Sustainable energy

Prof. Andrea Contin – University of Bologna, Ravenna Campus

Joint EPS-SIF International School on Energy 2019
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?

- Total usable energy
- Total energy consumption
- Non-renewable energy (fossile+fissile)
- Renewable energy

Source: CMDC/WSEC

A. Contin, Varenna, 22/7/2019
What if?

A. Contin, Varenna, 22/7/2019

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

E(PWh)(years)
200
100
-1000 0 1000 2000 3000 4000 5000
source CMDC/WSEC
Total energy consumption
Total usable energy
Non-renewable energy
(fossile+fissile)
Renewable energy
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

USA

- Coal: 100 years
- Natural Gas: 60 years
- Petroleum: 70 years
- Hydroelectric: 40 years
- Wood: 70 years
- Nuclear: 70 years
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 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
- Aesthetic 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 Declaris, The law of sustainable development – general principles, Report to the European Commission, 2000
Ethical considerations - sustainability

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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 Declaris, The law of sustainable development – general principles, Report to the European Commission, 2000
Ethical considerations - sustainability

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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 capacity 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
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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 De Cleris, The law of sustainable development – general principles, Report to the European Commission, 2000
Ethical considerations - sustainability

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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
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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.

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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 DeClaris, The law of sustainable development – general principles, Report to the European Commission, 2000
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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.

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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
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- Coordinated efforts in equilibrium with nature within the capabilities of the system
- Avoiding, e.g., mono-cultures of energy crops
- Reduced pollution in cities (e.g., transportation)
- Participated effort
Electricity

- **Total usable energy**
- **Total energy consumption**
- **Non-renewable energy** (fossil + fissile)
- **Renewable energy**

Sustainable energy supply:
- fission
- solar energy (direct)
- wind power
- hydropower/tidal/wave power
- ocean and geothermal energy
- ambient energy
- muscle power
- biomass/biogas energy

Source: CMDC/WSEC

Essentially electricity
Heat

Total usable energy

Total energy consumption

Non-renewable energy (fossil + fissile)

Renewable energy

Sustainable energy supply:
- fission
- solar energy (direct)
- wind power
- hydropower/tidal/wave power
- ocean and geothermal energy
- ambient energy
- muscle power
- biomass/biogas energy

source CMDC/WSEC

Heat

A. Contin, Varenna, 22/7/2019
Hydrocarbons

Total usable energy

Total energy consumption

Non-renewable energy (fossil/fissile)

Renewable energy

Sustainable energy supply:
- fission
- solar energy (direct)
- wind power
- hydropower/tidal/wave power
- ocean and geothermal energy
- ambient energy
- muscle power
- biomass/biogas energy

only source of hydrocarbon-like molecules

source CMDC/WSEC

A. Contin, Varenna, 22/7/2019
How much energy do we need?

UN Human Development Index corrected for Gini index (IHDI)

- **Long and healthy life**
  - Life expectancy at birth
  - Life expectancy index

- **Knowledge**
  - Expected years of schooling
  - Mean years of schooling
  - Education index

- **A decent standard of living**
  - GNI per capita (PPP $)
  - GNI index

**Graphs:**
- Human Development Index (HDI) vs. GDP/person (US$ 2005)
- Human Development Index (IHDI) vs. Energy consumption (toe/person)
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)

- **Electric Energy**: 22%
- **Transportation (no EE)**: 30%
- **Industry + Households (no EE)**: 48%
Italy energy consumption (2017)

Data in Mtoe
Three main sectors

<table>
<thead>
<tr>
<th></th>
<th>source</th>
<th></th>
<th>location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>fixed</td>
<td>mobile</td>
<td>centralized</td>
</tr>
<tr>
<td>Industry/Civil (heat)</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Electric Energy</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

All sectors must be satisfied!
**How to satisfy needs**

- can use EE (e.g., heat pumps)
- easiest to produce with RES

<table>
<thead>
<tr>
<th>Industry/Civil (heat)</th>
<th>source</th>
<th>location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>fixed</td>
<td>mobile</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric Energy</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

most difficult even if...
Electric mobility

- 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
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

- 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 H₂O content
- High Heating Value
- Directly usable in dual-fuel CHPs or blended with bio-diesel

Recent (2014) development by Fraunhofer-Gesellshaft, Germany

- High H content (35-40% vol.)
- Usable in dual-fuel CHPs
- Source of «green» H₂

Feedstock

550 °C Intermediate Pyrolysis

Carbonisate

Catalytic Reforming

700 °C

Syngas

Oil

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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
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

TCR
Water → Char → Gasifier
Syngas → PSA
Oil

Gasifier
PSA
Tail gas

HDO

H₂

Liquid fuel

H₂
Energy balance

Feedstock
- Oil 20%
- Syngas 24%
- Tail gas 14%
- Bio-char 29%
- Water 1%
- Loss 27%

Heat
- HDO 22%
- H₂ 3%
- Tail gas 14%
- Bio-char 29%
- Loss 5%

Useful products
- Used to produce heat and power for the plant itself
- HDO oil 22%
TCR-oil from sewage sludge

- High quality, engine-ready
- LHV: ≈34 MJ/kg

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

Table:

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>83.7 wt. %</td>
</tr>
<tr>
<td>H</td>
<td>9.0 wt. %</td>
</tr>
<tr>
<td>N</td>
<td>2.1 wt. %</td>
</tr>
<tr>
<td>S</td>
<td>0.9 wt. %</td>
</tr>
<tr>
<td>O (diff.)</td>
<td>3.7 wt. %</td>
</tr>
<tr>
<td>H₂O</td>
<td>0.6 wt. %</td>
</tr>
<tr>
<td>TAN</td>
<td>0.6 mg KOH/g</td>
</tr>
<tr>
<td>Ash</td>
<td>&lt; 0.005 wt. %</td>
</tr>
</tbody>
</table>

Excellent precursor for Hydrotreatment
Syngas from sewage sludge

Engine-ready gas
HHV: $\approx 14$-18 MJ/m$^3$

<table>
<thead>
<tr>
<th>Component</th>
<th>Concentration (v/v%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$</td>
<td>$38 \pm 3$</td>
</tr>
<tr>
<td>CO</td>
<td>$8 \pm 2$</td>
</tr>
<tr>
<td>CO$_2$</td>
<td>$30 \pm 3$</td>
</tr>
<tr>
<td>CH$_4$</td>
<td>$14 \pm 2$</td>
</tr>
<tr>
<td>C$_x$H$_y$</td>
<td>$3 \pm 1$</td>
</tr>
</tbody>
</table>

High Hydrogen Content Essential for Hydrogen separation by PSA
**TCR-oil + HDO**

**Hydrodeoxygcnation:**

\[ R_2O + 2H_2 \rightarrow H_2O + 2RH \]

*Catalysts: sulfided nickel-molybdenum or cobalt-molybdenum*

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

### Table 2: Ultimate Analysis and Properties of the HDO TCR Bio-oil

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th>Units</th>
<th>TCR-HDO Oil</th>
<th>Fossil Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher Heating Value</td>
<td>MJ/Kg</td>
<td>46</td>
<td>44.7</td>
</tr>
<tr>
<td>Lower Heating Value</td>
<td>MJ/Kg</td>
<td>43</td>
<td>41.9</td>
</tr>
<tr>
<td>Acid Number</td>
<td>Mg KOH/g</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Viscosity</td>
<td>cSt</td>
<td>1.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Water</td>
<td>Wt%</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Ash</td>
<td>Wt%</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

### Ultimate Analysis

<table>
<thead>
<tr>
<th>Component</th>
<th>Wt%</th>
<th>TCR-HDO Oil</th>
<th>Fossil Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>86</td>
<td>84.7</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>13.6</td>
<td>13.2</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>0.5</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td></td>
</tr>
<tr>
<td>O*</td>
<td>0.7</td>
<td>1.4</td>
<td></td>
</tr>
</tbody>
</table>

**Drop-in fuel: directly usable in cars**

Before HDO

After HDO

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Drop-in fuel

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

Milano-Nosedo Wastewater Treatment Plant (1,200,000 inhabitants)
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.

- **Carbonisate**: Material for wastewater filtering
- **Syngas**: Green hydrogen, methanol
- **Oil**: Chemical building blocks (phenols and other aromatics)
TCR®-2 in Ravenna
Energy storage («biobattery»)

Biobattery application
Flexible energy supply

1.8 Part power (for the Process)

8.2 Parts Biomass

3.7 Parts Gas/Oil

3.6 Parts Biochar

2.4 Part losses

0.3 watery Phase

1.8 Parts Power

1.9 Parts health

e.g. Co-fermentation

e.g. Co-combustion, filter, soil conditioner

A. Contin, Varenna, 22/7/2019
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
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
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)