological characteristics of the area which are interdependent and have unity

The landscape does not belong to anyone, it is a common asset like the air and the sea, and anyone who spoils it is violating the rights of other people

Only the spatial planning, applying criteria of public interest, can determine where interventions are to take place

Michael Decleris, The law of sustainable development – general principles, Report to the European Commission, 2000

Ethical considerations - sustainability

Principles:

- Public Environmental Order
- Sustainability
- Carrying Capacity
- Obligatory Restoration of Disturbed Ecosystems
- Biodiversity
- Common Natural Heritage
- Sustainable Urban Environment
- Aestetic Value of Nature
- Environmental Awareness

Citizens should take an active part in protecting the environment, in collaboration with the state

- citizens are entitled to receive information
- systematic education and training for citizens on environmental issues
- legitimate interest of citizens in setting in motion the mechanism of judicial protection of the environment

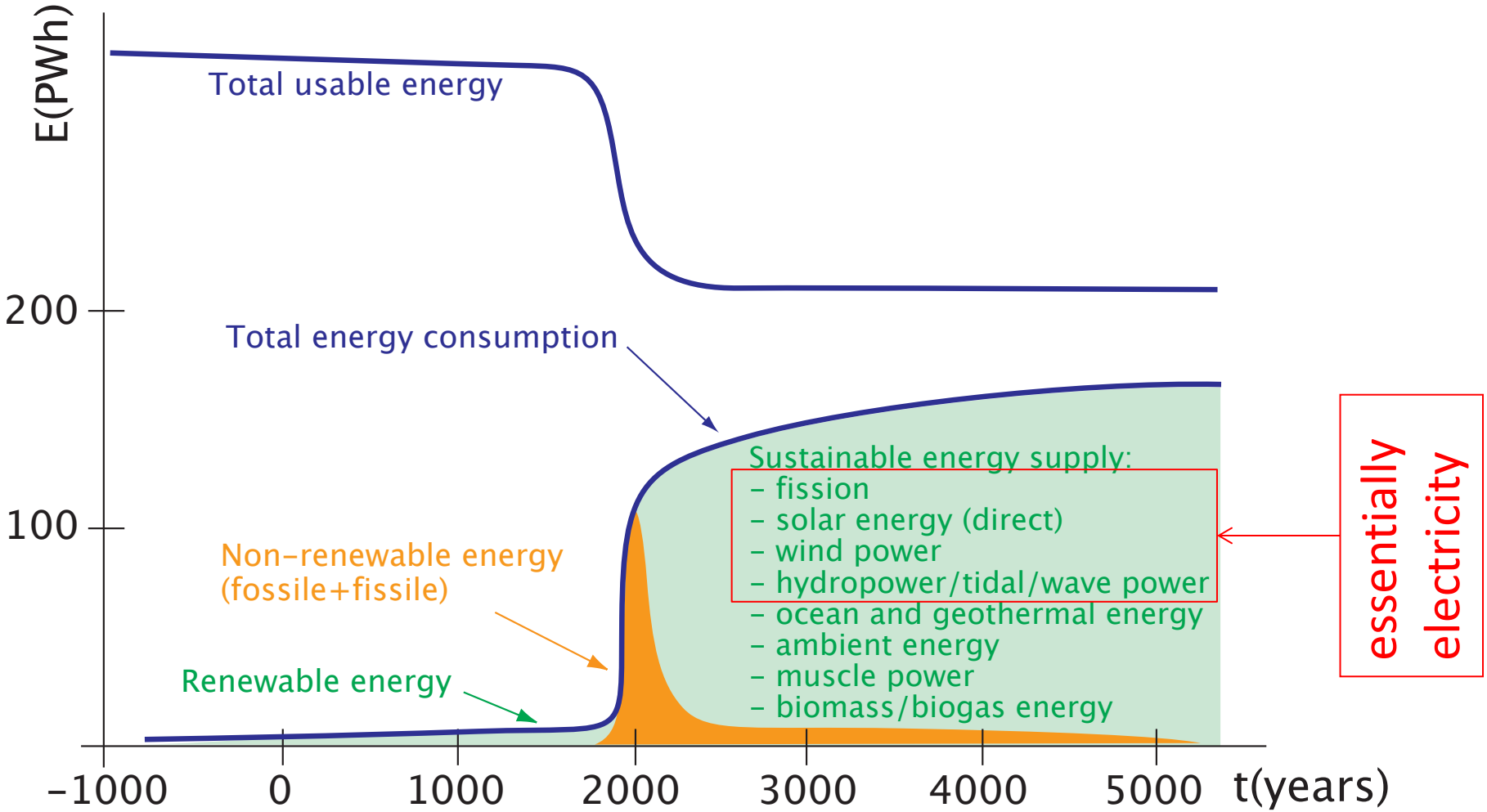
Michael Decleris, The law of sustainable development – general principles, Report to the European Commission, 2000

How to apply the sustainability principles to the energy sector

Principles:

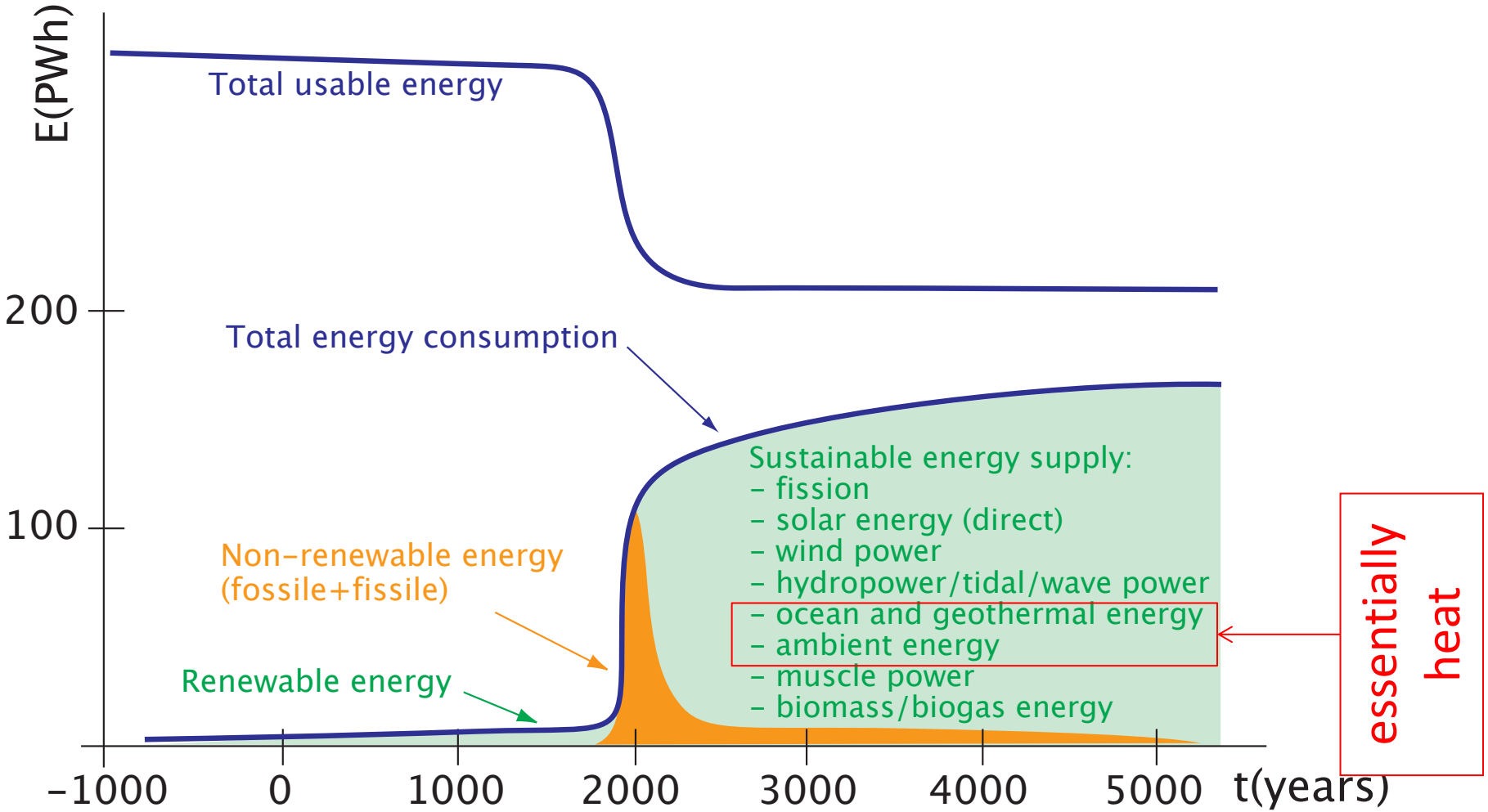
▪ Public Environmental Order	coordinated efforts
▪ Sustainability	in equilibrium with nature
▪ Carrying Capacity	within the capabilities of the system
▪ Obligatory Restoration of Disturbed Ecosystems	
▪ Biodiversity	avoiding, e.g., mono-coltures of energy crops
▪ Common Natural Heritage	
▪ Sustainable Urban Environment	reduced pollution in cities (e.g., transportation)
▪ Aestetic Value of Nature	
▪ Environmental Awareness	participated effort

Electricity



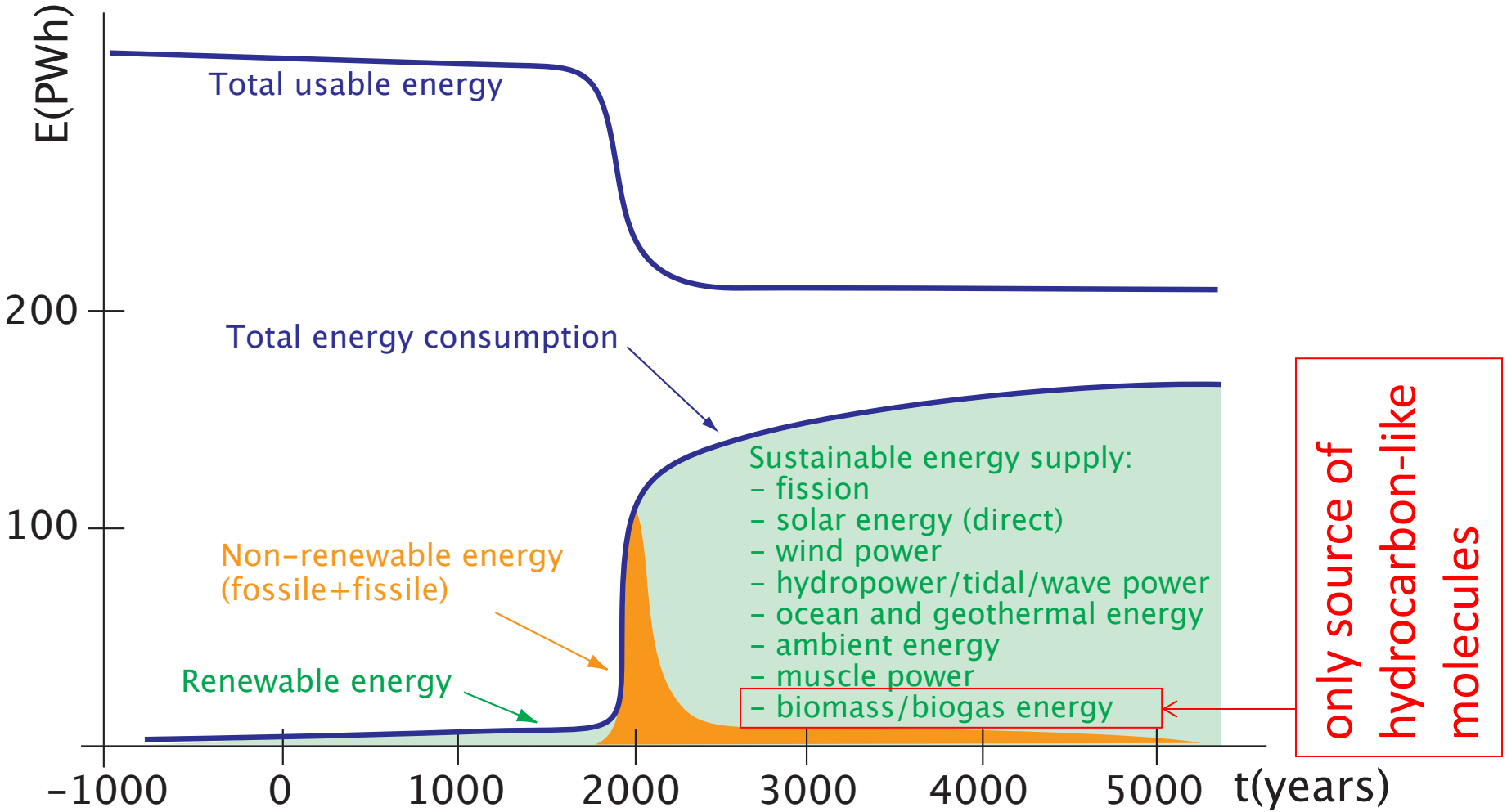
source CMDC/WSEC

Heat



source CMDC/WSEC

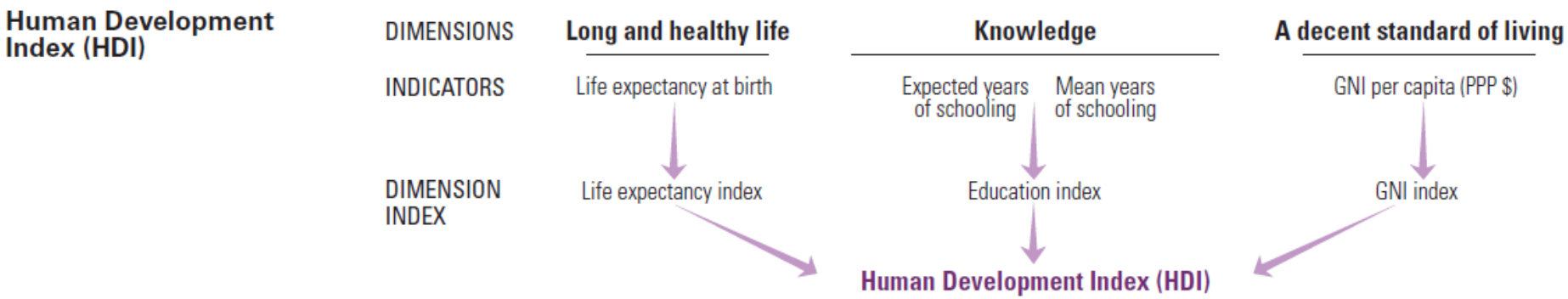
Hydrocarbons

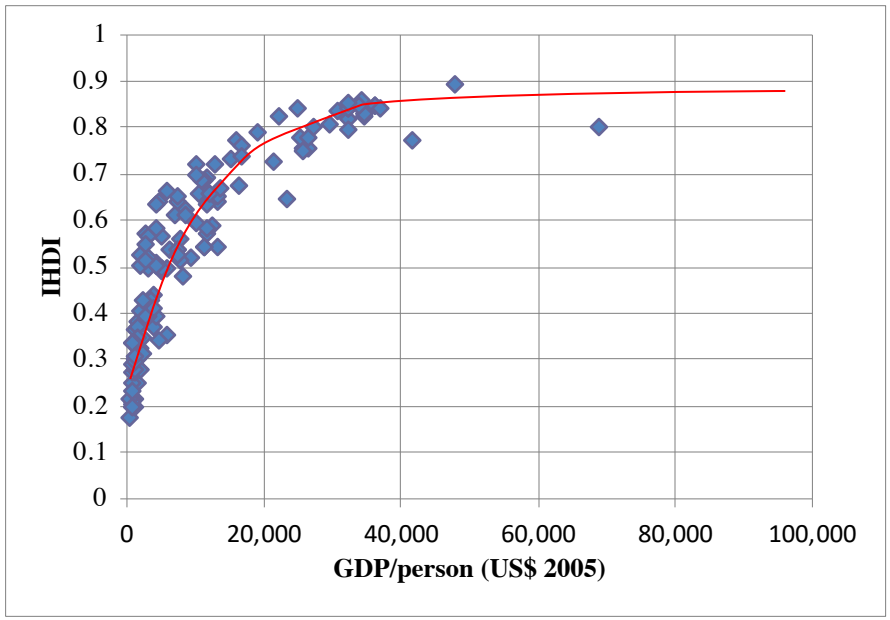


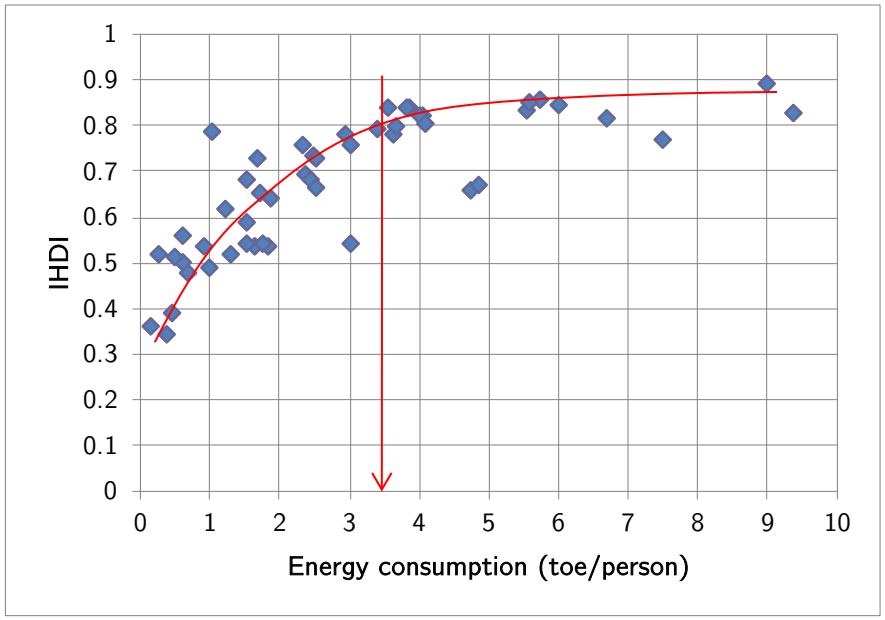
source CMDC/WSEC

How much energy do we need?

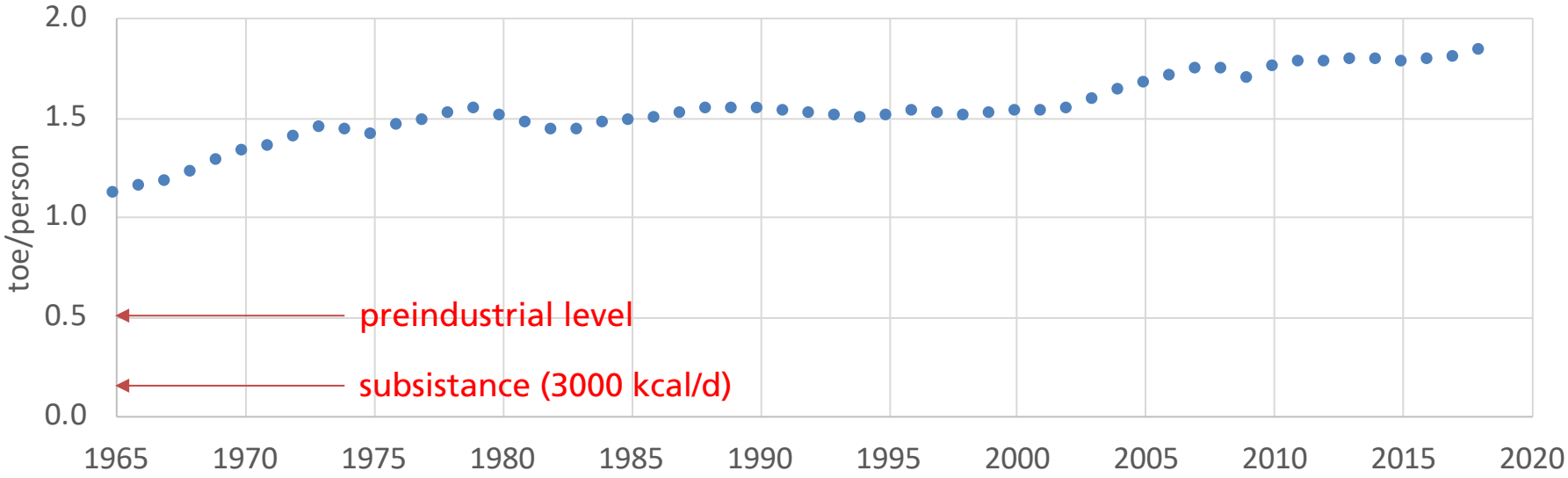
UN Human Development Index corrected for Gini index (IHDI)







How much energy do we use?



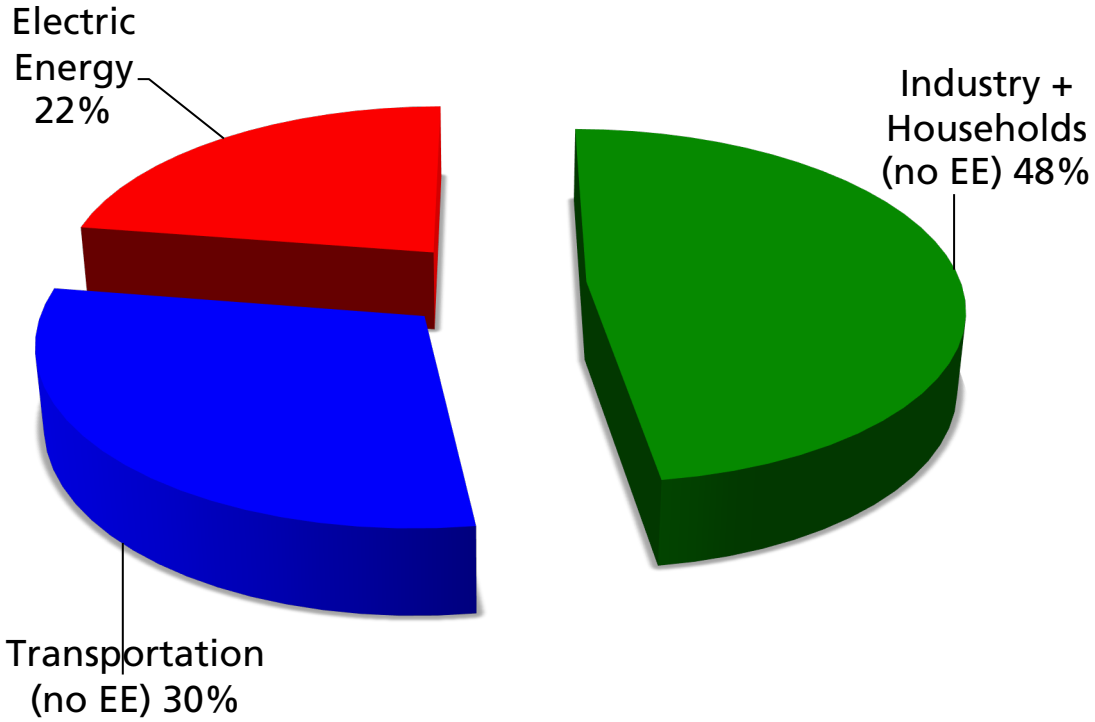
BP statistical review, 2019

A simple calculation

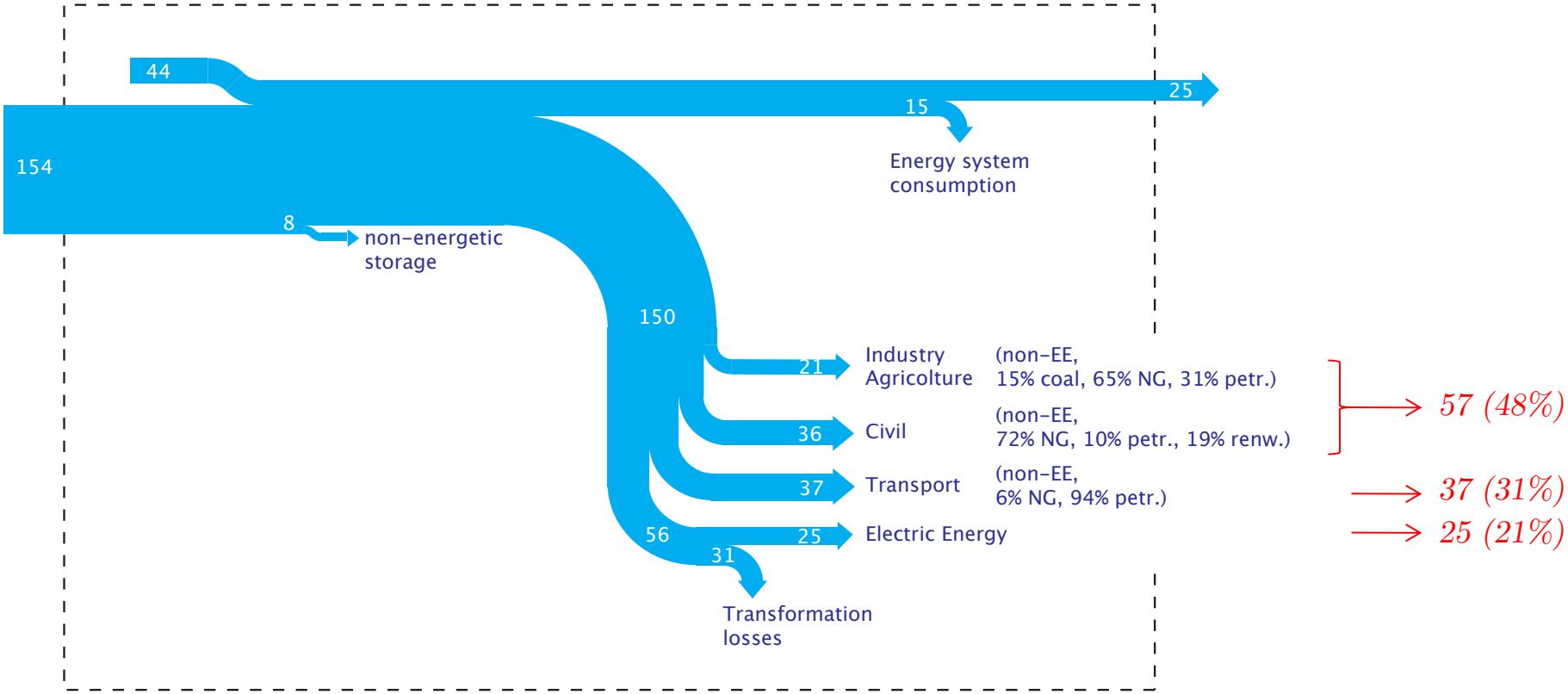
2018: 1.8 toe/person, 7.6 billion persons ⇒ 13.7 Gtoe
2050: 3.5 toe/person, 9 billion persons ⇒ 31.5 Gtoe

In principle, to answer YES to the first question (Should all members of mankind have equal opportunities?) we need to more than double the energy consumption in 30 years (and make it more equally distributed)

World energy consumption (2017)



Italy energy consumption (2017)



Data in Mtoe

Three main sectors

	source		location	
	fixed	mobile	centralized	distributed
Industry/Civil (heat)	X			X
Transportation		X		X
Electric Energy	X		X	X

All sectors must be satisfied!

How to satisfy needs

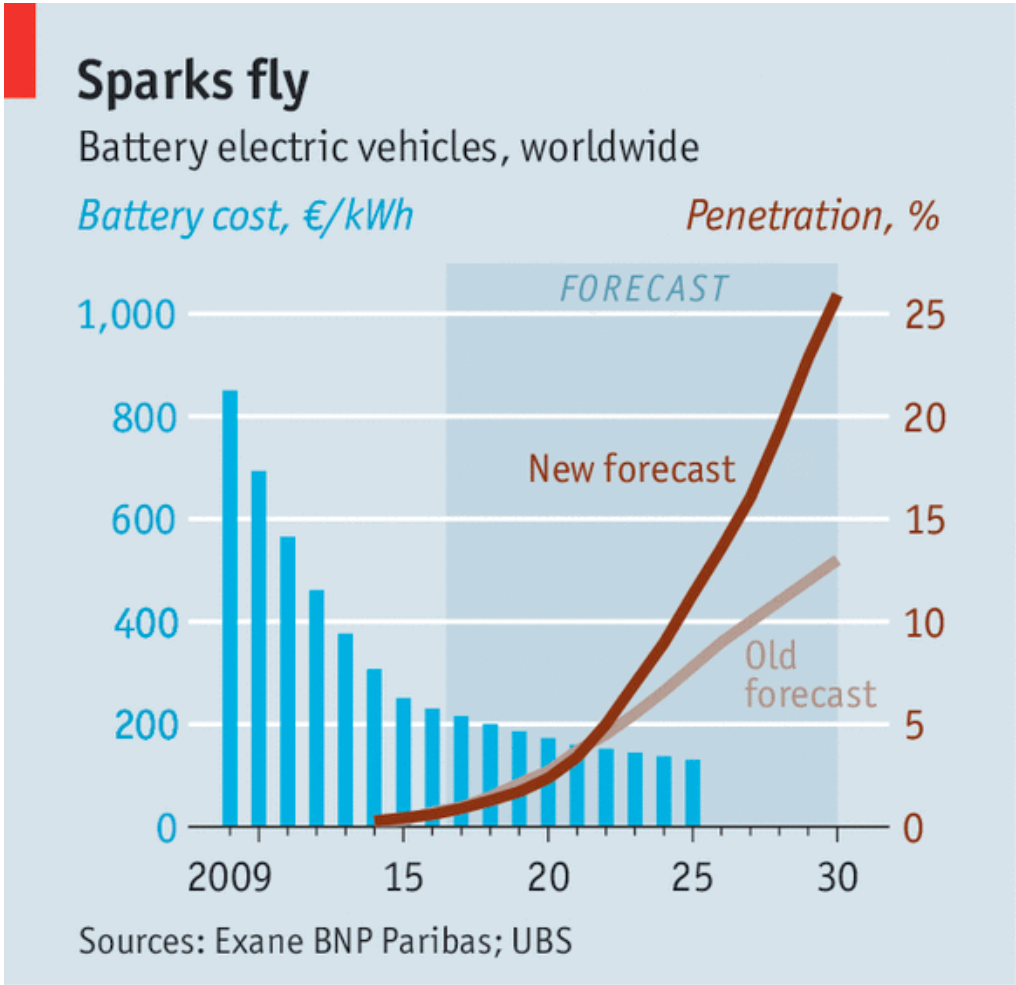
can use EE (e.g., heat pumps)

most difficult even if…

	source		location	
	fixed	mobile	centralized	distributed
Industry/Civil (heat)	X			X
Transportation		X		X
Electric Energy	X		X	X

easiest to produce with RES

Electric mobility



Economist.com

- In 2030, at least 75% of the vehicles will still run on liquid fuel
- At present, the number of road vehicles approaches 1 billion
- This number is expected to double by 2050 and triple by 2100

Oil substitution

The major goal of advanced research in waste biomass treatment is to produce something sufficiently similar to crude oil to be fed into standard refineries.

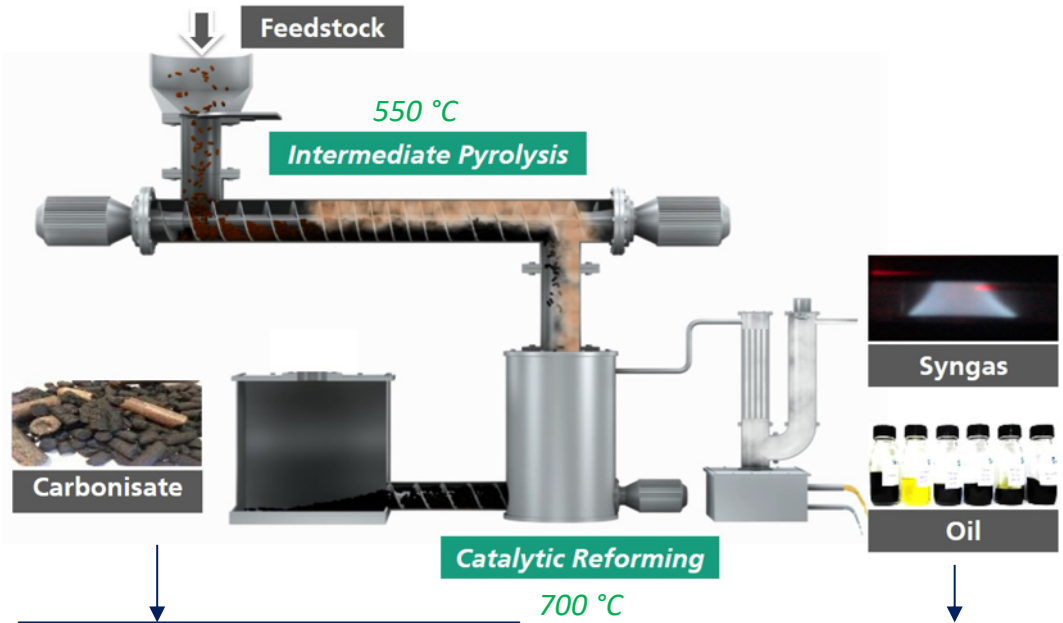
Note also that about 8% of oil is used for purposes other than energy. This can become the real bottleneck for our civilization.

I will illustrate one possible way in the following slides.

Thermo-Catalytic Reforming (TCR®) process

- Nearly all biogenic material

Recent (2014) development by Fraunhofer-Gesellshaft, Germany



- High H content (35-40% vol.)
- Usable in dual-fuel CHPs
- Source of «green» H_2

- Usable for heat and power production
- Usable as a wastewater filter thanks to the high surface/volume ratio

- High C content
- Low O content
- Low H_2O content
- High Heating Value
- Directly usable in dual-fuel CHPs or blended with bio-diesel

TO-SYN-FUEL H2020 Project

http://www.tosynfuel.eu

TO-SYN-FUEL
Demonstration of Waste Biomass to Synthetic Fuels and Green Hydrogen

14.5 M€ Innovation Action, 5 years
Started May, 1st 2017

300 kg/h TCR being commissioned at Fraunhofer UMSICHT, Sulzbach-Rosenberg Branch, Germany

The TO-SYN-FUEL project has received funding from the European Union's Horizon 2020 research and innovation programme under grand agreement No 745749.

TO-SYN-FUEL Partnership

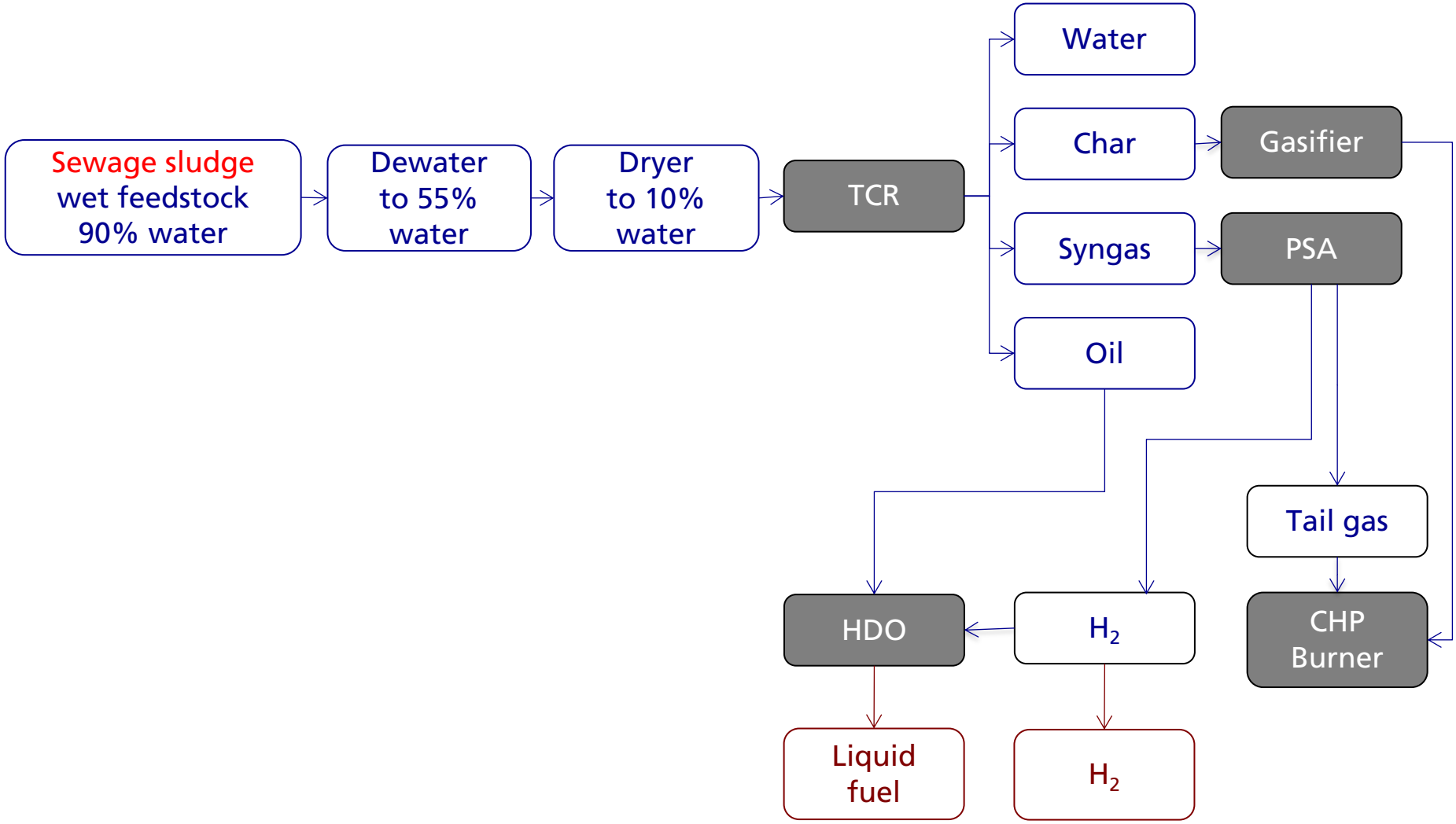
- 12 partners from 5 different countries

Fraunhofer
ENGIE
etaflorence renewableenergies
Susteen Technologies GmbH
eni
VTS
HYGEAR
ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA
UNIVERSITY OF BIRMINGHAM
LEITAT Technological Center
WRG Europe Ltd GrantCraft
SNB Haalt meer uit slib!

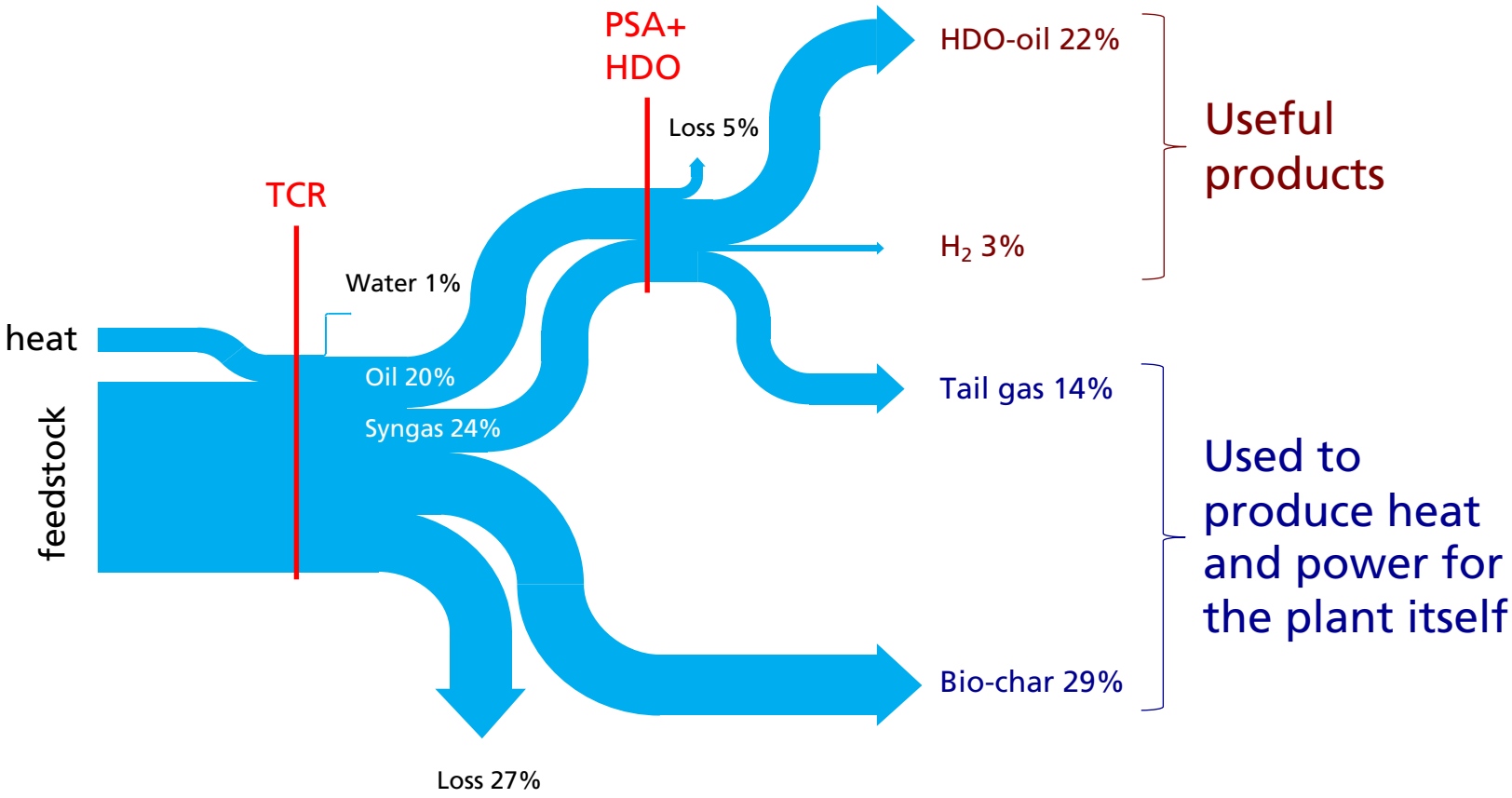
TO-SYN-FUEL Roles

- **Plant (TCR, PSA, HDO) Engineering and Construction:** Engie, Susteen, Fraunhofer, VTS, Hygear
- **Demonstration Phase:** Engie, Susteen, Fraunhofer, VTS, SNB, Hygear
- **Product Fuel Demonstration, Engine Tests, CHP Tests:** ENI, University of Birmingham, Fraunhofer
- **Social Sustainability:** Leitat, University of Bologna, Fraunhofer
- **Environmental Performance**: University of Bologna, Leitat, Fraunhofer
- **Exploitation and Business Potential:** Engie, Susteen, ENI, Fraunhofer
- **Regulatory Issues and Risk Management:** University of Bologna, Leitat, VTS, Engie
- **Dissemination:** ETA Florence, WRG, Fraunhofer, ENI, University of Bologna, University of Birmingham, Leitat, VTS

TO-SYN-FUEL


Sewage sludge
wet feedstock
90% water
Dewater
to 55%
water
Dryer
to 10%
water
TCR
Water
Char
Gasifier
Syngas
PSA
Oil
Tail gas
HDO
H_2
CHP
Burner
Liquid
fuel
H_2

Energy balance



TCR-oil from sewage sludge

High quality, engine-ready

LHV: ≈34 MJ/kg

C	83.7 wt. %
H	9.0 wt. %
N	2.1 wt. %
S	0.9 wt. %
O (diff.)	3.7 wt. %
H_2O	0.6 wt. %
TAN	0.6 mg KOH/g
Ash	< 0.005 wt.%

- Thermal stable
- Low in O, S, N
- Low water content
- High heating value

→ Excellent precursor for Hydrotreatment

Syngas from sewage sludge

Engine-ready gas

HHV:
≈14-18 MJ/m³

H_2	38 ± 3 v/v%
CO	8 ± 2 v/v%
CO_2	30 ± 3 v/v%
CH_4	14 ± 2 v/v%
C_xH_y	3 ± 1 v/v%

High Hydrogen Content Essential for Hydrogen separation by PSA

TCR-oil + 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

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)

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

After HDO

Drop-in fuel: directly usable in cars

Drop-in fuel
HDO-oil tested on AUDI XL1

AUDI XL1

HDO-oil tested on AUDI XL1

Delocalisation

Production of sewage sludge: approx. 30 kg/inhabitant/y (dry matter)
3 t/h TCR ➡ 21000 t/y ➡ 700,000 inhabitants

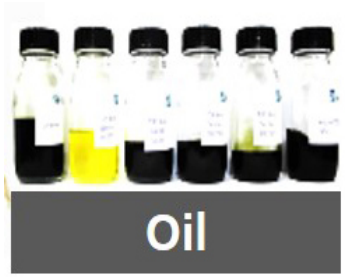
Delocalization is an advantage

Higher added value products

To increase the economic value of the system, an R&D program is starting in the new Fraunhofer Project Center for Waste Valorization and Future Energy Supply at University of Bologna (FPC_WE@UNIBO) in Ravenna. The goal is to find better alternatives to Heat & Power production

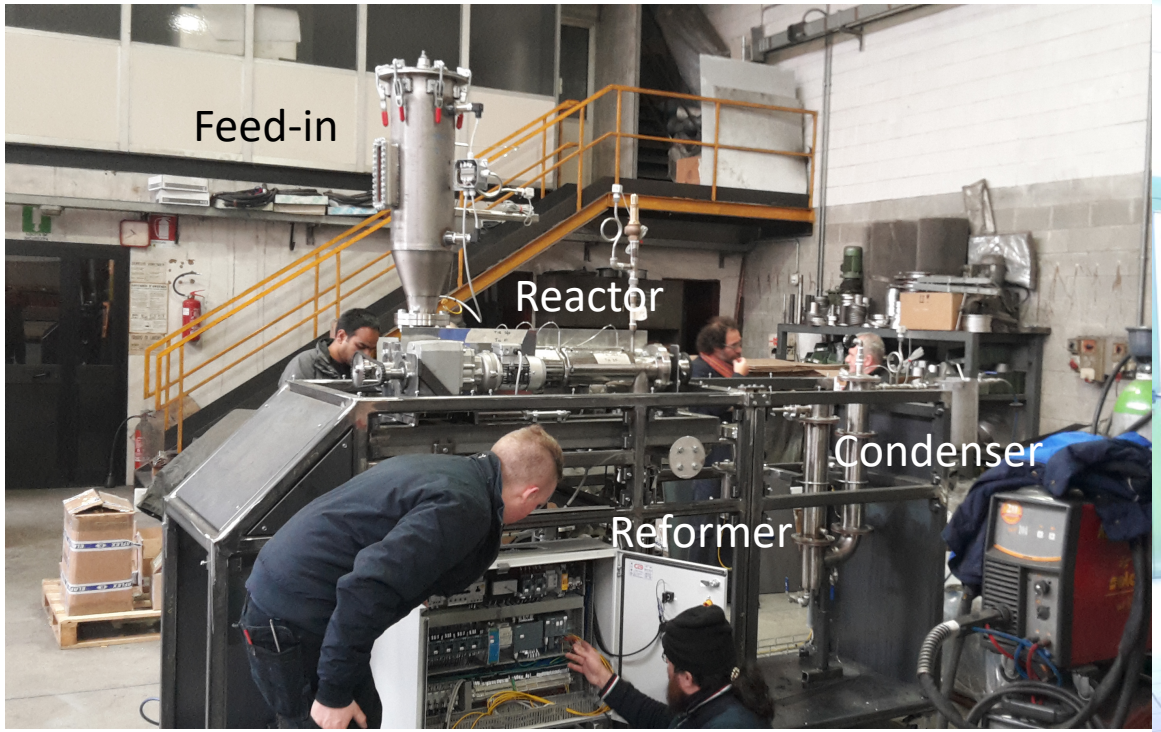
Material for wastewater filtering

Green hydrogen, methanol



Chemical building blocks (phenols and other aromatics)

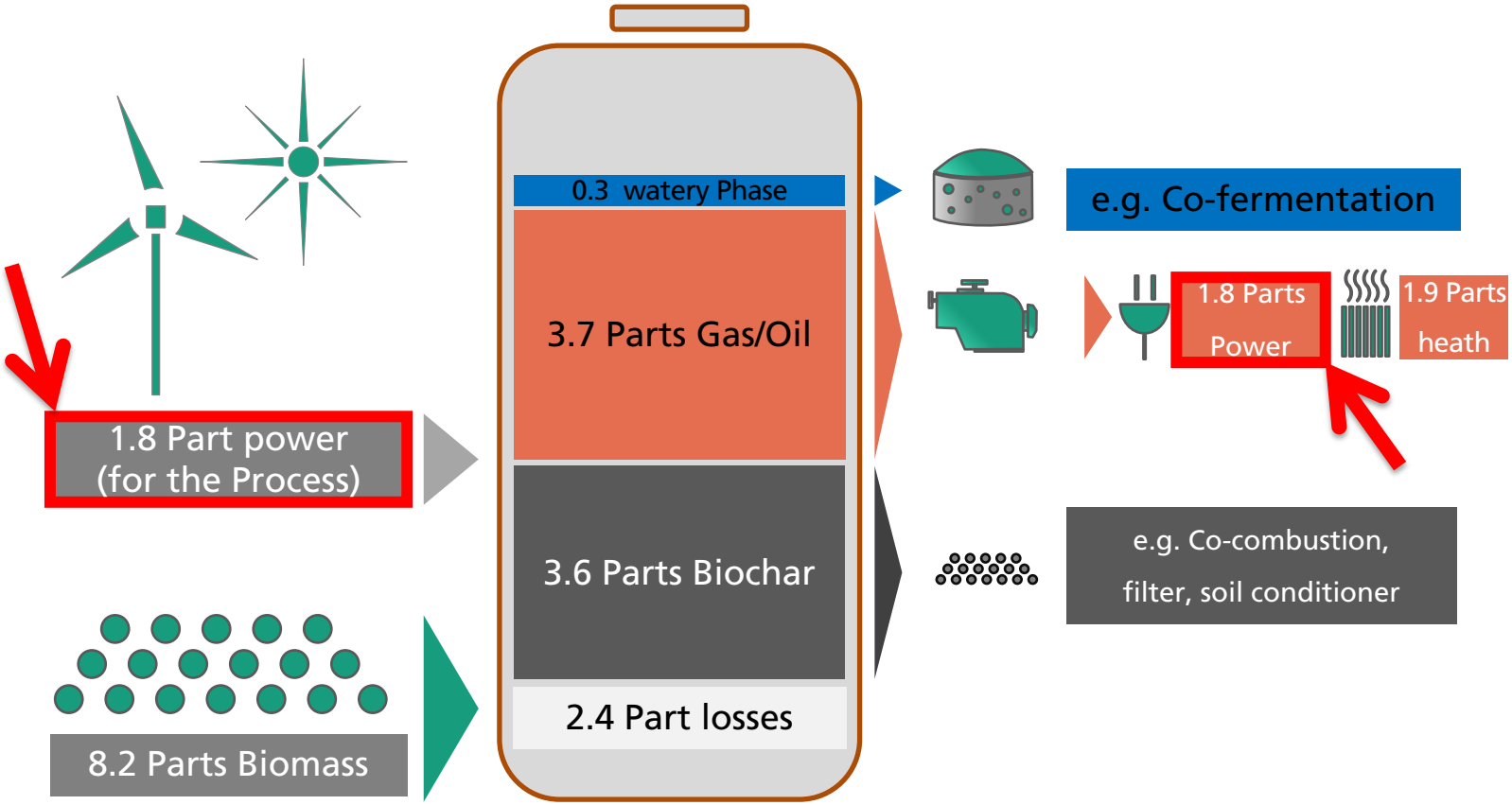
TCR®-2 in Ravenna



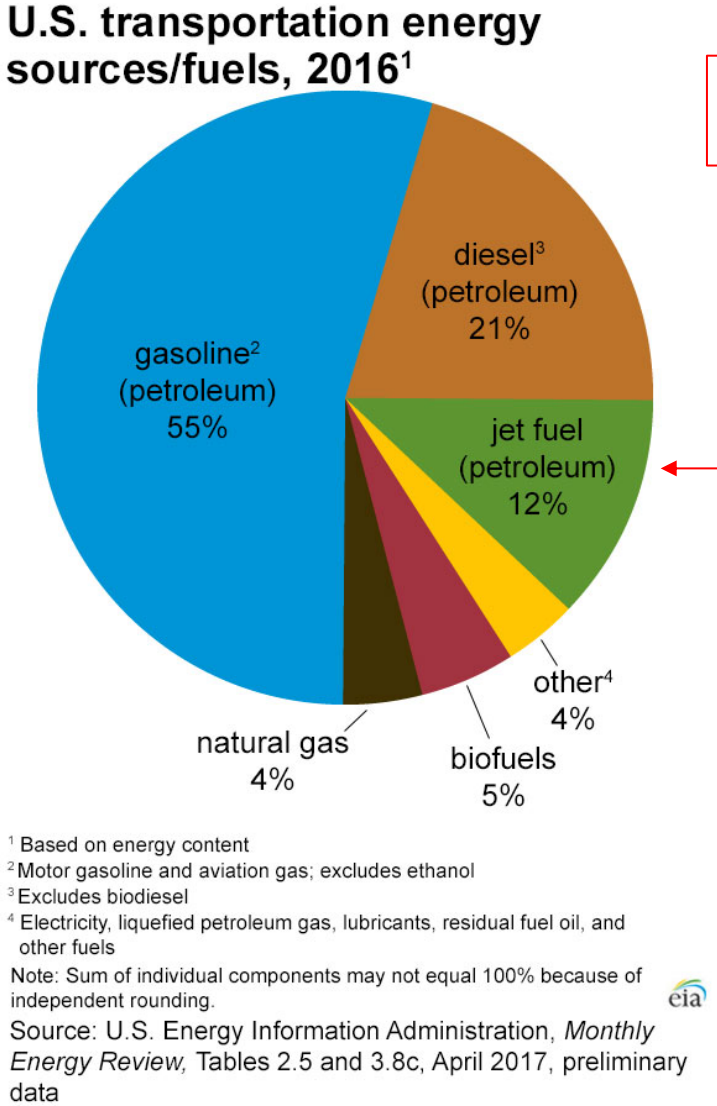
Energy storage («biobattery»)

Biobattery application

Flexible energy supply

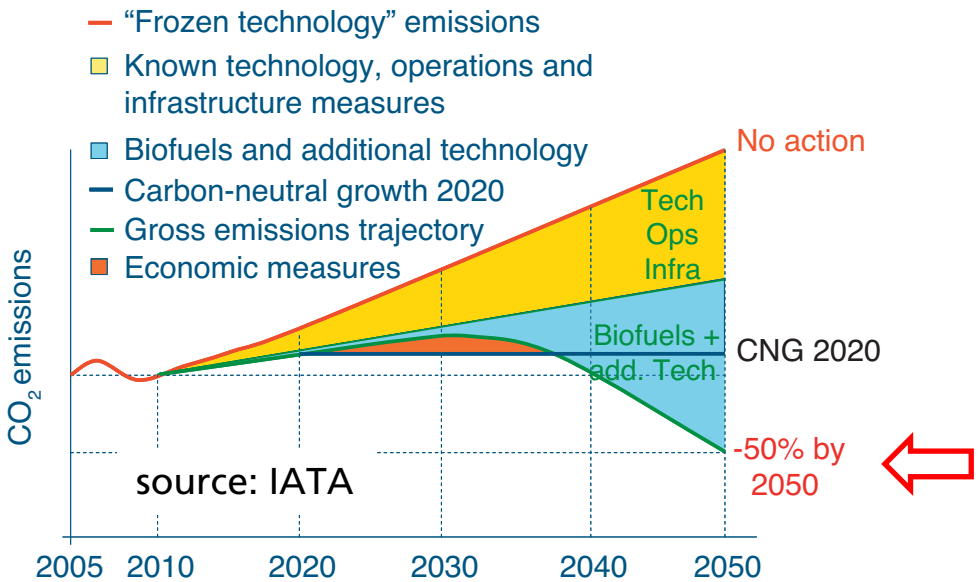


Jet fuel



Jet Fuel accounts for 12% of consumption in USA

Market increases by 6%/year

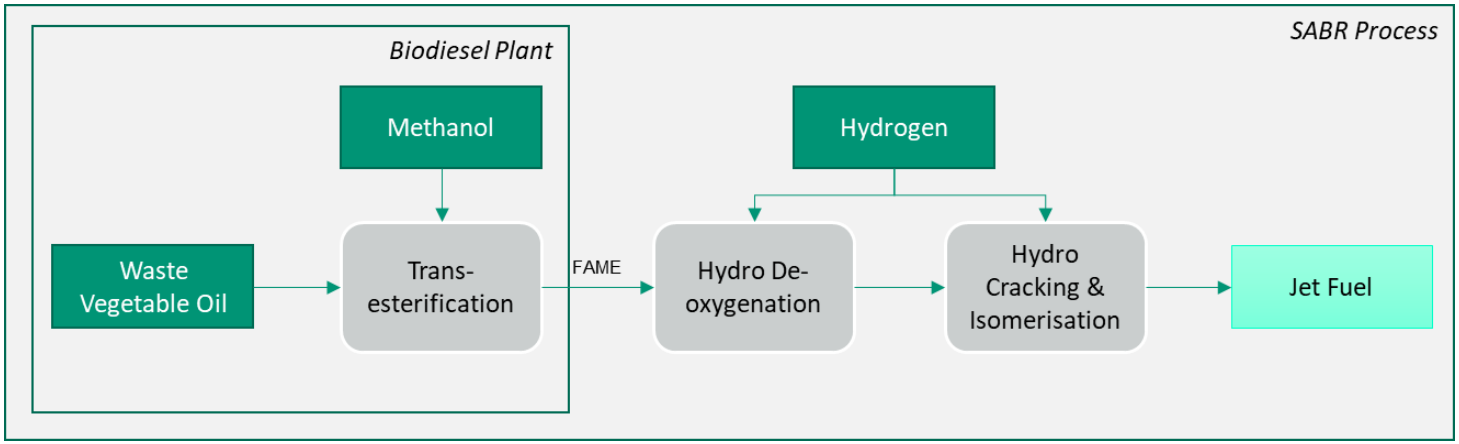


Presently certified routes

- Fischer-Tropsch synthesized hydro-processed paraffinic kerosene
- Iso-paraffins from hydro-processed fermented sugars (FTJ)
- Synthesized jet fuel from alcohols (ATJ)
- Paraffinic kerosene from hydro-processed esters & fatty acids (HEFA)
- SABR, developed and patented by Green Fuels (patent no. US8715374 B2: Methodology of post-transesterification processing of biodiesel resulting in high purity FAME fractions and new Fuels")

SABR

- Scalable and low capital intensity plant
- Integration to existing biodiesel plants to upgrade to certified jet fuel
- Flexible production (either biodiesel or jet fuel)
- Flexible feedstock



FlexJET H2020 Project

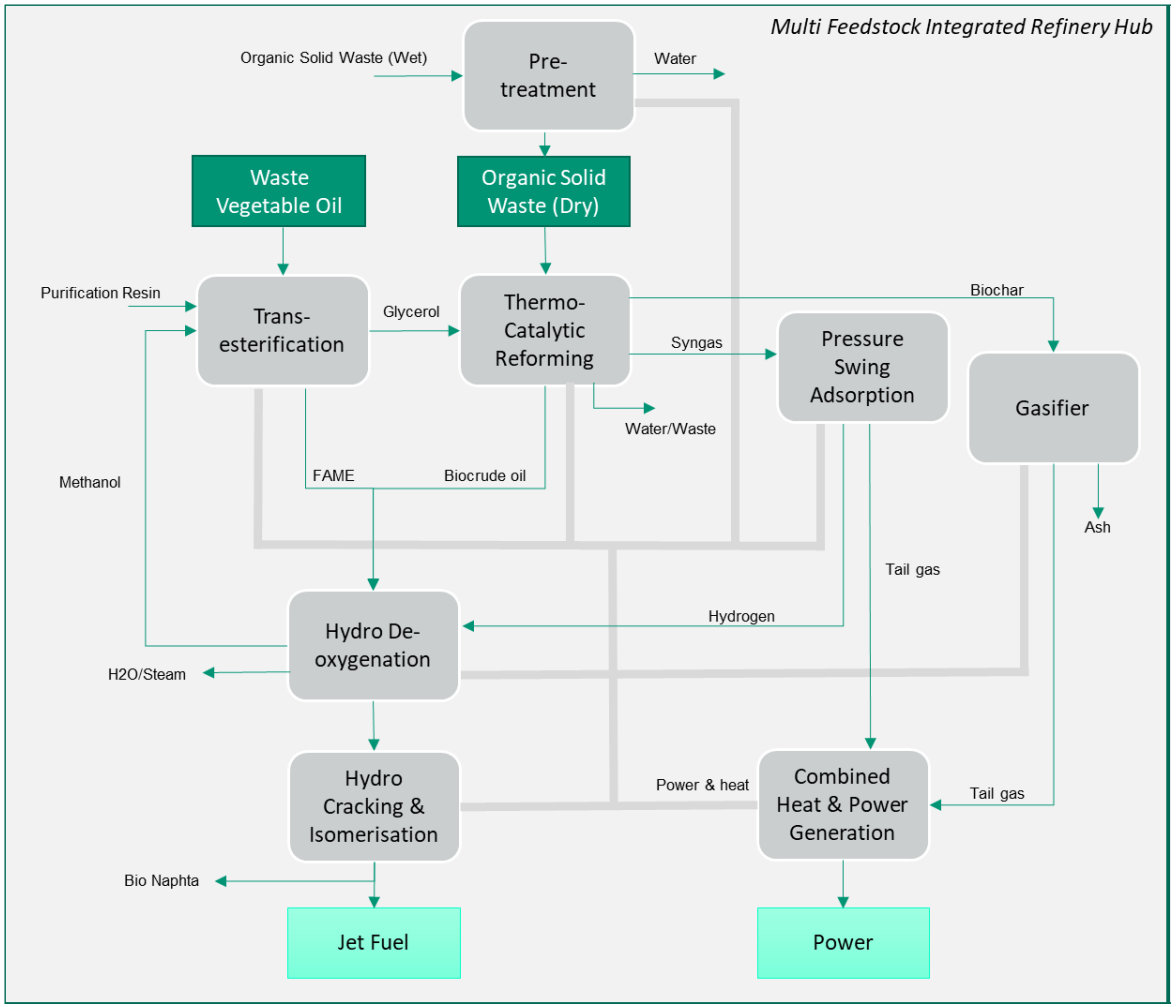
http://www.flexjetproject.eu

flexJET
Sustainable Jet Fuel from Flexible Waste Biomass

10 M€ Innovation Action
Started April 1st 2018, 4 years

The FlexJET project has received funding from the European Union's Horizon 2020 research and innovation programme under grand agreement No 792216.

FlexJET goals



Goals:

- First step:
  non-food competing waste vegetable oils (cooking oils) will be transformed into aviation biofuel in line with existing standards (HEFA route – ASTM D7566, Appendix 2), using hydrogen from residual biomass conversion by TCR®
- Second step:
  co-refining of organic waste fats with TCR® biocrude oil from food and market waste: the resulting novel aviation biofuel will be targeted for the ASTM approvals process

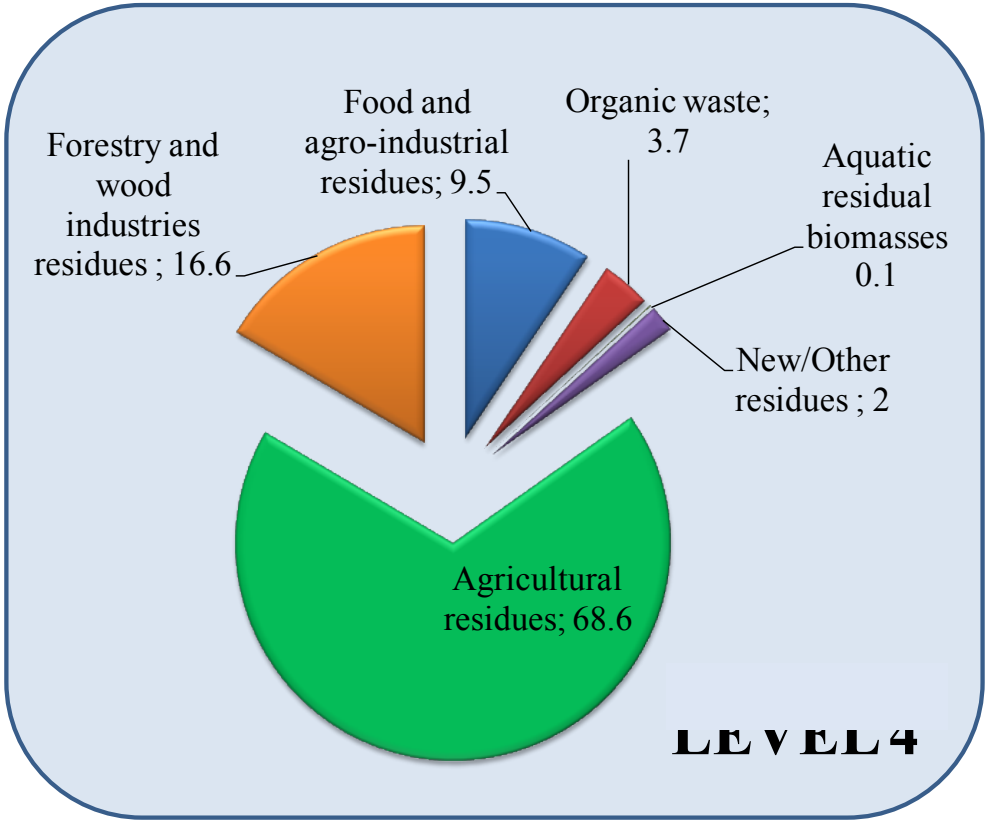
Project prototype: 4,000 t/y input material, 1,200 t/y jet fuel production

Residual biomasses

Emilia-Romagna Region (Italy):

- 106 different types of residual biomasses
- theoretical potential of 3.5±0.3 Mton/year of total solids for thermochemical valorisation
- theoretical potential of 3.4±0.6 Mton/year of total solids suitable for biological treatment

(16% of regional total primary consumption)

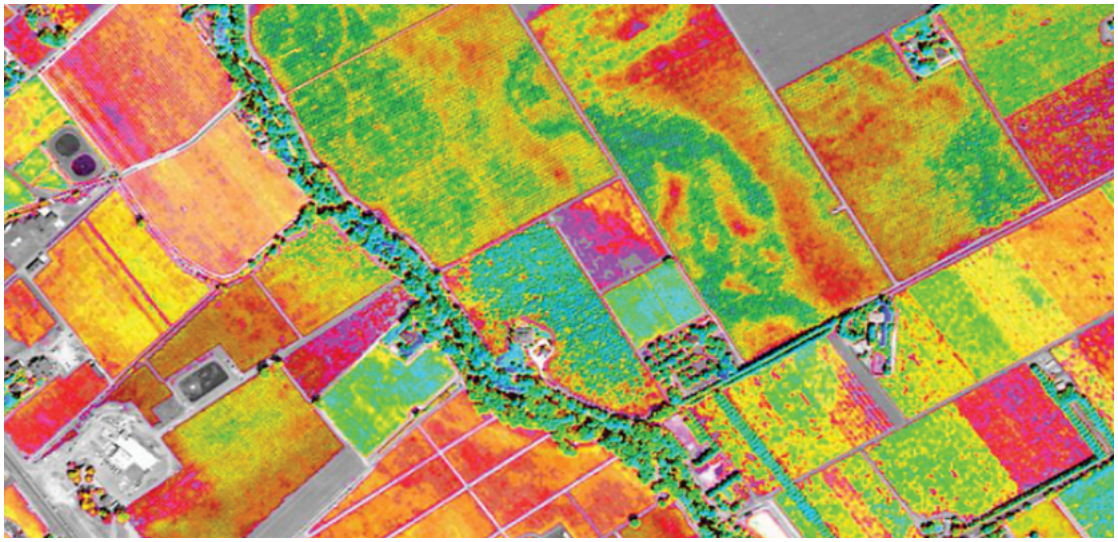


N. Greggio et al., Theoretical and unused potential for residual biomasses in the Emilia Romagna Region (Italy) through a revised and portable framework for their categorization, Renewable and Sustainable Energy Reviews 112 (2019) 590-606

Residual biomasses

At present, I have one graduate student in ESRIN (ESA Centre for Earth Observation), Frascati, to develop analysis tools for crop identification.

Crop identification ⇒ residual biomass estimation



Merge:

- RADAR (Sentinel 1)
- Optical (Sentinel 2)

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
CAMPUS DI RAVENNA

Prof. Andrea Contin
Director
interdepartmental Center for Research in Environmental Sciences

andrea.contin@unibo.it
www.emrg.it