News Views on De-carbonisation: Good and Bad Carbon

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Department of Process Integration at UMIST 1990 – 2004
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- Energy-water nexus

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Motto

• The increase in the world population that has occurred has placed increasing pressure on the demands of world society, and especially that of industrial and agricultural production.

• The accelerating development of countries with large populations has resulted in increased demands on agricultural production and processing, which resulted in further increases in energy and water demands.

• The supplies sharply increase in cost and many cases of shortages of all forms of energy and water are witnessed
Outline

1. Good and Bad Carbon introduction + Statistics

2. Example of solutions/strategies for GHGs (Bad Carbon) reduction

3. Relationship with the non-main global warming contributors (the air pollutants). Limitation of current assessments

4. Environmental footprints

5. Concluding Remarks
Carbon is an ASSET

Design with the natural cycle in mind to ensure the carbon end ups in the right place, right dose & right duration

“It is we who made carbon toxic”

- Climate change is a design failure
- CO₂ in the atmosphere is a liability but in the soil it is an asset

<blogs.scientificamerican.com/observations/new-view-carbon-is-not-the-enemy/>
The New Language

• **Fugitive Carbon** - ended up somewhere unwanted and can be toxic as emissions (e.g. atmosphere)

• **Durable Carbon** - Locked in stable solids that are used and reused (e.g. soil)

• **Living Carbon** - Organic, flowing in biological cycles, providing fresh food, healthy forests and fertile soil

<www.nature.com/news/carbon-is-not-the-enemy-1.20976>
Management Strategies

• **Carbon Negative** - actions pollute the land, water and atmosphere with various forms of carbon

• **Carbon Neutral** - actions transform or maintain carbon in durable earthbound forms and cycles for use across generations; or renewable energy such as solar, wind and hydropower that do not release carbon emissions.

• **Carbon Positive** - actions convert atmospheric carbon/carbon from organic materials to forms that enhance soil nutrition, green plants grow or to durable forms.

<www.nature.com/news/carbon-is-not-the-enemy-1.20976>
Carbon World: The Good

- Every living organism on the planet is a carbon based life form.

18% carbon

Energy
Total Annual Anthropogenic GHG Emissions

(FOLU - Forestry and Other Land Use, F-Gases = Fluorinated Gases)

The Bad Carbon

The Global Emission GHG: Types and by Sectors

Data for Year 2010

CO₂ (fossil fuel & industrial processes) [PERCENTAGE] 21%

Electricity 31%

Industry 21%

Agriculture 9%

Commercial & Residential 12%

F-gases 2%

Nitrous Oxide 6%

Methane 16%

CO₂ (forestry and other land use) [PERCENTAGE] 12%

[www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data>
C emissions Climate Influence

Radiative Forcing relative to 1750 (W m$^{-2}$)

-0.5
0
0.5
1
1.5
2
2.5

Carbon dioxide
Methane
Halocarbons
Nitrous oxide
Carbon monoxide
Non-methane volatile organic compound
Aerosols & precursors
Cloud adjustment due to aerosols
Albedo change due to land use
Changes in solar irradiance
2011
1980
1950

CO$_2$ and CH$_4$

*Between Year 1750-2011, refer the reference for SD value

CO₂ Contributors

The data only considers carbon dioxide emissions from the burning of fossil fuels and cement manufacture, but not emissions from land use, land-use change and forestry. Emissions from international shipping or bunker fuels are also not included in national figures.

CO₂ emissions by country

- China: 29.5%
- United States: 14.34%
- European Union: 9.62%
- India: 6.81%
- Russia: 4.88%
- Japan: 3.47%

Global mean energy budget under present-day climate conditions

Heat-trapping gases, in balanced proportions, keeping temperatures within a range that enables life to thrive

Methane $\text{CH}_4$

- Flaring of Methane by petroleum industry is much more regulated
- Main problem - The natural gas. **Shale gas development**, venting of unburned $\text{CH}_4$ from oil field facilities and equipment (fugitive emissions or leaks),

International Energy Agency
Methane fluxes from coastal sediments

- Eutrophication, has been recognized to be the principal driver for the enhanced GHG flux from aquatic environments.
- According to recent budgets, shallow aquatic systems may contribute ~10% of global N$_2$O emissions.
- No clear consensus on the contribution of these environments to the global CH$_4$ emission because source magnitude and variability remain highly uncertain.
- However, up to 30–40% of the methane emissions may be due to methane produced in sediments of aquatic ecosystems.
- The role of coastal benthic macrofauna in mediating gas release is still amply debated since the mechanisms regulating production and transport of gases by invertebrates are largely unknown.
- Bivalves isolated from coastal sediments were shown to be strong emitters of N$_2$O. However, it is not clear from these studies whether the N$_2$O produced by bivalves reaches the water column or is reduced to dinitrogen by denitrifying bacteria living in the sediment.

Methane fluxes from coastal sediments
THE ROLES OR MACROFAUNA

- Macrofauna contributes to GHG production and that the extent is dependent on lineage.
- It may play an important but overlooked role in regulating GHG production and exchange in coastal sediment ecosystems

Solutions/ Strategies for Bad Carbon (emissions)

• SAVING and EFFICIENCY
• Through Electricity and Heat Sector (Renewable energy, Process Integration)
• Through Transportation Sector (Electrical transport, brake system etc)
• Waste Management (Waste to energy etc)
• Sequestration
Energy

The most environmentally friendly is energy not used / saved

How to achieve better energy efficiency and conservation?
US Balance: Economy Wide Losses

More than two-thirds of the fuel used to generate power in the U.S. is lost as heat.

Conversion Losses: 63.9%
- Plant Use: 1.7%
- T&D Losses: 3.1%
- Residential: 11.1%
- Commercial: 10.6%
- Industrial: 8.2%
- Transportation: 0.1%
- Direct Use: 1.3%
- Unaccounted for: 0.46%
- Net Imports of Electricity: 0.1%

Economy Wide Losses: 25%
- Coal: 51.1%
- Natural Gas: 16.9%
- Petroleum: 0.2%
- Other Gases: 0.4%
- Nuclear Electric Power: 19.6%
- Renewable Energy: 10.1%
- Other: 0.18%

Estimated Energy Consumption in 2,457 Mtoe

Units: Mt of oil equivalent

Lawrence Livermore National Laboratory and the Department of Energy (US)
Electricity and Heat

- Statistics (Renewables energy)
- Examples/ issues (RE & PI)
Global energy consumption, (2015)

Transport = 2,704 Mtoe
Other = 3,132 Mtoe
Non-energy use = 836 Mtoe

Total Final Consumption 49%
Industry = 2,712 Mtoe

Final Energy Consumption (Mtoe)

Energy production & consumption

Arranged in decreasing GDP

- United States: RE = 6.87%
- China: RE = 11.24%
- Japan: RE = 36.36%
- Germany: RE = 11.57%
- United Kingdom: RE = 6.75%
- United States: 39.86%
- China: 36.94%
- Japan: 40.86%
- Germany: 52.85%

Renewable Energy

• RE is one of the contributors to high energy loss and low energy efficiency. (Desjardins, 2016)

• More research attention is needed to further promote the development of better dispatch ability and efficiency, as well as to lower the cost of renewable energy technologies.

• The sources of RE can be classified into natural resources (such as sun, water, wind, waves, geothermal and biomass) and waste (such as agricultural, plastic, industrial and municipal solid waste).

• Hybrid solar PV and wind energy systems are among the most common combinations because of the natural synergies of sun and wind (co-located) (FS-UNEP, 2017).


Renewable energy

EU renewable-energy consumption
Generated from sources including wind, geothermal, solar, biomass and waste
Terawatt hours

Source: BP
*Not including hydroelectricity generation

RE deployment 2020, 2030

EU

Unscheduled power flows

- Peaks in wind electricity supplies, have caused serious and costly problems in Central Europe, for example between the Czech Republic and Germany. (Korab and Owczarek, 2016)

Transportation

- Statistics
- Examples and issues
Transportation Sector

• Utilisation of biofuels and the development of electric cars.

• Recently, countries such as the UK, France, Netherland and China have considered banning the production of petrol and diesel cars.

• A range of battery issues needs to be solved for meeting the targets.

• Would the electric car will completely displace the roles of petrol and diesel?

• eCars energy recuperation

<www.sciencealert.com/the-netherlands-is-planning-to-end-all-its-coal-power-by-2030>

FT (Financial Times), 2017. China eyes eventual ban of petrol and diesel cars. <www.ft.com/content/d3bcc6f2-95f0-11e7-a652-cde3f882dd7b>
## Vehicle technologies

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Initial cost (kUSD)</th>
<th>Power plant to wheel efficiency</th>
<th>Commercial availability</th>
<th>Main challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric</td>
<td>21.3</td>
<td>High (&gt;50%)</td>
<td>Now</td>
<td>Chemical sustainability, battery costs</td>
</tr>
<tr>
<td>Hybrid electric</td>
<td>24.2</td>
<td>Moderate (≤50%)</td>
<td>Now</td>
<td>Chemical sustainability, battery costs</td>
</tr>
<tr>
<td>Hydrogen internal combustion engine</td>
<td>18</td>
<td>Low (&lt;25%)</td>
<td>In 2–3 y</td>
<td>Lack of infrastructure</td>
</tr>
<tr>
<td>Fuel-Cell</td>
<td>40</td>
<td>Low (&lt;25%)</td>
<td>In 2–3 y</td>
<td>Lack of infras. high costs</td>
</tr>
<tr>
<td>Biofuels</td>
<td>17.1</td>
<td>Low (&lt;25%)</td>
<td>Now</td>
<td>CO₂ fixation, responsible farming</td>
</tr>
</tbody>
</table>

Toyota- Hydrogen-Fuel Trucks. The only emission is water vapour
<www.sciencealert.com/toyota-s-trucks-that-only-emit-water-vapour-are-moving-goods-in-la>

Sea Transportation

Lower CO$_2$ emission? Greener freight transportation mode?
Transportation: Ship

<table>
<thead>
<tr>
<th>Mode</th>
<th>PM2.5</th>
<th>PM10</th>
<th>SOx</th>
<th>NOx</th>
<th>NMVOC</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>International aviation</td>
<td></td>
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<tr>
<td>Domestic aviation</td>
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<tr>
<td>International shipping</td>
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<tr>
<td>Domestic shipping</td>
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<tr>
<td>Railway</td>
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<tr>
<td>Road transport non-exhaust</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Road transport exhaust</td>
<td></td>
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</tr>
</tbody>
</table>

**Emission Factor-Example**

- **CO₂/t-km:** Truck = 348 g/tkm  🚛 Ship = 4 g/tkm 🚤

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Road Transport (Truck)</th>
<th>Sea Transport (Ship)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOₓ</td>
<td>0.00175</td>
<td>0.091</td>
</tr>
<tr>
<td>NOₓ,</td>
<td>0.127</td>
<td>0.033</td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>0.00136</td>
<td>0.00187</td>
</tr>
<tr>
<td>CO</td>
<td>0.272</td>
<td>0.0402</td>
</tr>
</tbody>
</table>

- VOCs, lead, PM₁₀, PM>10 etc

*Ecoinvent Database*

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<www.nature.com/>  
</twitter.com/KNectMaritime>
Distance

Example: Rotterdam to Genoa

1,181.47 km

4,092.82 km

Presented by <www.searates.com/reference/portdistance/>, Google maps
Concentration at Place

Dirty Ten

Published by Nature Publishing Group <www.nature.com/news>

PM$_{2.5}$ concentration (µg per m$^3$)
- 0-0.05
- 0.05-0.1
- 0.1-0.2
- 0.2-0.5
- 0.5-1
- 1-2

Tianjin China | 14.1
Guangzhou, China | 15
Dubai, United Arab Emirates | 15.6
Qingdao, China | 17.3
Busan, South Korea | 17.8
Hong Kong, S.A.R., China | 20.1
Ningbo-Zhoushan, China | 20.6
Shenzhen, China | 24.2
Singapore | 30.9
Shanghai, China | 36.5

Container Volume (MTEU)

Brindisi (Italy)- Port city of the Adriatic sea

3. The emissions factors of CO$_2$ is much lower, but it might not for the other harmful pollutants (e.g. SO$_x$). A longer distance may be needed by ship but it has a larger capacity.

4. The high concentration at one place (big port cities) could significantly affect the local air quality and human health.

5. The impact of other activities such as ship scrapping, container loading, unloading, distribution also contribute to the pollution. The ship engines are not always turn off at the berth.
Freight

- Method and measurement of emission ✔
- Assessment **approach/ framework/ methodology** for decision making needs more development.
  (**Environmental issues vs time vs cost vs flexibility/frequency vs reliability/safety**)
Waste Management

- Waste to Energy
- Issues
# WtE technologies

<table>
<thead>
<tr>
<th>WtE technologies</th>
<th>Form of energy produced</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermochemical</strong></td>
<td></td>
</tr>
<tr>
<td>1. Incineration (Mass burn &gt;1,000°C, Co-combustion with coal, biomass, Refuse-derived fuel)</td>
<td>Heat, power, Combined heat and power (CHP)</td>
</tr>
<tr>
<td>1. Thermal gasification (Conventional 750°C, Plasma arc 4,000-7,000 °C)</td>
<td>Hydrogen, methane, syngas</td>
</tr>
<tr>
<td>1. Pyrolysis (300-800°C, absence of O₂)</td>
<td>Char, gases, aerosols, syngas</td>
</tr>
<tr>
<td><strong>Biochemical</strong></td>
<td></td>
</tr>
<tr>
<td>1. Fermentation</td>
<td>Ethanol, hydrogen, biodiesel</td>
</tr>
<tr>
<td>1. Anaerobic digestion</td>
<td>Methane</td>
</tr>
<tr>
<td>1. Sanitary landfill</td>
<td>Methane</td>
</tr>
<tr>
<td>1. Microbial Fuel cell</td>
<td>Power</td>
</tr>
<tr>
<td><strong>Chemical</strong></td>
<td></td>
</tr>
<tr>
<td>1. Esterification</td>
<td>Ethanol, biodiesel</td>
</tr>
</tbody>
</table>

WtE technologies

• The global WtE market was valued at USD 25.32 x 10^9 in 2013, a growth of 5.5% over the previous year. WtE plant can save 100-350 kg CO₂eq/t of waste processed.

• Thermal energy conversion leads the WtE market, 88.2% of total market revenue in 2013.

• The EU is the largest market (47.6%), fastest market growth is in China. Important discovery and leap forward for a sustainable future.

• Inconsistent supply, burdening effect of waste collection and pre-treatment for different waste characteristics are the key barriers to the current implementation.

Current Waste Treatment Practice is Sustainable?!

Good business (source=waste), but in ENVIRONMENT PERSPECTIVE?

- **Incineration**: Emission worries, Importing garbage/waste from the other city/country (E.g. Sweden)
- **MBT plant**: Discourage waste separation at source, centralised (transport issues)
- **AD plant**: Planting of energy crop
- **Composting**: Open process (emission, leachate) without energy recover, heavy metal issues, compost application
Propose of New Footprint

SMOG/HAZE FOOTPRINT

• Over the past few years, the concern of anthropogenic emission has been focused on the **greenhouse gases** than the air pollutants $\text{SO}_x$, $\text{NO}_x$, VOC, Particulate Matter (PM) that causing air pollution and poses an **instantaneous impact to human health**.

• GHG and the air pollutants share some of the components, but the evaluation perspective is different.

• Major source: Transportation, burning etc.
Mortality and burden of disease from ambient air pollution

Ambient air pollution DALYS attributable to air pollution, 2012

Worldwide, ambient air pollution contributes to 5.4% of all deaths

Environmental Sustainability far wider than carbon emissions and climate change. A multi-dimensional approach is needed in optimisation study and planning.

Image by <www.perceiveproject.eu/2017/08/29/european-cities-are-smart/>
Concluding Remarks

• Let’s recognise carbon as an resources and the life-giving carbon cycle as a model for human designs.

• The management for an environmentally sustainable system is not all about minimisation. Prevention (e.g. waste)

• Environmental sustainability solution is not just about CO$_2$/GHG reduction.

• Change is the only permanent, toward the efficient resources allocation or utilisation to adapt the activities changes of population and economic development is important for a sustainable future.
Overall Remarks

Air emission impact in optimisation study - consider both GHG and the air pollutants in an overall system

• Especially: Transportation mode, Biomass energy etc.

• Methodology with defined criteria, boundary, interaction/relationship between GHG and air pollutant is needed

• To minimise the potential of footprint shifting and support more appropriate decision-making.
20th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction

In conjunction with

CHISA 2018- 23rd International Congress of Chemical and Process Engineering

25 – 29 August 2018 @Prague, Czech Republic

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Footprint is a quantitative measure showing the appropriation of natural resources by human beings (Hoekstra, 2008).

Footprints:
- Carbon footprint (CFP)
- Energy footprint (EFP)
- Water footprint (WFP)
- Ecological footprint (ECOFP)
- Nitrogen footprint (NFP)
- Land footprint (LFP)
- Social footprint (SFP) etc.

Carbon footprint - definitions

- CFP usually stands for the amount of CO₂ and other greenhouse gases, emitted over the full life cycle of a process or product.

- The CFP is quantified using indicators as the Global Warming Potential, which stands for the quantities of greenhouse gases that contribute to global warming and climate change, by considering a specific time horizon, usually 100 y.

- The land-based definition of CFP stands for the land area required for the sequestration of atmospheric fossils’ CO₂ emissions through aorestation (De Benedetto and Klemeš, 2009).

  De Benedetto L., Klemeš J., 2009, The environmental performance strategy map: an integrated LCA approach to support the decision making process, Journal of Cleaner Production, 17, 900-906

- Wiedmann and Minx (2008) proposed that CFP is a measure of exclusive direct and indirect CO₂ emissions over a life cycle.

  Wiedmann T., Minx J., 2008, A definition of ‘carbon footprint’. In: C. C. Pertsova, Ecological Economics Research Trends: Ch 1, 1-11, Nova Science Publisher, Hauppauge, NY, USA

Most recognised concept
Nitrogen footprint

- Increases as a result of artificial nitrogen fertilization, manure run-off, burning of biomass and fuels, and planting of legumes.

- Nitrogen fertilization leads to the contamination of drinking water, algal blooms, eutrophication, etc.

- NO\textsubscript{x} emissions can lead to smog, acid-rain, haze and climate change.

- The deposition of N, P and other contaminants is expected to have an impact on the biodiversity.

- N pollution damages ecosystems and affects human health, including respiratory diseases and the risk of birth defects (N-Print).
Water Footprint - Definition

WFP stands for the total volume of direct and indirect freshwater used, consumed and/or polluted.

WFP consists of:
- **Blue** (consumption of surface and groundwater),
- **Green** (consumption of rainwater)
- **Grey water footprint** - polluted water sometimes expressed as the volume of water required to dilute pollutants to water quality standards.

Mekonnen M. M., Hoekstra A. Y., 2010, The green, blue and grey water footprint of farm animals and animal products, Value of Water Research Report Series No. 48, UNESCO-IHE, Delft, the Netherlands

Source: Umweltbundesamt
WF of primary energy carriers

<table>
<thead>
<tr>
<th>Primary energy carriers</th>
<th>Global average WF (m³/GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>0.11</td>
</tr>
<tr>
<td>Coal</td>
<td>0.16</td>
</tr>
<tr>
<td>Crude oil</td>
<td>1.06</td>
</tr>
<tr>
<td>Uranium</td>
<td>0.09</td>
</tr>
<tr>
<td>Wind energy</td>
<td>Negligible</td>
</tr>
<tr>
<td>Solar thermal energy</td>
<td>0.30</td>
</tr>
<tr>
<td>Hydropower</td>
<td>22.30</td>
</tr>
<tr>
<td>Biomass energy</td>
<td>70 (range: 10-250)</td>
</tr>
</tbody>
</table>

(Gerbens-Leenes et al., 2008; <www.waterfootprint.org>)