BRNO UNIVERSITY OF TECHNOLOGY FACULTY OF MECHANICAL ENGINEERING

NETME Centre

SPIL

Environmental Footprints as a Tool to Progress to the Circular Economy

Jiří Jaromír Klemeš*, Yee Van Fan, Petar Sabev Varbanov

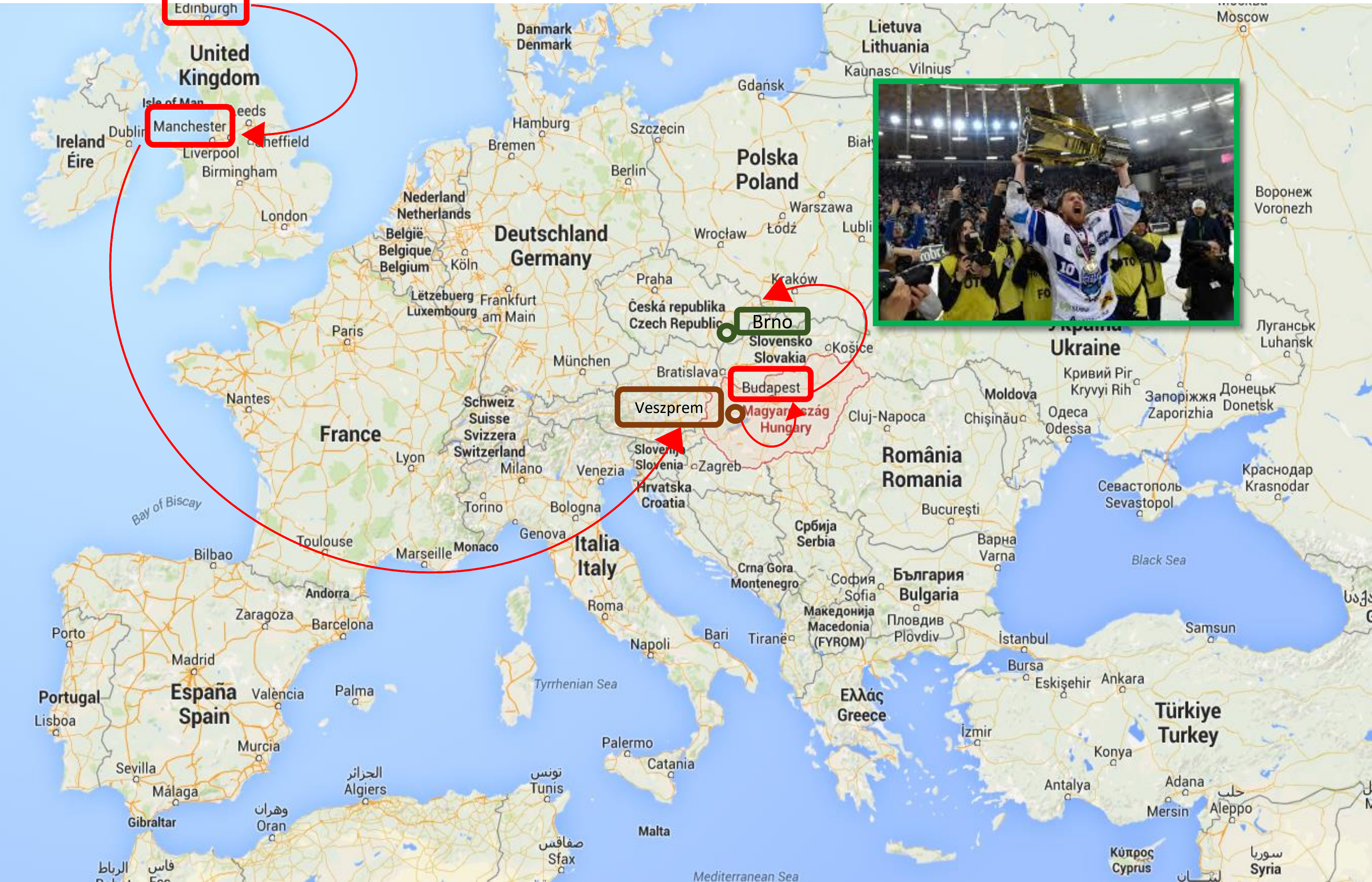
Sustainable Process Integration Laboratory – SPIL, NETME Centre,
Faculty of Mechanical Engineering, Brno University of Technology - VUT BRNO, Technická 2896/2, 616 69 Brno, Czech Republic

klemes@fme.vutbr.cz

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

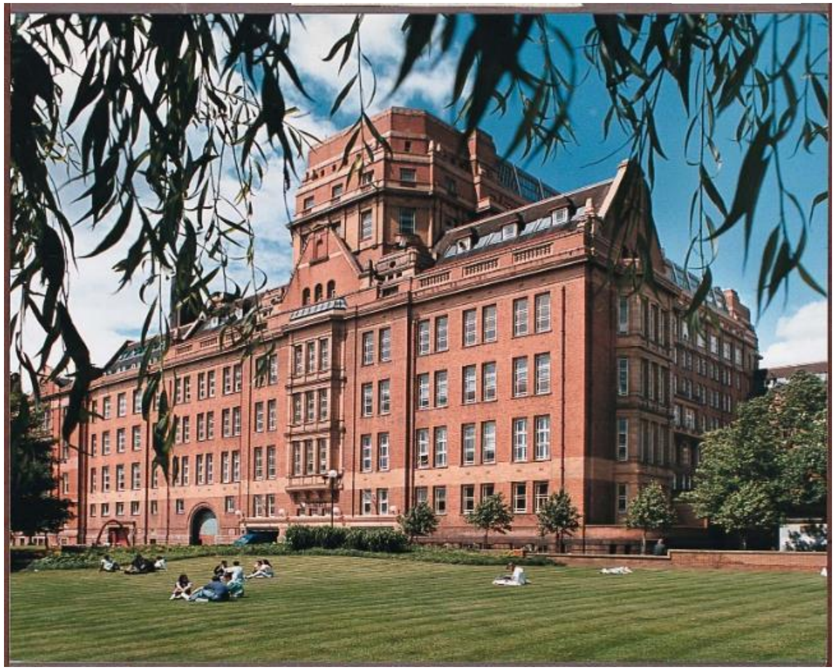
MŠMT
MINISTRY OF EDUCATION, YOUTH AND SPORTS

The Route
United Kingdom→ Hungary → Czech Republic



UMIST – Pioneering Pinch Analysis

Department of Process Integration at UMIST 1990 – 2004



University of Pannonia, Veszprem Hungary

BRNO UNIVERSITY OF TECHNOLOGY | FACULTY OF MECHANICAL ENGINEERING

NETME Centre

SUSTAINABLE PROCESS INTEGRATION LABORATORY

SPIL Research Team

Prof Dr **Jiří Jaromír KLEMEŠ**, DSc, Dr h c (mult)
Head of SPIL

Assoc Prof Dr **Petar Sabev VARBANOV**
DDr **Andreja NEMET**
Dr **Timothy WALMSLEY**
Dr Abdoulmohammad CHOFREH
Xuexiu JIA, MSc
Yee Van FAN, MPhil
Xuechao Wang, MSc
Assoc Prof Dr **Jiří POSPÍŠIL**
Dr **Martin PAVLAS**
Dr **Lubomír KLIMEŠ**
Dr **Vojtěch TUREK**
Dr **Radovan ŠOMPLÁK**
Michal ŠPILÁČEK, MSc

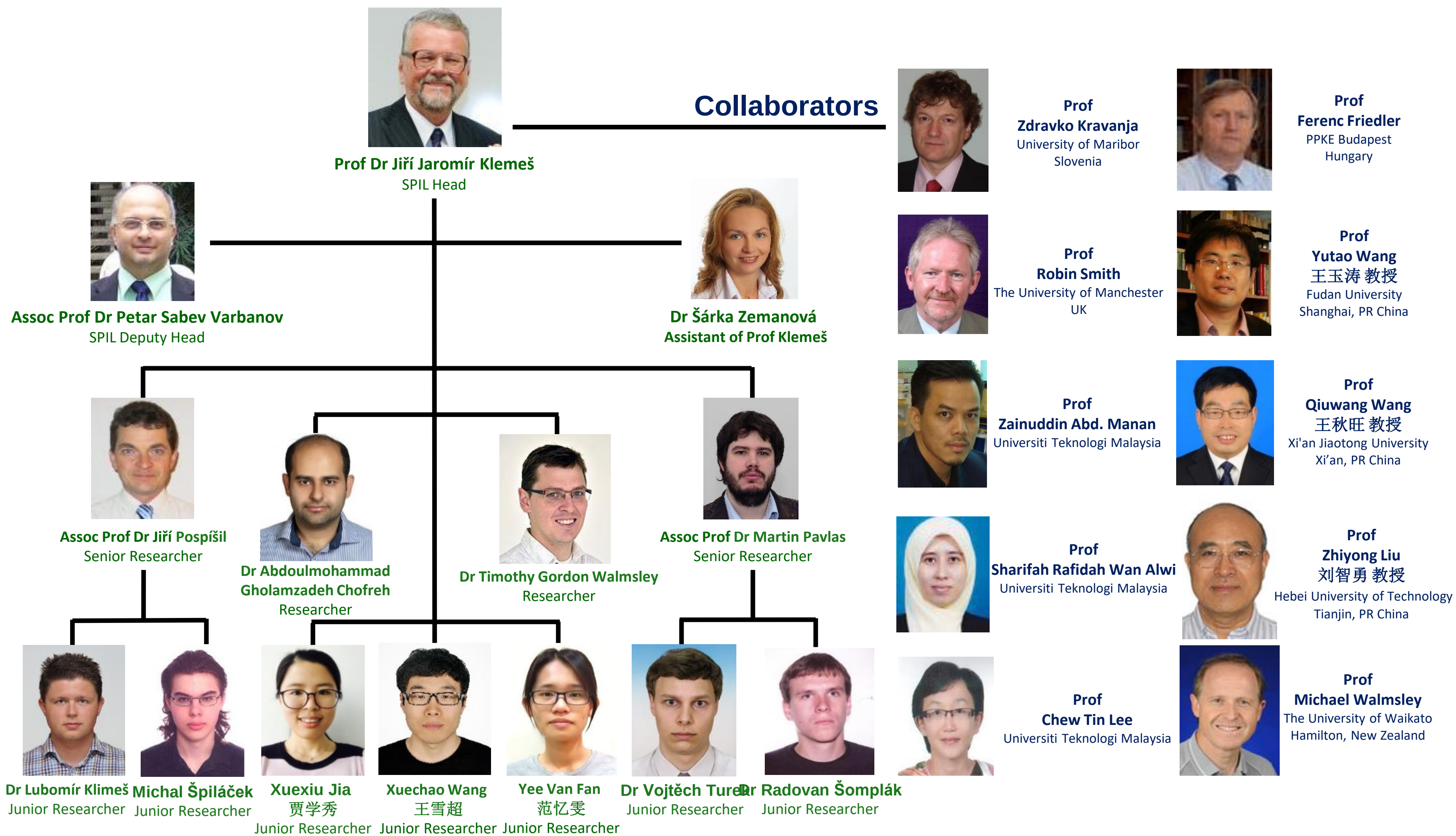
Collaboration Partners

University of Maribor, SI
The University of Manchester, UK
Universiti Teknologi Malaysia, MY
Hebei University of Chemical Technology, CN
Pázmány Péter Katolikus Egyetem, HU

EUROPEAN UNION
European Scructural and Investing Funds
Operational Programme Research, Development and Education

MINISTRY OF EDUCATION, YOUTH AND SPORTS

Sustainable Process Integration Laboratory (SPIL)



Submit Your Paper

View Articles

Guide for Authors

Abstracting/ Indexing

Track Your Paper

Order Journal

Journal Metrics

CiteScore: **5.79**

More about CiteScore

Impact Factor: **5.651**

5-Year Impact Factor: **6.352**

Source Normalized Impact per Paper (SNIP): **2.194**

SCImago Journal Rank (SJR): **1.467**

View More on Journal Insights

Article Enrichments

AudioSlides

Interactive Plot Viewer

Related Links

Author Stats

Publishing Campus

Author Services

Journal of Cleaner Production

Editorial Board

<www.journals.elsevier.com/journal-of-cleaner-production>

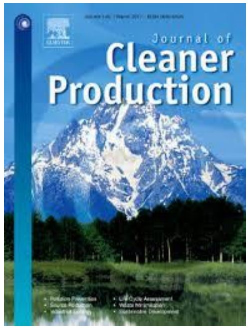
Co-Editors-in-Chief

Jiří Jaromír Klemeš
Brno University of Technology - VUT Brno, Brno, Czech Republic
Email Jiří Jaromír Klemeš

• Cleaner Production and Technical Processes• Green/sustainable engineering• Green/sustainable supply chains• Biomass• Energy use and consumption• Waste minimisation• Pollution reduction• Renewable energy• Environmental assessment• Emergy/exergy analyses• LCA of product and process - Footprints and other assessment types• Supply chains (modelling, mathematical, and engineering)• Eco-industrial parks• Energy-water nexus

Cecília Almeida
Paulista University, São Paulo, Brazil
Email Cecília Almeida

Yutao Wang
Fudan University, Shanghai, China
Email Yutao Wang



Founder and Editor-in-Chief Emeritus

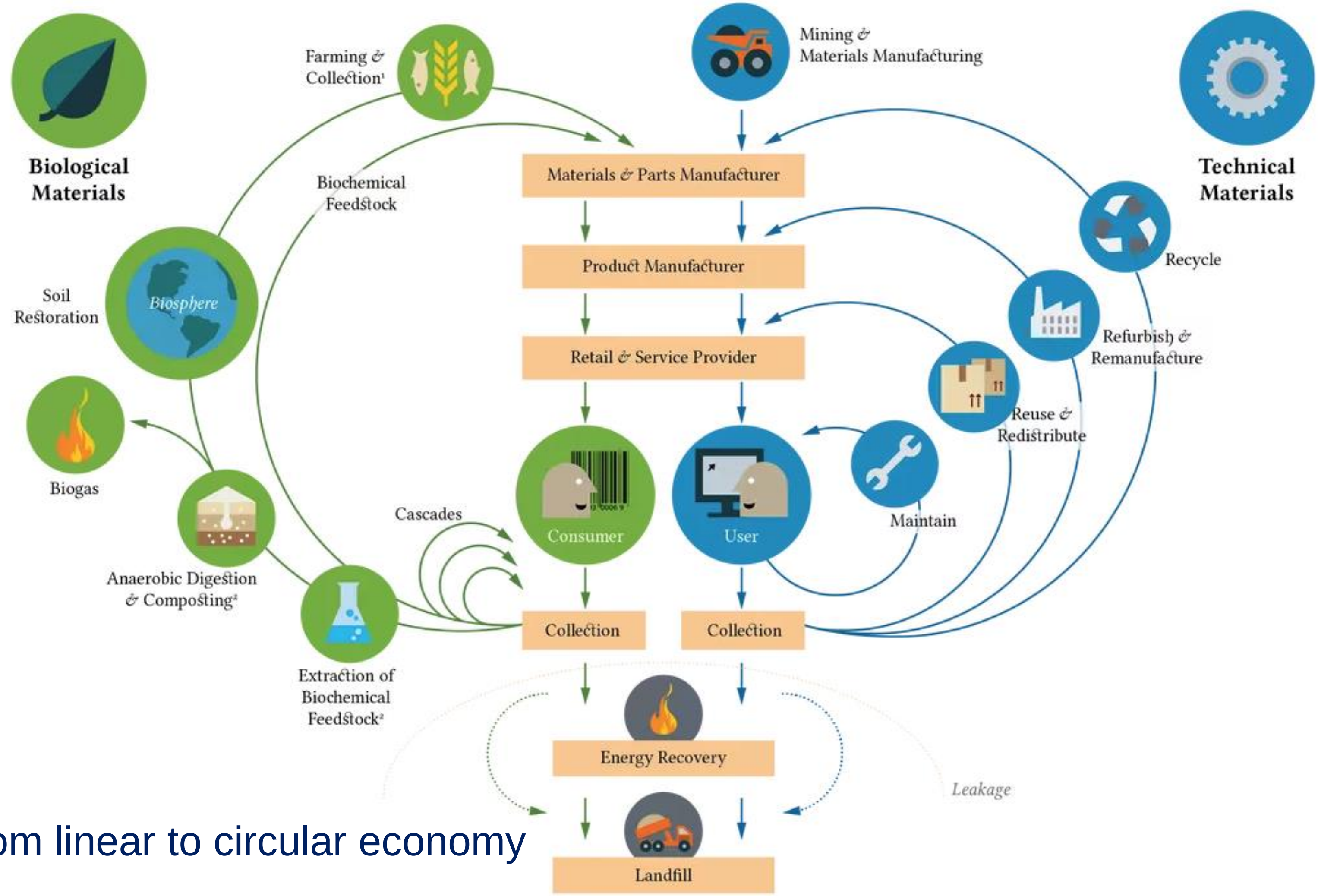
Don Huisingh
University of Tennessee, Knoxville, Tennessee, USA

Scarcity to extract natural resources

Circular Economy

Increase in raw material price and volatility

Overview of Circular Economy



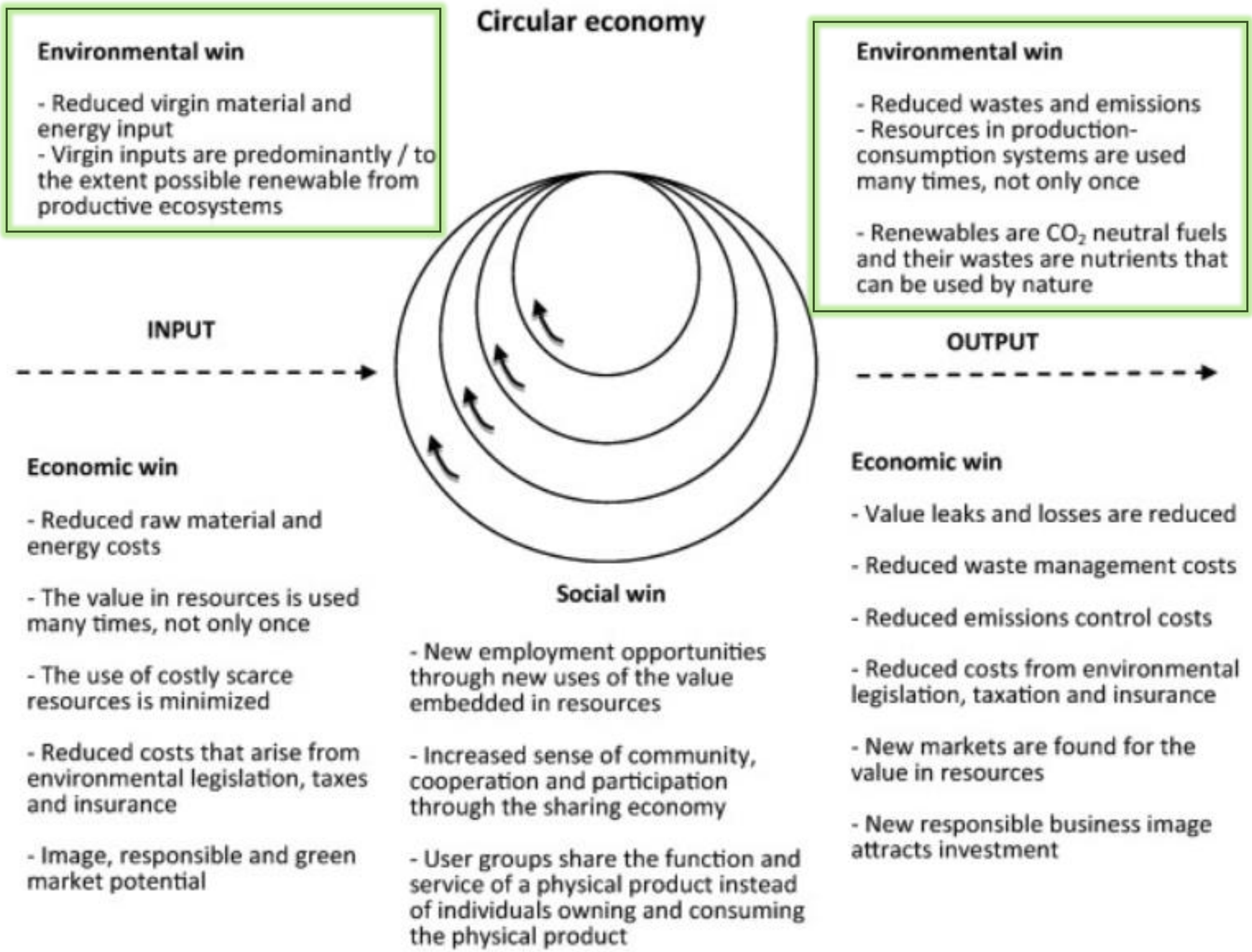
Transition from linear to circular economy

<aspenpartnerships.com/what-is-the-circular-economy/> accessed 20/3/2018

Market Drivers

- Win-win situation, create value
- Risk management - raw material shortage, disruption in the supply chain
- Environmental efficiency
- Innovation and brand image

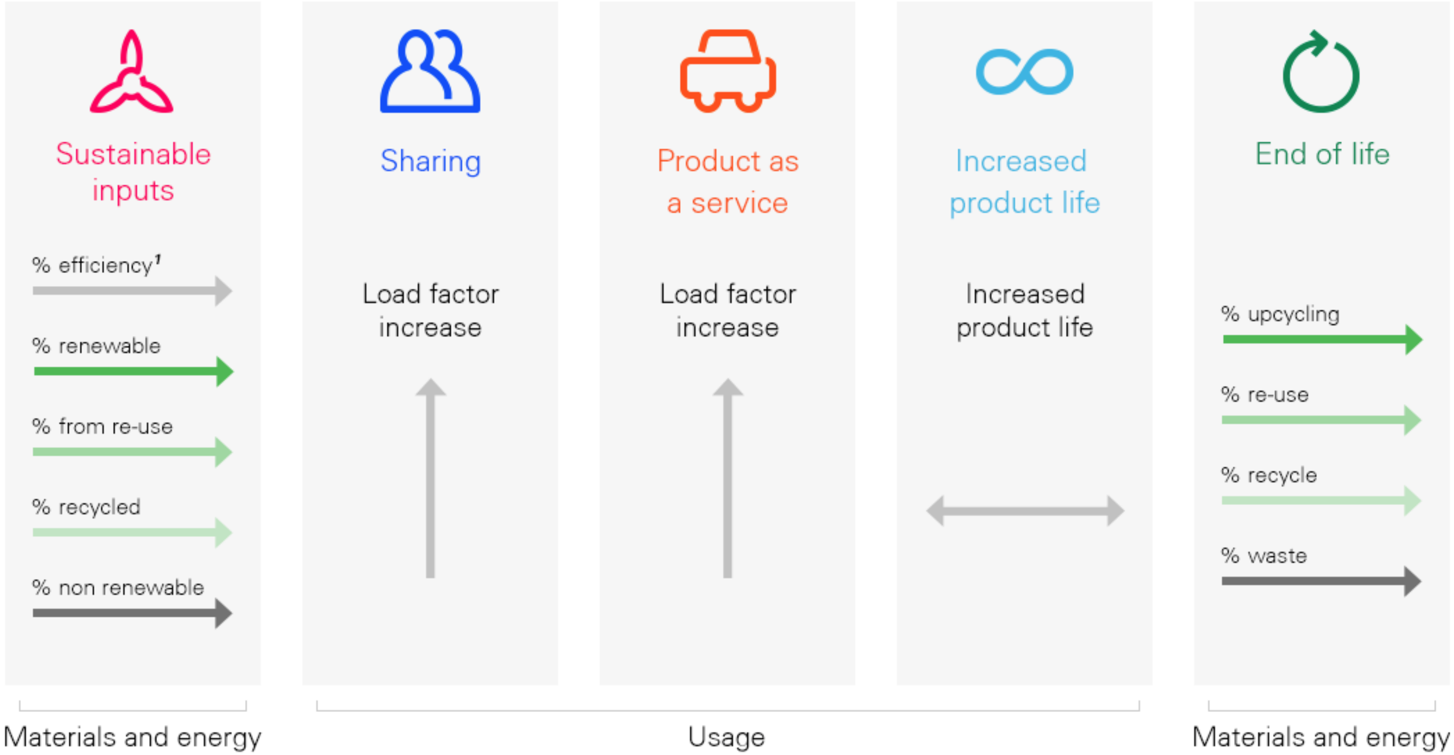
The Advantages



Korhonen, J., Honkasalo, A., Seppälä, J. (2018). Circular economy: the concept and its limitations. Ecological economics, 143, 37-46.

Circular Measurement Model

- Takes into account all five pillars of Circular Economy, applied by using a number of sub-indicators
- Defines a single circularity index. Calculate based on flow circularity and usage circularity
- To evaluate the success and effectiveness of the circular economy



Enel. CirculAbility Model <corporate.enel.it/en/circular-economy-sustainable-future/performance-indicators> accessed 2 July 2018

Energy Efficiency

How much energy is required to operate a circular economy?

Challenges in CE

- **Thermodynamic limits**
  - Cyclical systems consume resources and create waste and emissions
- **System boundary limits**
  - Spatial: problems are shifted along the product life cycle
  - Temporal: short term non-renewables used to build long-term renewable infrastructure
- **Limits posed by physical scale of the economy**
  - Rebound effect, Jevon's paradox, boomerang effect
- **Limits posed by path-dependency and lock-in**
  - First technologies retain their market position despite of in-efficiency
- **Limits of governance and management**
  - Intra-organizational and intra-sectoral management of inter-organizational and inter-sectoral physical flows of materials and energy
- **Limits of social and cultural definitions**
  - The concept of waste has a strong influence on its handling, management and utilisation
  - The concept is culturally and socially constructed
  - The concept of waste is always constructed in a certain cultural, social and temporal context and this context is dynamic and changing

Korhonen, J., Honkasalo, A., Seppälä, J. (2018). Circular economy: the concept and its limitations. Ecological economics, 143, 37-46.

Environmental Footprints

Circular economy practices led to low-carbon emission footprint and the other benefits (low N footprint, water footprint etc)

Footprints

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

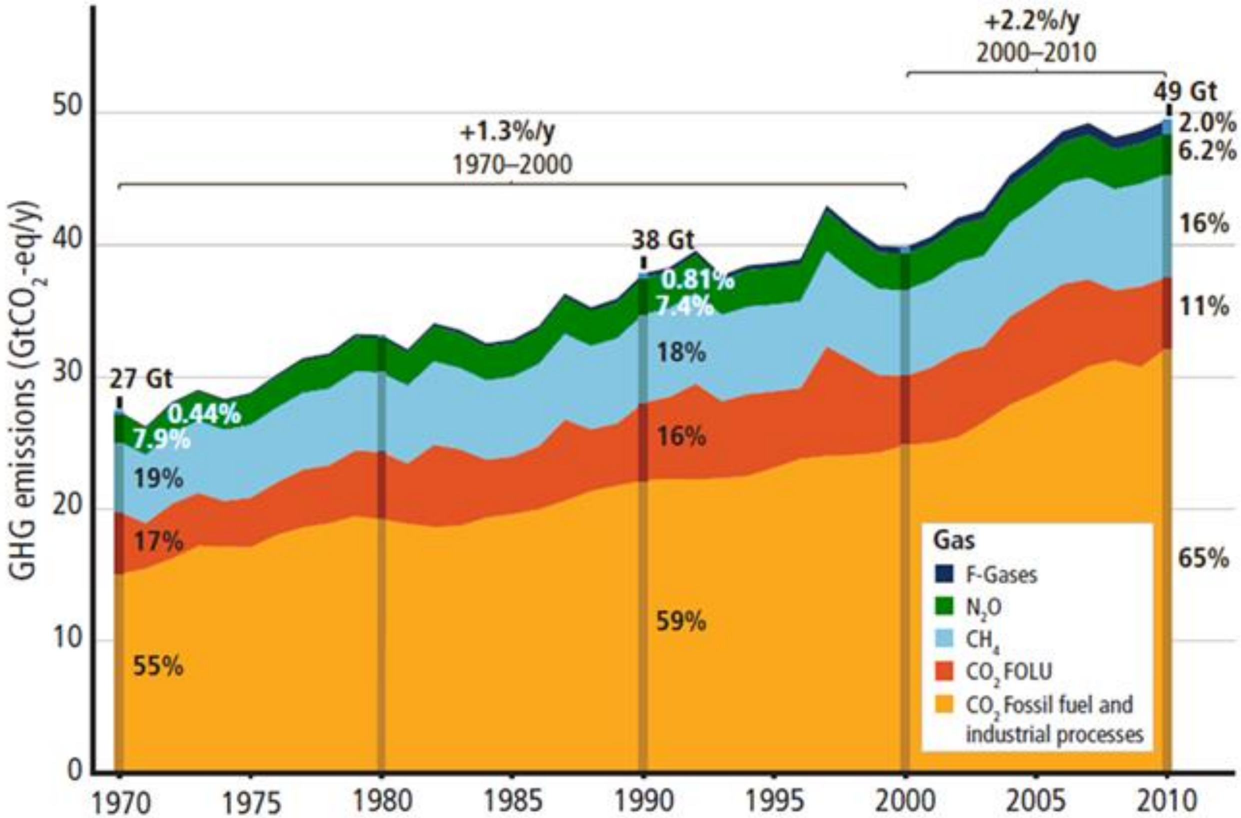
Hoekstra A. Y., 2008, Water neutral: Reducing and offsetting the impacts of water footprints, Value of Water Research Report Series No. 28, UNESCO-IHE, Delft, the Netherlands

Footprints:

- **Carbon emissions footprint (CFP) – GHG Footprint**
- **Nitrogen footprint (NFP)**
- **Water footprint (WFP)**
- Energy footprint (EFP)
- Ecological footprint (ECOFP)
- Land footprint (LFP)
- Social footprint (SFP)
- etc.

Čuček, L., Klemeš, J. J., Kravanja, Z. (2012). A review of footprint analysis tools for monitoring impacts on sustainability. Journal of Cleaner Production, 34, 9-20.

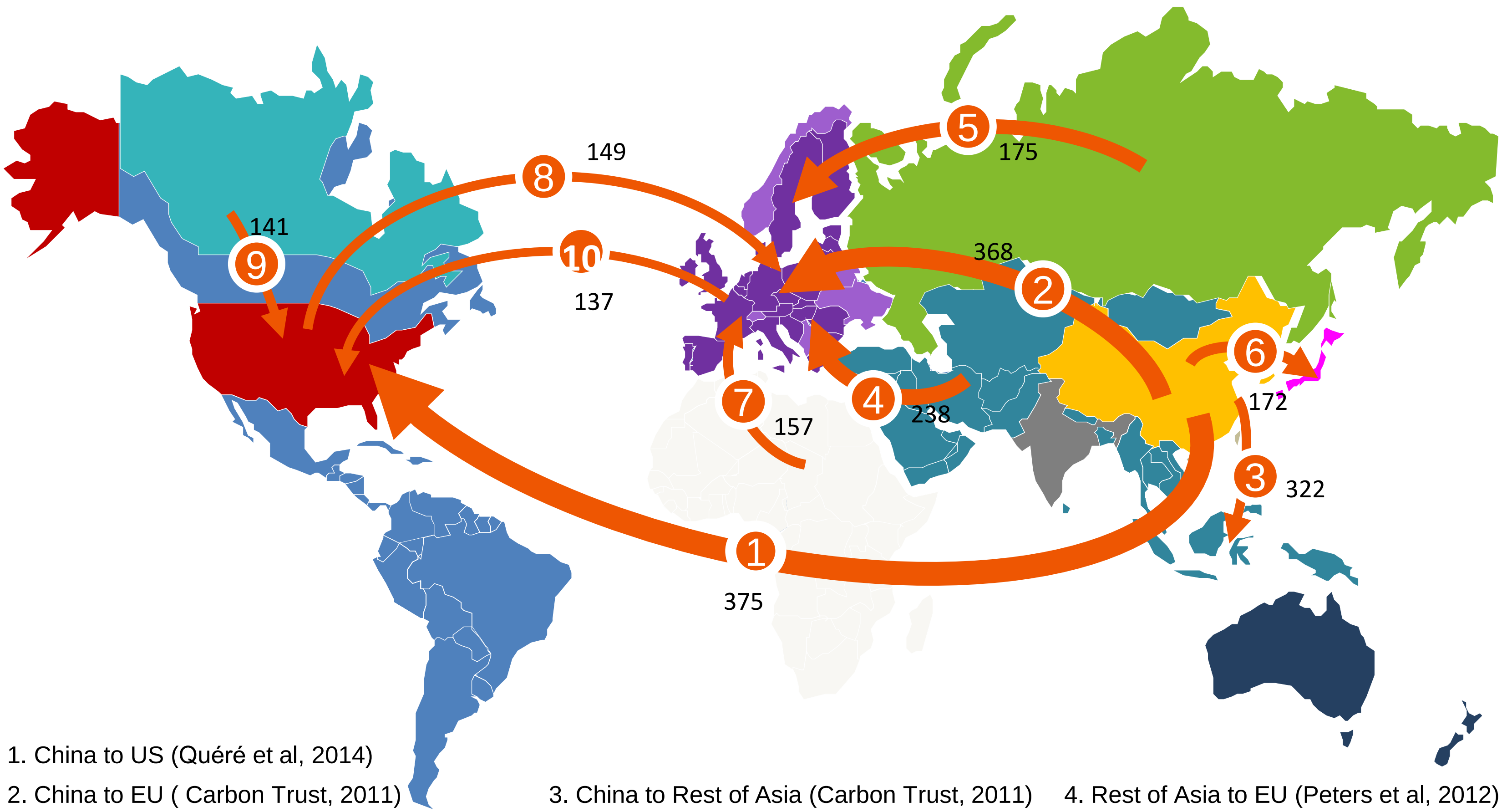
The Total Annual Anthropogenic GHG Emissions



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

IPCC (Intergovernmental Panel on Climate Change), Developed from Climate Change 2014: Synthesis Report, Report Graphic, IPCC Secretariat, World Meteorological Organization, Geneva, Switzerland <www.ipcc.ch/report/graphics/index.php?t=Assessment%20Reports&r=AR5%20-%20Synthesis%20Report&f= Topic% 203> accessed 02.10.2017

Virtual GHGs Emissions Flows in the International Trade



1. China to US (Quéré et al, 2014)
2. China to EU (Carbon Trust, 2011)
3. China to Rest of Asia (Carbon Trust, 2011)
4. Rest of Asia to EU (Peters et al, 2012)
5. Russian Federation to EU (Peters et al, 2012)
6. China to Japan (Carbon Trust, 2011)
7. Africa to EU (Peters et al, 2012)
8. US to EU (Peters et al, 2012)
9. Canada to EU (Petar et al, 2012)
10. EU to US (Petar et al, 2012)

Proposal of a New Footprint

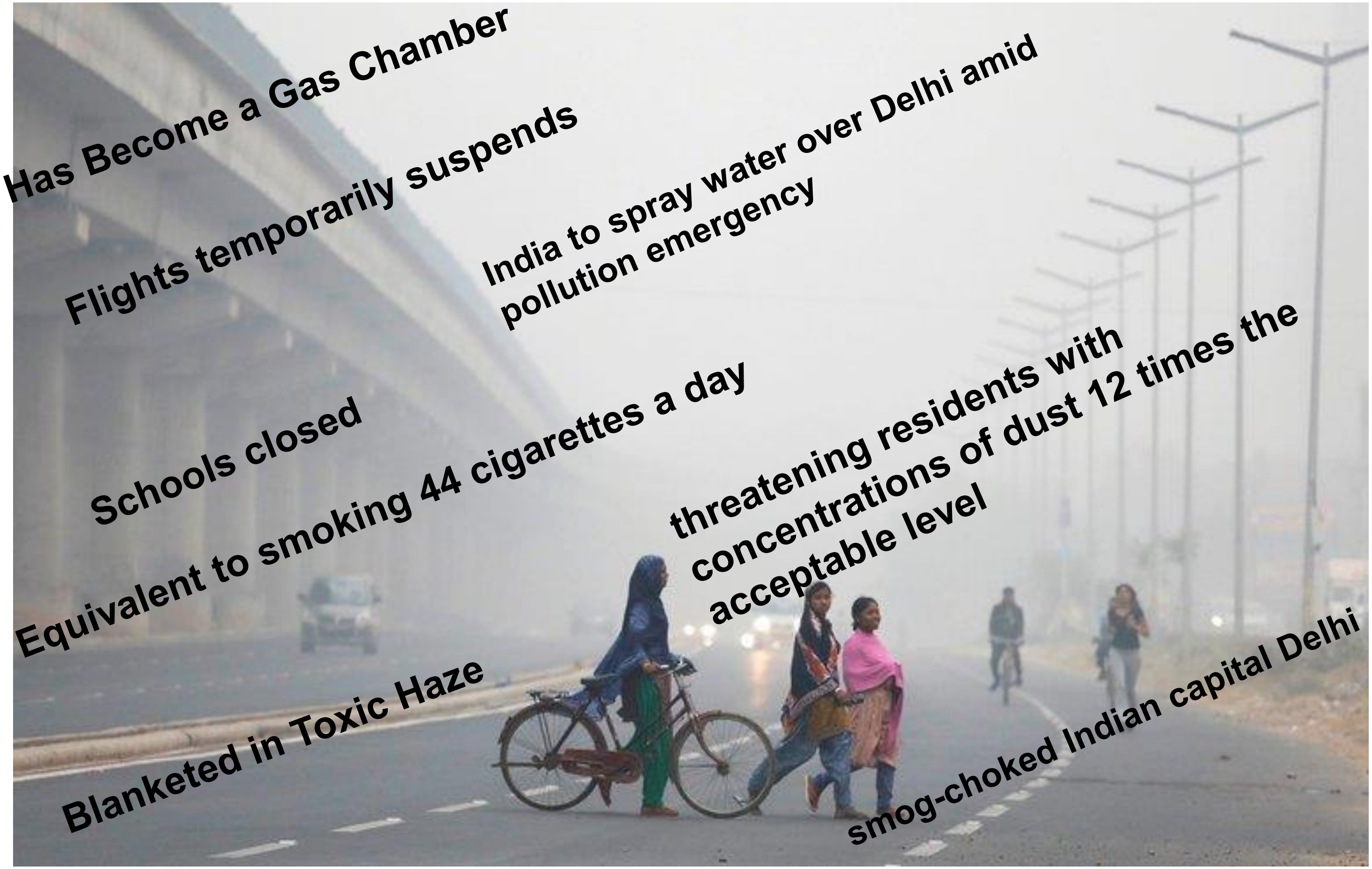
WHY?

SMOG/HAZE FOOTPRINT

- Over the past few years, the **concern** of anthropogenic emission has been **focused on the greenhouse gases** than the **air pollutants, e.g. SO_x, NO_x, VOC, Particulate Matter (PM)** that causing air pollution and poses an **instantaneous impact to human health**.
- GHG (climate change) and the air pollutants share some of the components, but the evaluation perspective is different.

YV Fan, JJ Klemeš, CT Lee. Smog/haze footprint assessment and minimisation. Submitted manuscript

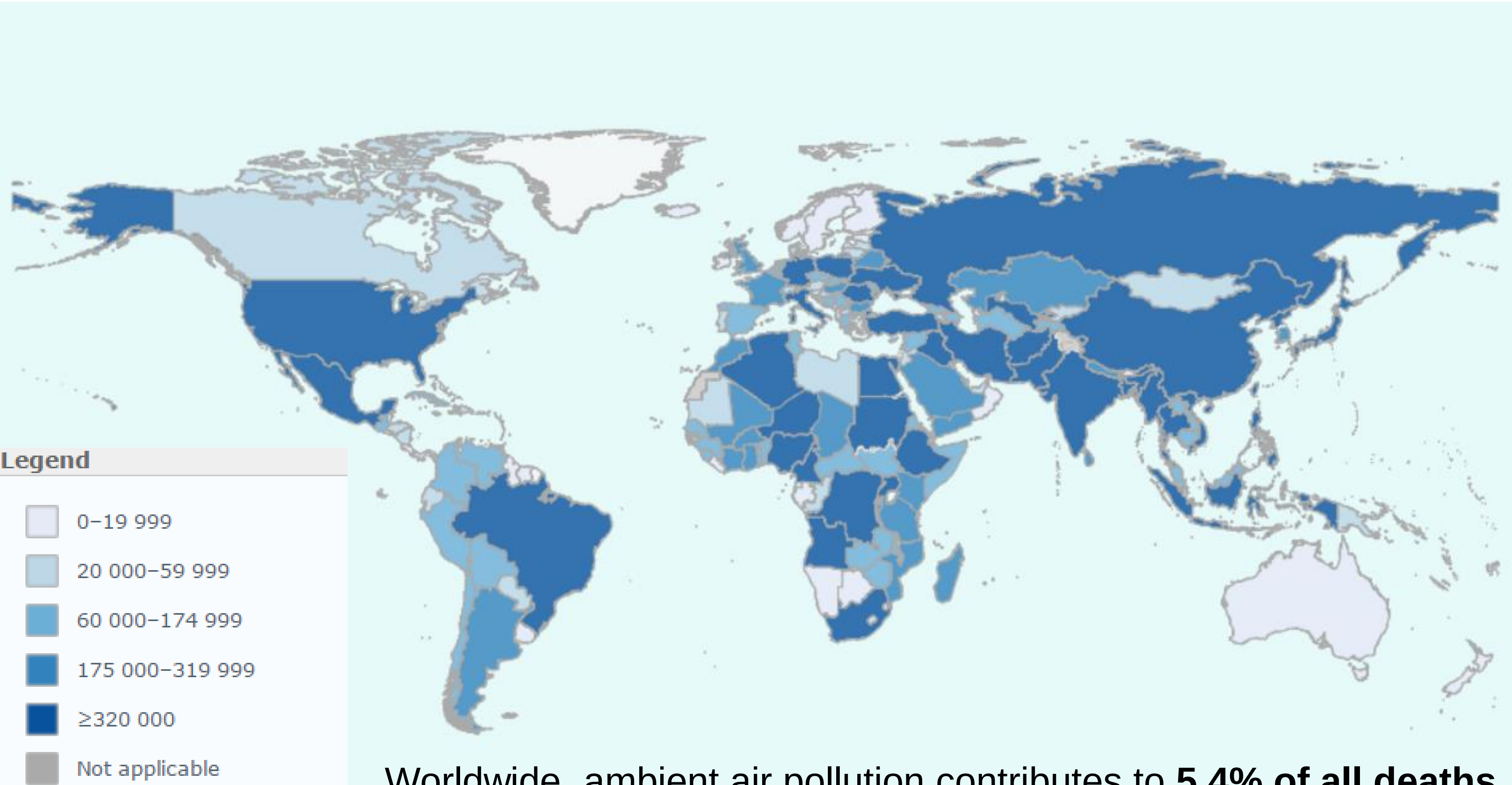
Smog and Haze Footprints



<www.nytimes.com/2017/11/07/world/asia/delhi-pollution-gas-chamber.html?mc=adintl&mcid=facebook&mccr=edit&ad-keywords=GlobalTruth> accessed 14/11/2017

Mortality and Burden of Disease from Air Pollution

Air pollution attributable to atmospheric emissions



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

Adopted from <www.who.int/gho/phe/outdoor_air_pollution/burden/en/> 2016. accessed 2 May 2017

Low Carbon?!

Zero Carbon?!

Carbon-free?!

Carbon is an ASSET

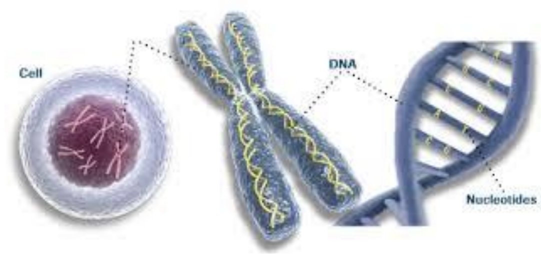
Design with the natural cycle in mind to ensure the carbon end ups in the right place, right dose &right duration

"It is we who made carbon toxic"

William McDonough (2016). Carbon is not the enemy. Nature, 539(7629):349-351. doi: 10.1038/539349a.

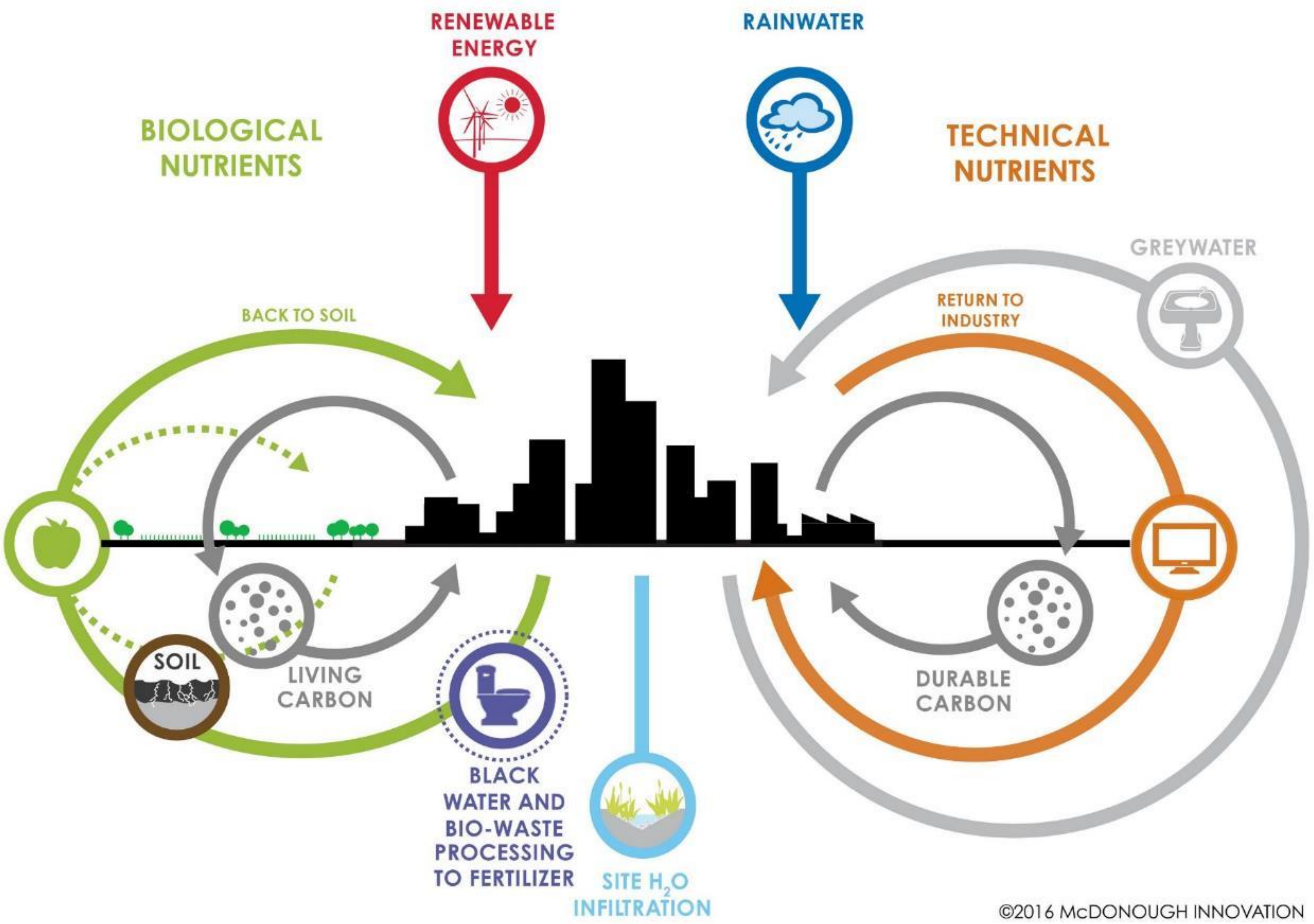
Carbon World: The Good

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



18 % carbon

Energy



- Climate change is a design failure
- CO_2 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 (BAD)** - ended up somewhere **unwanted** and can be **toxic as emissions** (e.g. atmosphere)

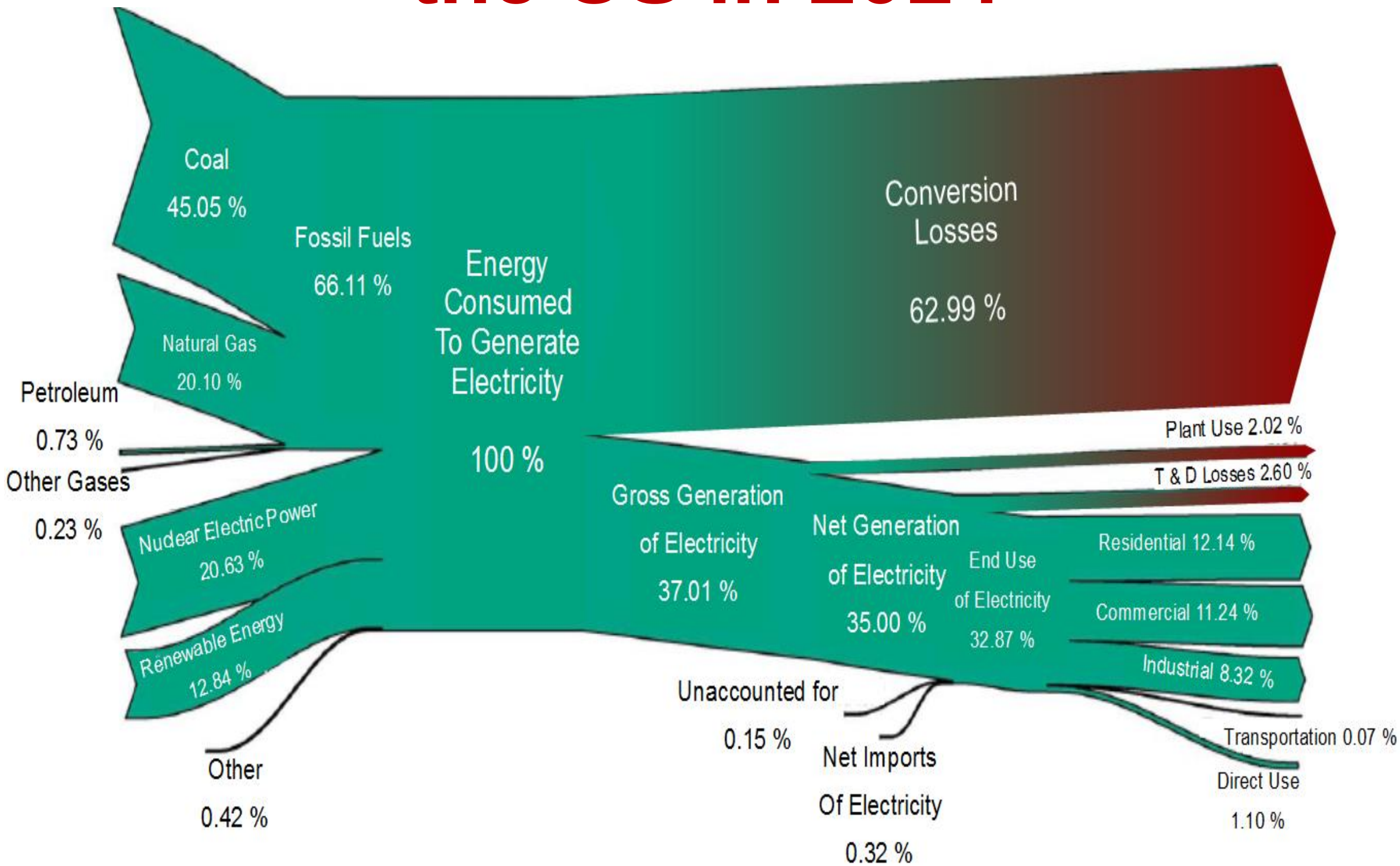
- Durable Carbon -**Locked** in stable solids that are **used and reused** (e.g. soil)

- 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> accessed 28/10/2017

Circular Economy in Energy

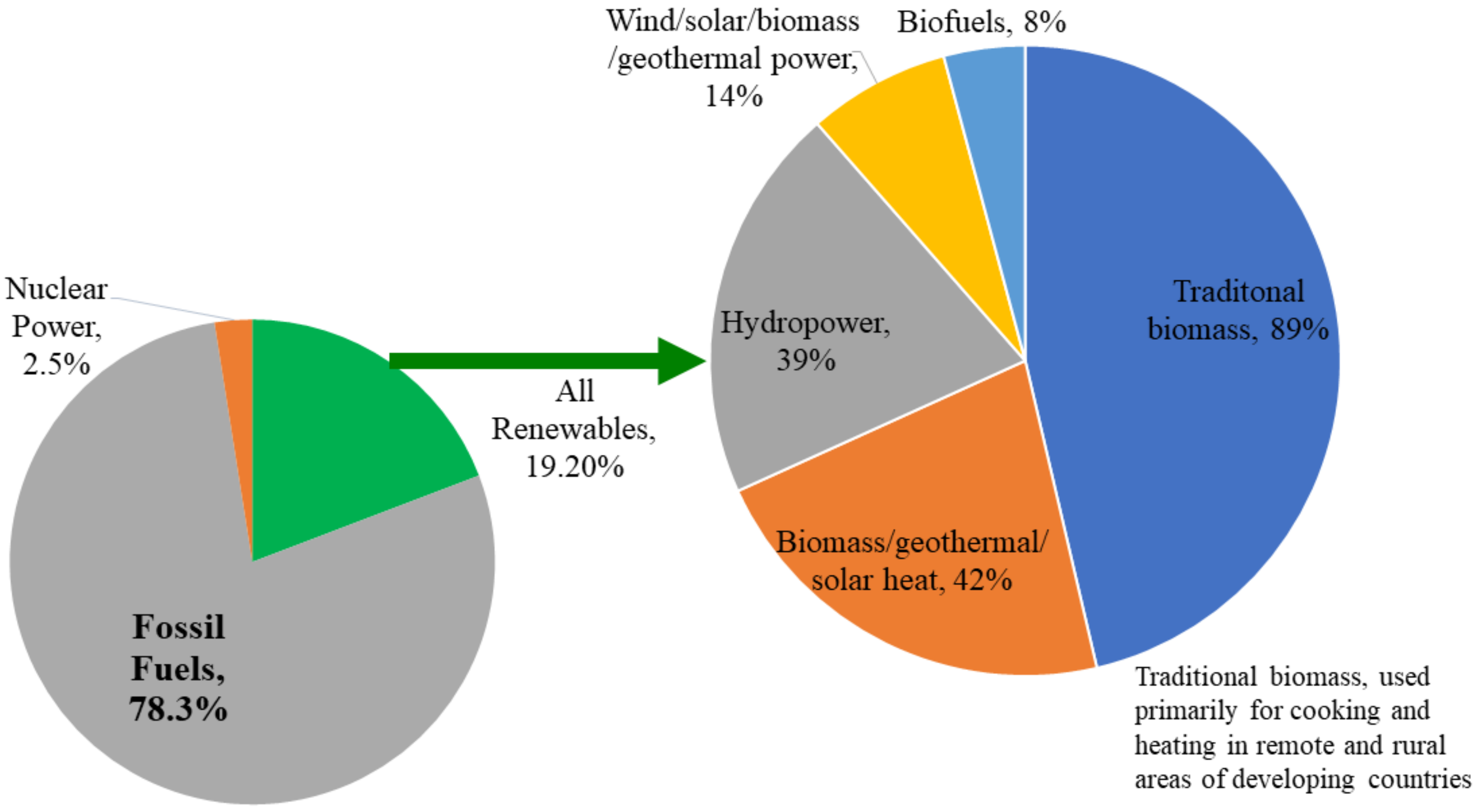
A Sankey Diagram for the Electricity Generation and Use in the US in 2014



EIA, International Energy Outlook, 2013,
<www.eia.gov/pressroom/ presentations/sieminski_07252013.pdf>, accessed 25.09.2015

Source of picture <newsletter.spectator.co.uk/q/122MWckxFYqrhfpswu45/wv>
accessed 14 April 2017

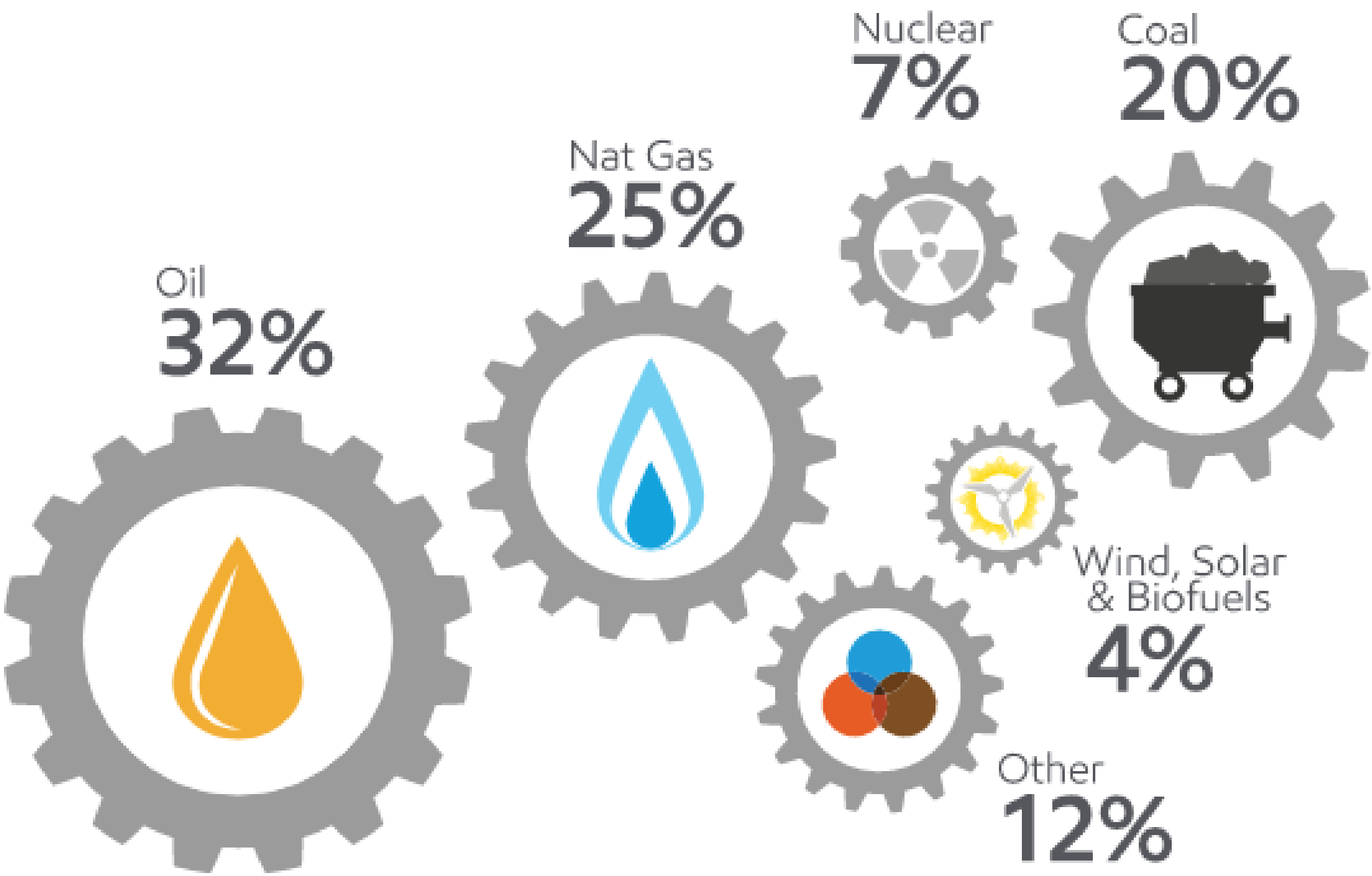
Renewable Energy Share of Global Final Energy Consumption in 2014



Lee, C. T., Lim, J. S., Van Fan, Y., Liu, X., Fujiwara, T., Klemeš, J. J. (2017). Enabling low-carbon emissions for sustainable development in Asia and beyond.

Projected Energy Mix

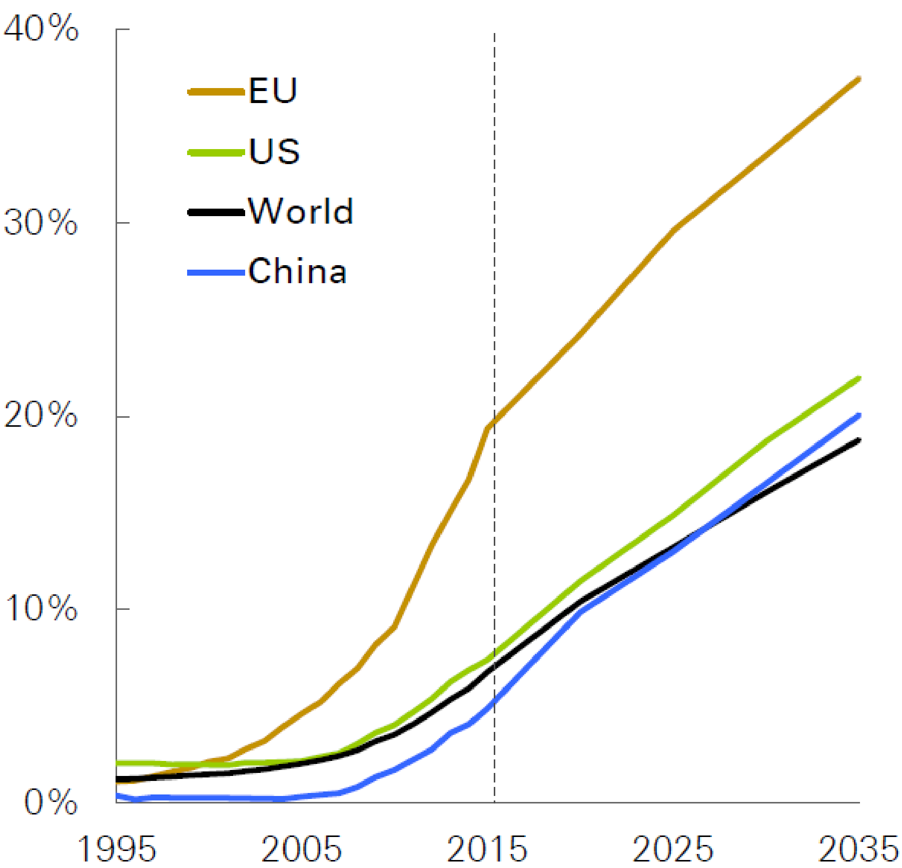
In 2040, the projected energy mix will be:



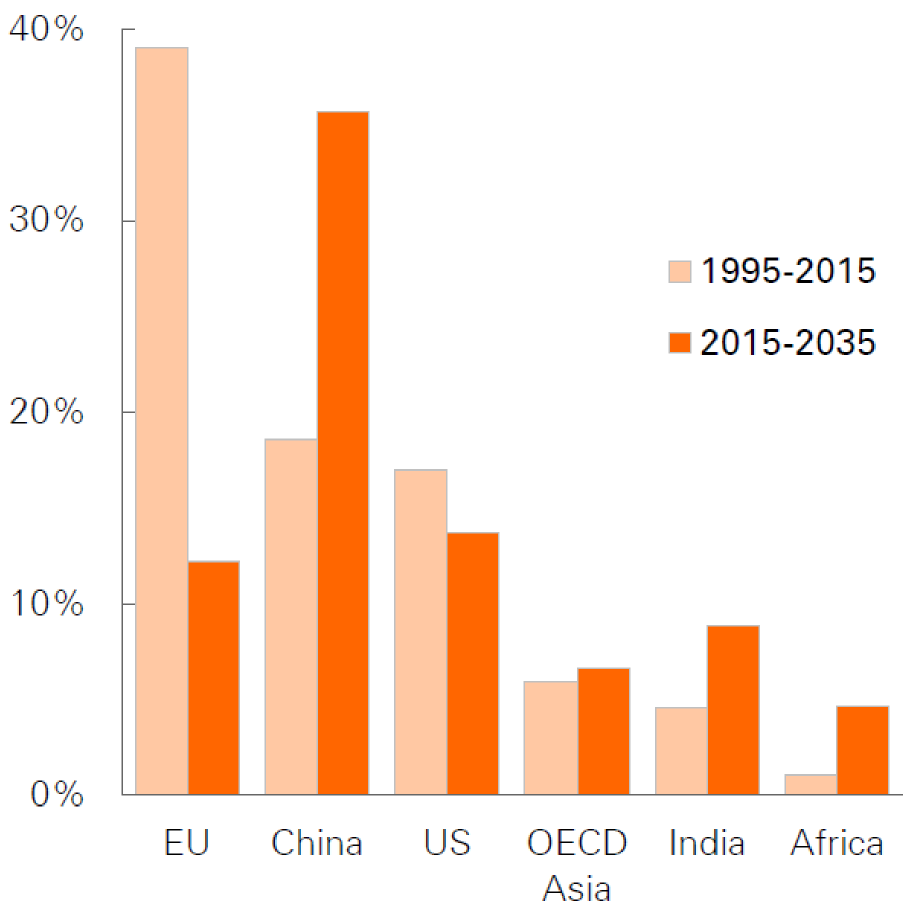
ExxonMobil <corporate.exxonmobil.com/en/energy/energy-outlook/highlights/> accessed 26 July 2017

Renewable Share

Renewables share of power generation



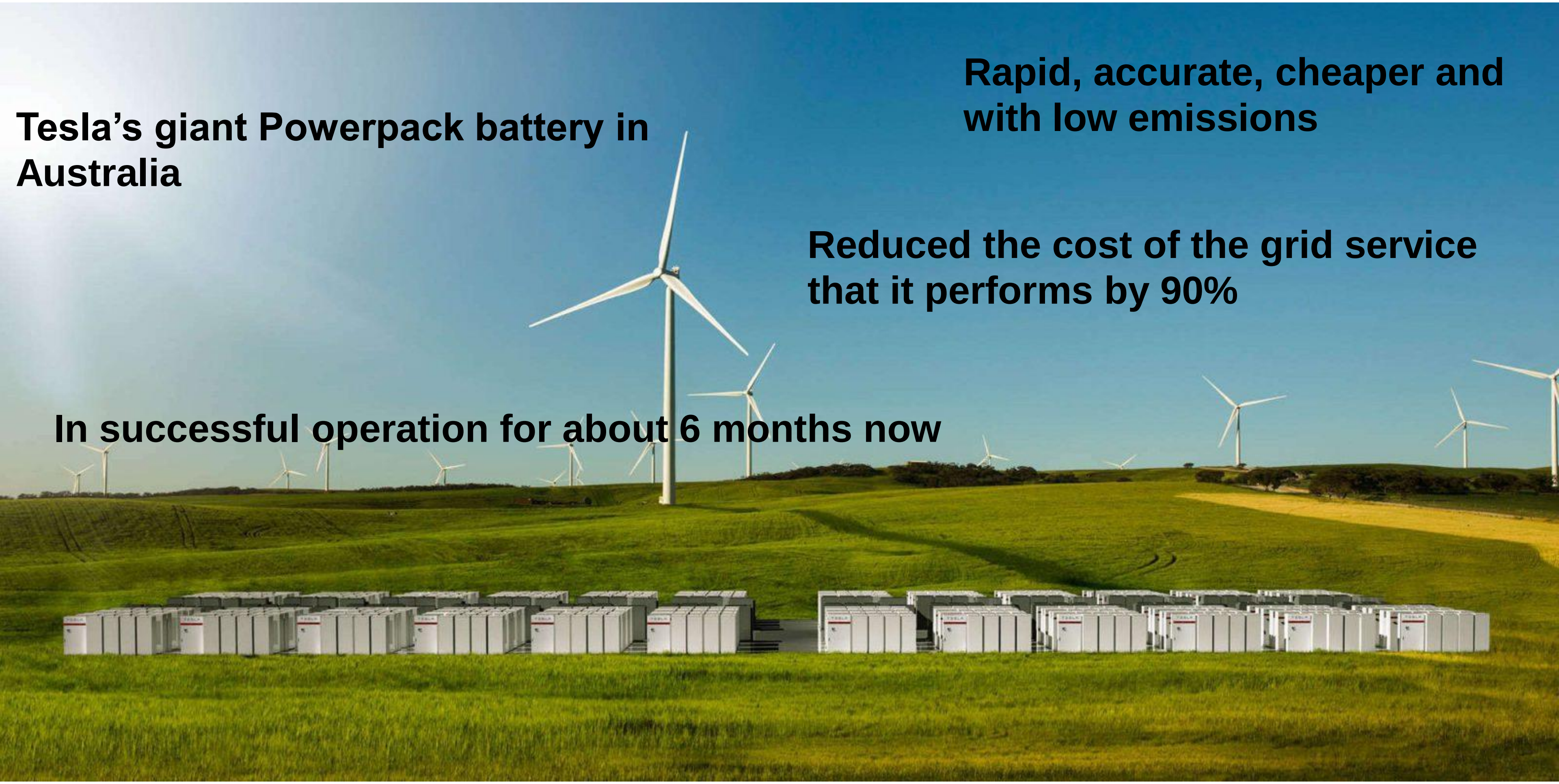
Shares of renewable power growth



British Petroleum (2017). BP Energy outlook 2017 edition. <www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2017/bp-energy-outlook-2017.pdf> accessed 26 July 2017

Energy Storage

- **100 MWh** lithium ion battery
- Stores considerable amounts of energy from renewable sources and funnels it out to the grid when usage is high



<electrek.co/2018/05/11/tesla-giant-battery-australia-reduced-grid-service-cost/> accessed 19 May 2018.

Effect of Energy Saving Measures

Study: Multifamily residential buildings in Slovakia

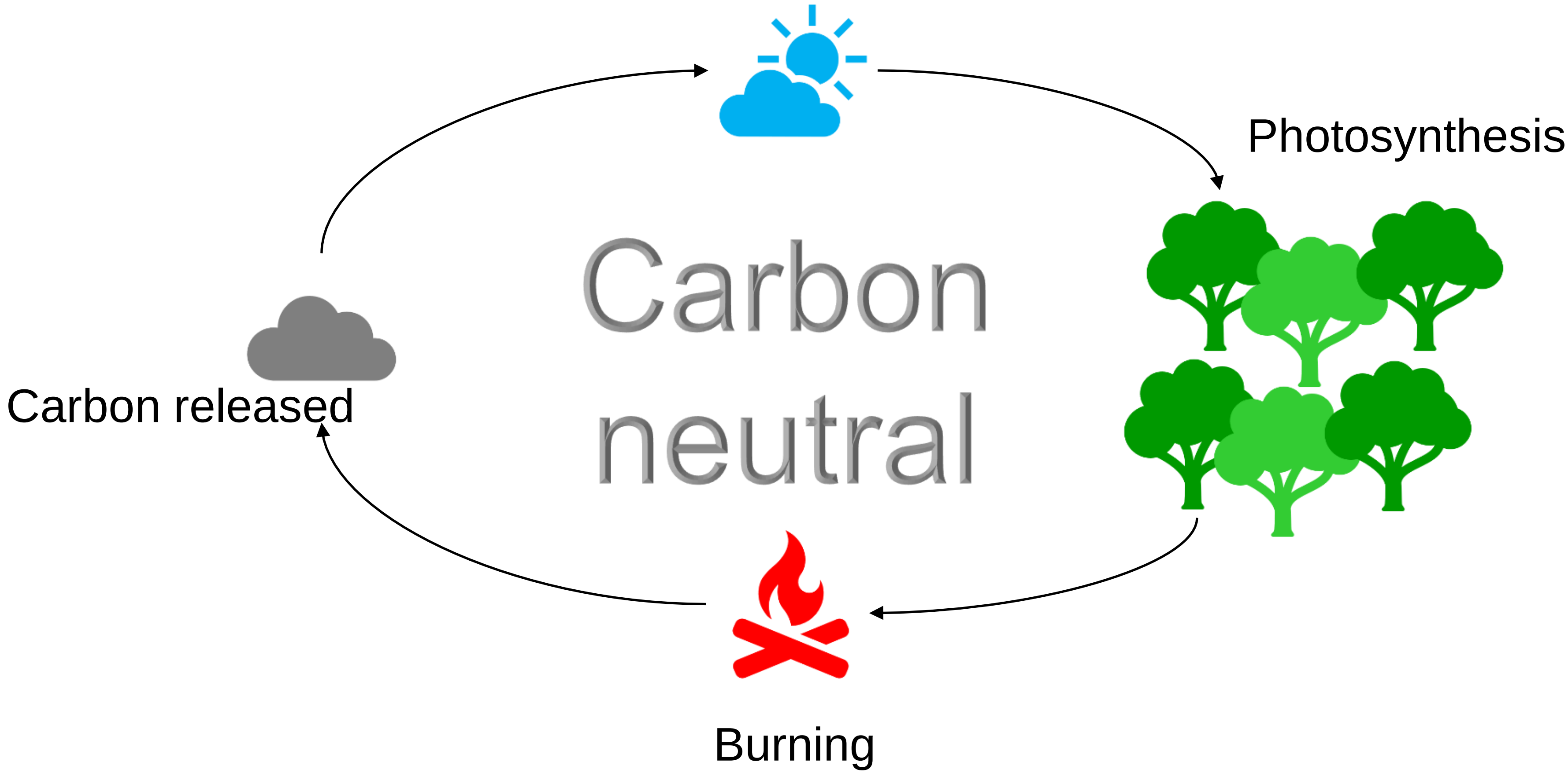
- Impact of energy renovation: CO_2 concentration higher, air exchange rates is lower, formaldehyde concentration increased.
- Energy saving measures can lead to insufficient ventilation rates
- Energy retrofitting efforts should be complemented with improved ventilation to avoid adverse effect on indoor air quality

Földváry, V., Bekö, G., Langer, S., Arrhenius, K., Petráš, D. (2017). Effect of energy renovation on indoor air quality in multifamily residential buildings in Slovakia. Building and Environment, 122, 363-372.

Biomass Energy

Why it is consider as Renewable Energy?

Ideally sustainable



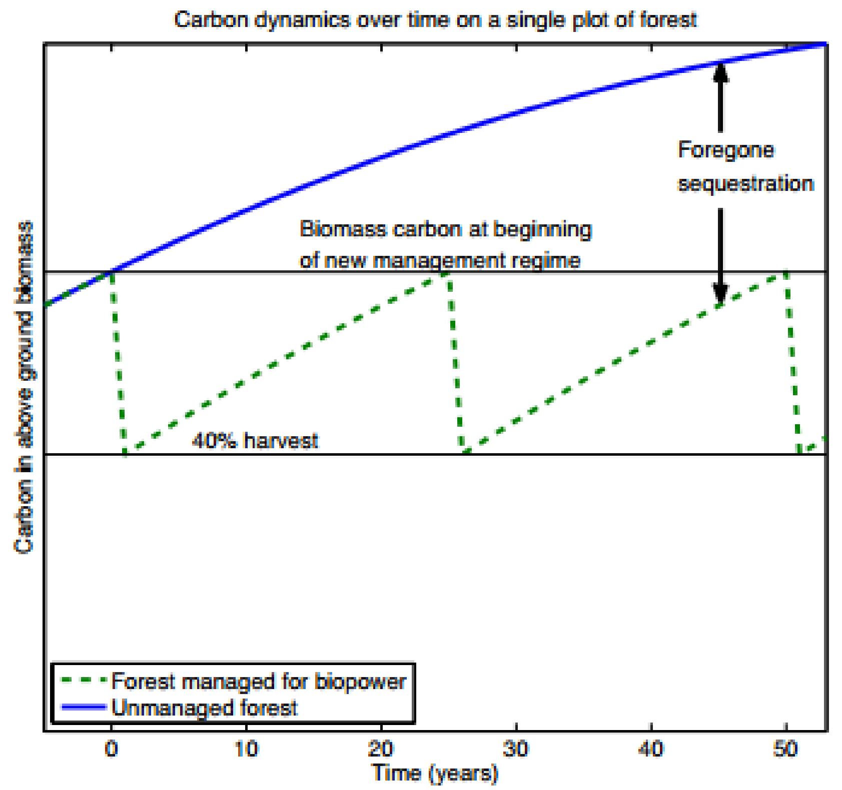
- Plant at least as many trees as you burn (a seedling/50 y tree)
- Biomass waste but not uncontrolled logging

What goes wrong?

Inappropriate Practice

- **Whole trees** from forest instead of wood scrap/ residue (waste)
- **Shipping** of wood pellets/ transporting

Figure 1: Aboveground carbon dynamics on unmanaged acre vs. acre managed for biopower[3]



<www.nrdc.org/sites/default/files/forests-not-fuel.pdf>

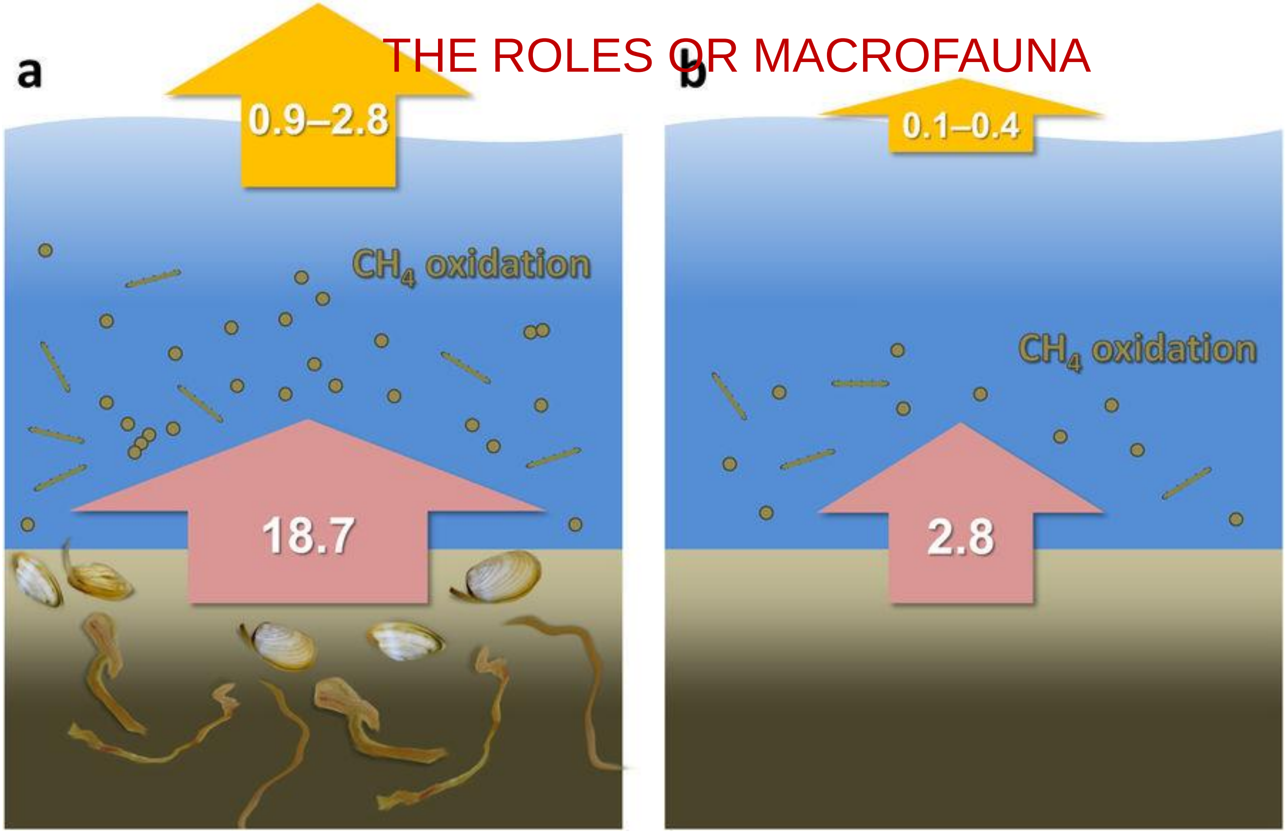
What goes wrong?

Inappropriate Assessment

- Take **several decades to fully compensate for the CO_2 emitted** during plant operation (for a tree to grow)
- Low efficiency (trees contain water, which means less potential energy per unit of C emissions in biomass energy than in fossil fuels)
- Emission: Release **more NOx, VOC, PM and CO** than a modern coal/**gas fired plant**.
- Degrades the C emissions sinks
- Biodiversity issues

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

Bonaglia, S., Brüchert, V., Callac, N., Vicenzi, A., Fru, E. C., Nascimento, F. J. (2017). Methane fluxes from coastal sediments are enhanced by macrofauna. *Scientific Reports*, *7*(1), 13145.

Methane Fluxes from Coastal Sediments

- Eutrophication a principal driver for the enhanced GHG flux from aquatic environments.
- Shallow aquatic systems contribute ~10% of global N_2O emissions.
- 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 due to methane produced in sediments of aquatic ecosystems.
- The role of coastal benthic macrofauna in mediating gas release is still debated as the mechanisms regulating production and transport of gases are largely unknown.
- Bivalves isolated from coastal sediments were shown to be strong emitters of N_2O.

Bonaglia, S., Brüchert, V., Callac, N., Vicenzi, A., Fru, E. C., Nascimento, F. J. (2017). Methane fluxes from coastal sediments are enhanced by macrofauna. *Scientific Reports*, *7*(1), 13145.

Circular Economy in Waste Treatment

Landfill

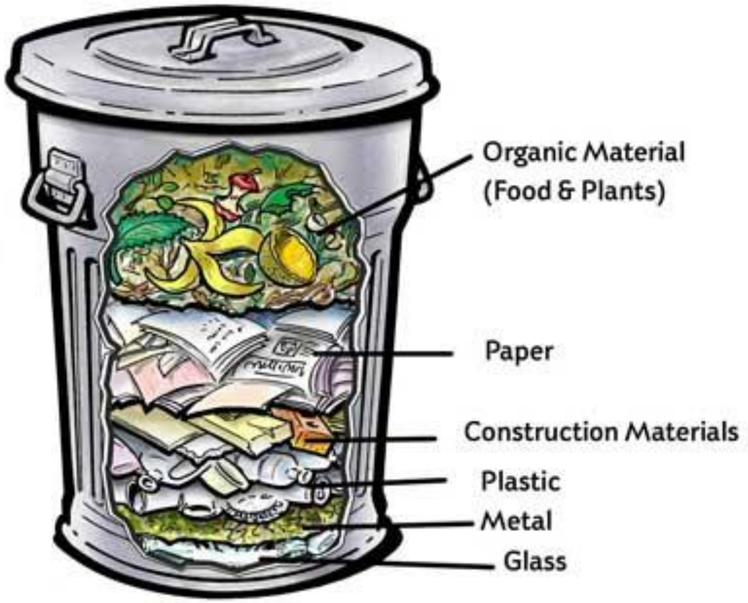
GHGs EMISSION

WATER POLLUTION

UNPLEASANT SMELL

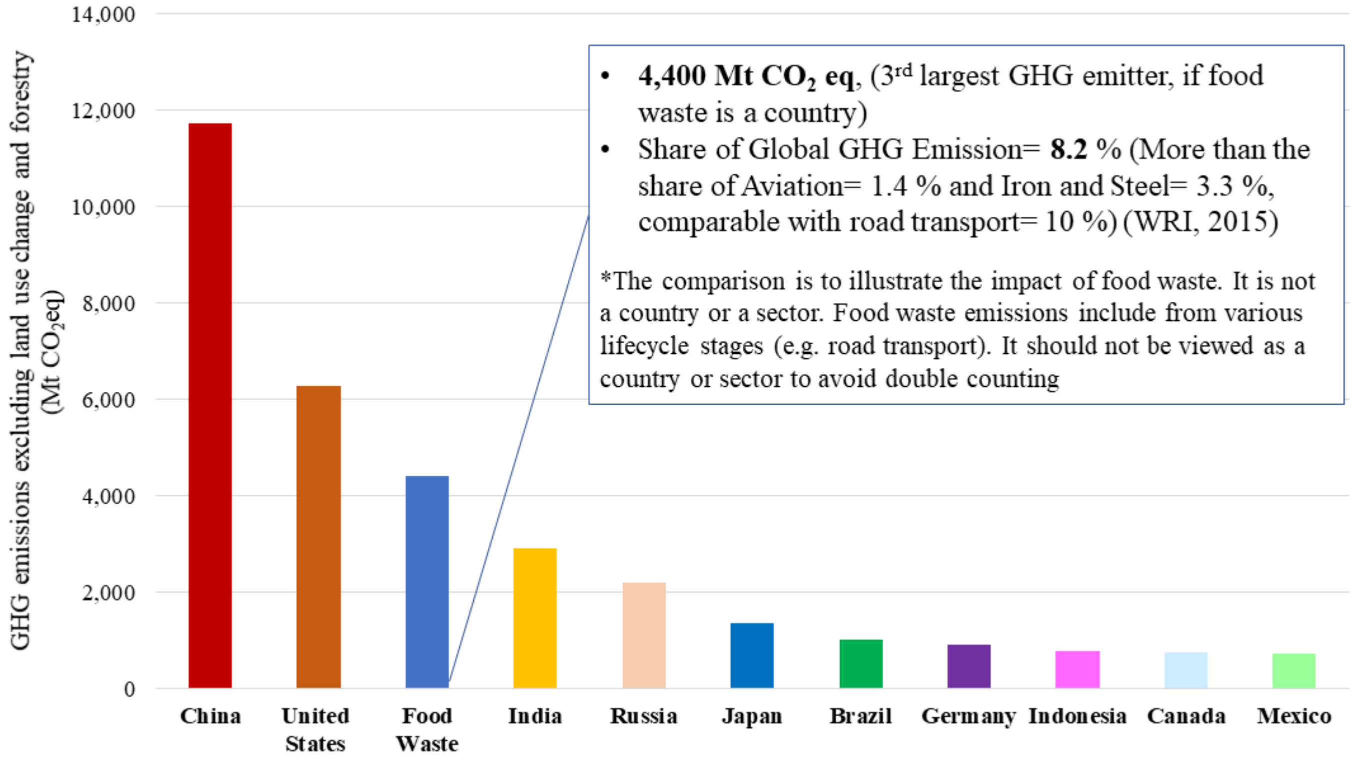
HEALTH & SAFETY ISSUES

Municipal Solid Waste



MSW

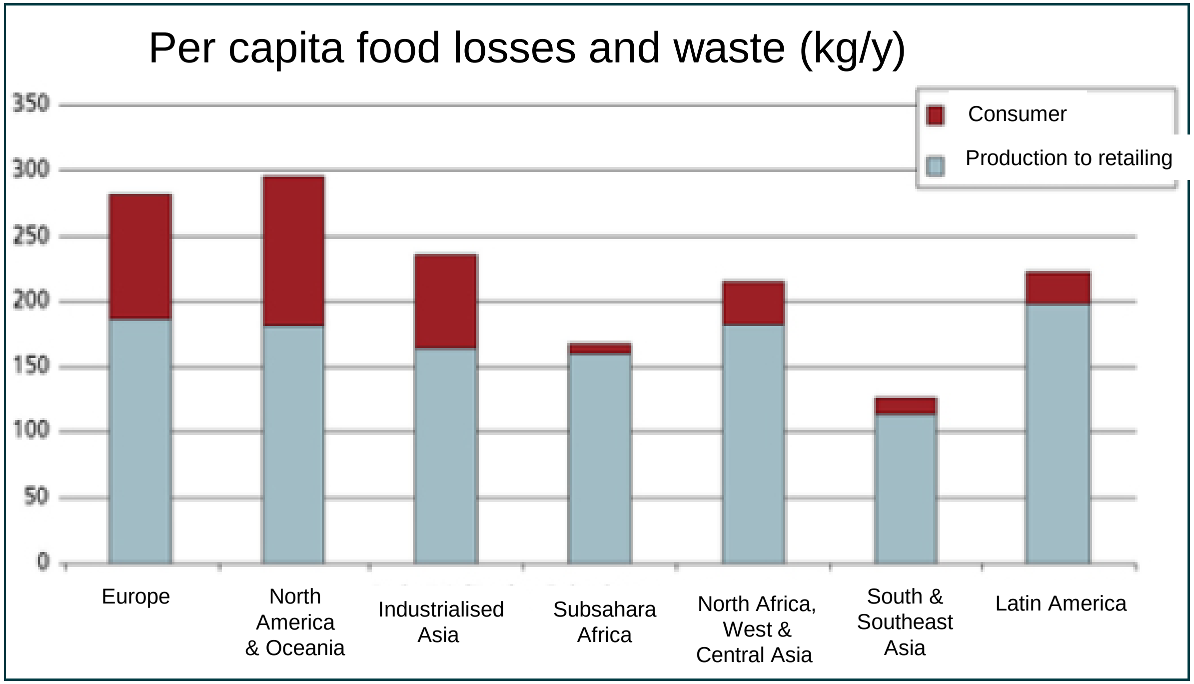
Top 10 GHG Emission Contributors and the Contribution of Food Waste



Lee, C. T., Lim, J. S., Van Fan, Y., Liu, X., Fujiwara, T., Klemeš, J. J. (2017). Enabling low-carbon emissions for sustainable development in Asia and beyond.

Food Waste

- About 1/3 of the food produced in the world for human consumption every year is wasted/lost (~1.3x 10^9 t).
- Cost: US$ 680*10^9 in industrialized countries and **US$ 310*10^9 in developing countries.**
- Fruits and vegetables, plus roots and tubers-highest wastage rates



<www.fao.org/save-food/resources/keyfindings/en/>accessed 18 May 2017

Food waste- in the year of 2020

Waste amount in EU27 (t/y)	GHG Emission (CO_2 eq/y)
126,000,000 t/y	240

European Commission (DG ENV-Directorate C), Final report- preparatory study on food waste, 10/2010; calculated based on EUROSTAT data, national sources and ETC/SCP working paper

Waste Prevention/ Reduction

Before waste production

Products and Packaging

- Design- minimise packaging, design for recycling, durable
- The materials use- recyclable/ compostable, easy to clean (e.g. food packaging)
- Process- maximise the utilisation, innovative use e.g. orange (juice, flesh, peel)

Reuse after the first cycle

- E.g. waste water, waste heat

Embedding Circular Economy Thinking in Waste Management

Regenerated and constantly flow around a "closed loop" system, rather than being used once and discard

Before waste production

1. Waste prevention/reduction

After waste production

2. Resources (waste to wealth) management

Circular Economy Strategies in Europe

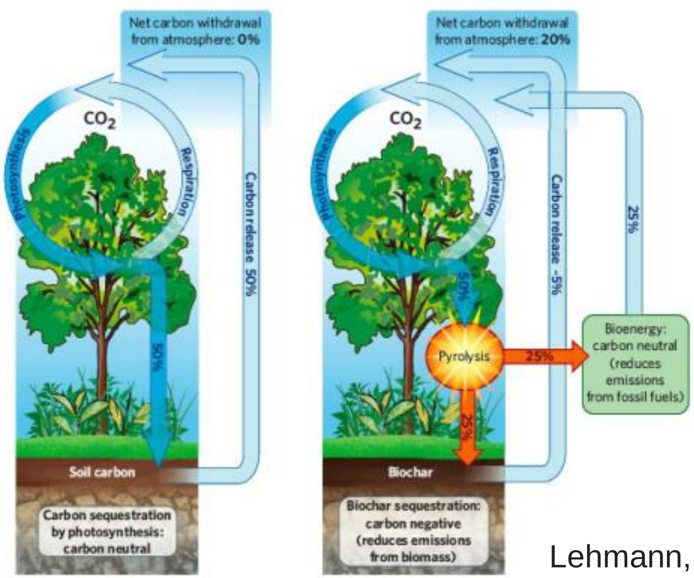
- Recycling of minimum 65 % of all MSW by 2030
- Maximum 10 % of MSW landfilling by 2030
- Promoting industrial symbiosis
- Encouraging eco-design

Tisserant, A., Pauliuk, S., Merciai, S., Schmidt, J., Fry, J., Wood, R., Tukker, A. (2017). Solid waste and the circular economy: A global analysis of waste treatment and waste footprints. Journal of Industrial Ecology, 21(3), 628-640.

Waste to Wealth

After waste production

- Reusing
- Waste separation-recycling
- Waste to energy (biogas-electricity, heat; biofuel etc)
- Waste to nutrient for soil (fertiliser, digestate, biochar etc)

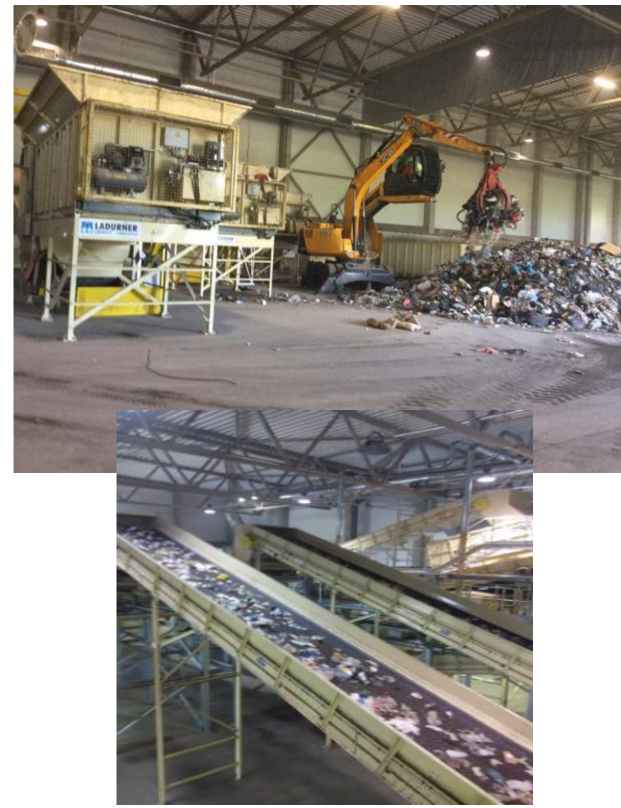


Lehmann, J. (2007). A handful of carbon. Nature, 447(7141), 143.

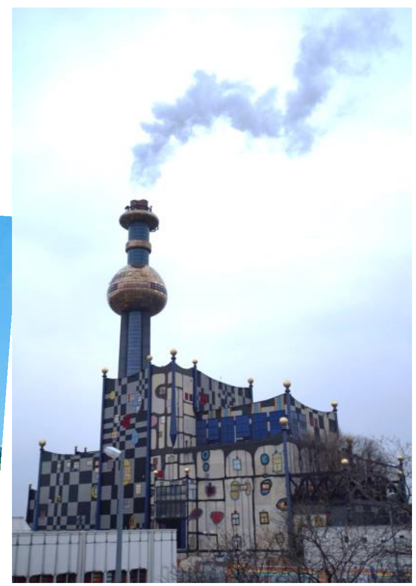
Treatment Options

- ✓Composting
- ✓Anaerobic digestion
- ✓Incineration
- ✓Sanitary landfill
- ✓Landfill
- ✓MBT[1]

MBT Plant in Vilnius, Lithuania



Incineration Plant in Vienna, Austria



Incineration Plant in Taipei, Taiwan

[1]Mechanical Biological Treatment: integration of **sorting facility** with biological treatment such as composting, anaerobic digestion and materials recovery facilities.

Composting & Anaerobic Digestion (AD)

Factor	Composting	Anaerobic Digestion
Plant capacity	Scalable	Only medium to large
Technology and process	Simple	Complex
Need of working surface	Higher	Lower
Investment cost	Lower	Higher
Output product	Solid	Liquid (semi solid)+ biogas

Compost:
Humified plant matter, organic matter, plant nutrients and microbes

Digestate:
Less stable carbon, more readily available nutrient

Compost-Limitation

- Does not degrade inorganic it only reduces their availability for plant uptake
- Itself may release some metallic contaminants
- ❖ Accumulation of hazardous substances in soil and plants
- ❖ Biomagnifications though the food chain: human health and environment concerns.
- Most of the EU countries do not consider mixed waste for composting. In Denmark, only green waste is utilised.
- Compost goes though MBT is not allowed for agricultural purpose

Heavy Metal Reduction Techniques

- **Implementation of at source waste segregation**
- **Selection of feedstock** (input materials)
- Addition of chemicals (natural zeolite, red mud, lime, sodium sulfide, bamboo charcoal and bamboo vinegar, etc.)
- Biological agent (eg Phanerochaete chrysosporium-remove lead; earthworm)

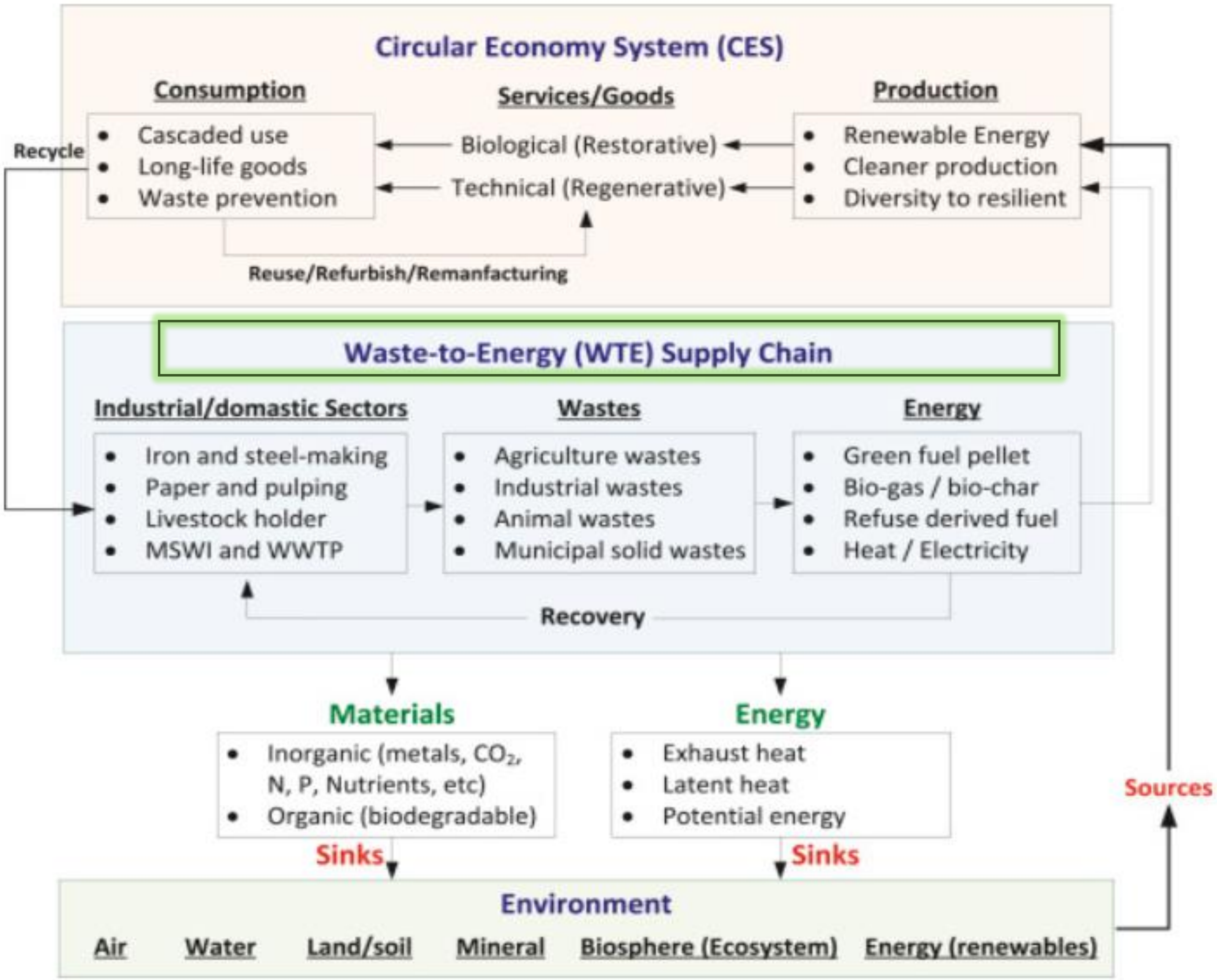
Is Current Practice Sustainable?!

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

- **Incineration:** 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 (similar issues as **BIOMASS ENERGY**)
- **Composting:** Open process (emission, leachate) without energy recovered, heavy metal issues

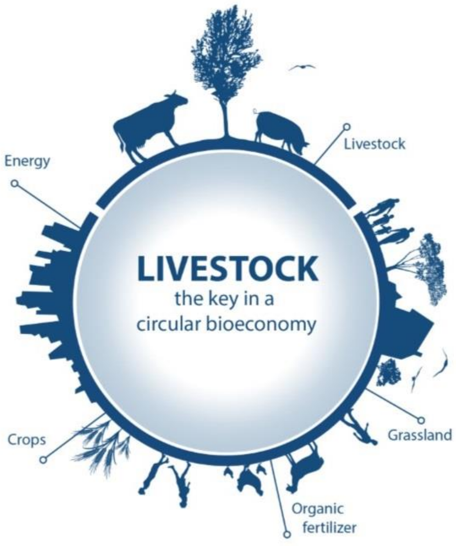
ASSESSMENT & IMPROVEMENT IS NEEDED

Relationship between Environment, WTE and Circular Economy System



Pan, S. Y., Du, M. A., Huang, I. T., Liu, I. H., Chang, E. E., Chiang, P. C. (2015). Strategies on implementation of waste-to-energy (WTE) supply chain for circular economy system: a review. Journal of Cleaner Production, *108*, 409-421.

Circular Economy in Agriculture



Animal Agriculture

Responsible for **18 %** GHGs (more than combined exhaust from all transportation)

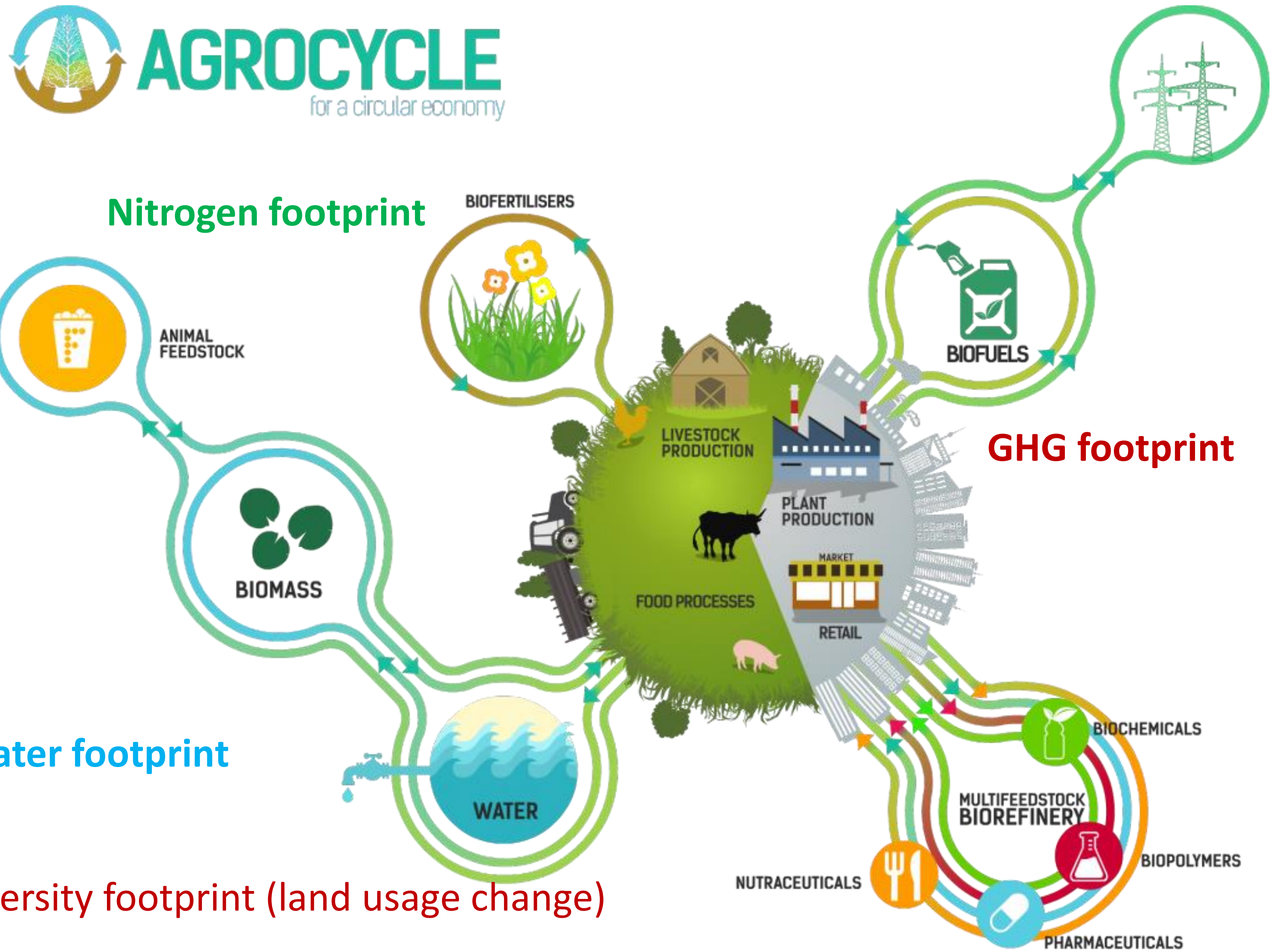
Livestock is responsible for **65 %** of all human-related emissions of N_2O

Emissions for agriculture projected to increase **80 %** by 2050.

Livestock and their by products account for at least **32,000 Mt** of CO_2eq/y

- Food and Agriculture Organization of the United Nations, 2006. Livestock's Long Shadow: environmental issues and options. Rome, Italy
- Hyner, C. A Leading Cause of Everything: One Industry That Is Destroying Our Planet and Our Ability to Thrive on It. Georgetown Environmental Law Review. 23 October 2015..
- U.S. Energy Information Administration. Emissions of Greenhouse Gases in the United States. 31 March 2011
- Tilman D., Clark M., "Global diets link environmental sustainability and human health". Nature. Vol. 515. 27 November 2014

Example: Agri-food Sector



Nitrogen footprint

GHG footprint

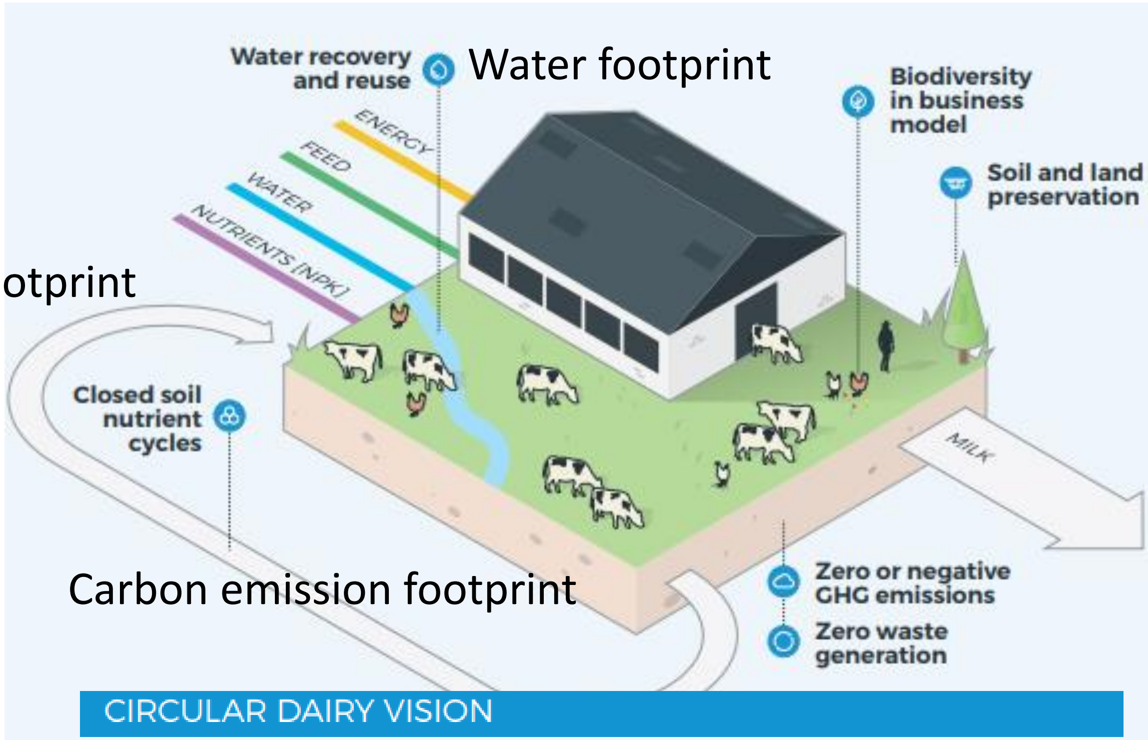
Water footprint

Biodiversity footprint (land usage change)

<www.agrocycle.eu/> accessed 20/3/2018

Example: Dairy Sector

Nitrogen footprint



CIRCULAR DAIRY VISION

- **Zero or negative GHG emissions** Net greenhouse gas emissions, including carbon sequestration, across a full dairy value chain are zero, or even negative.
- **Closed soil nutrient cycles** Nutrients extracted from the soil are returned to the same soils, without leakage to the environment, and nutrient levels are carefully optimised to reduce the use of artificial fertilisers.
- **Zero waste generation** There is no waste from dairy operations and all waste streams are treated and reused or recycled to maximise value recovery.
- **Water recovery and reuse** Dairy cows do not prohibit renewable freshwater availability for human food production.
- **Soil and land preservation** Dairy farming does not constrain available arable land for human food production, does not drive land use change and deforestation and has positive impact on the resilience of agriculture landscapes.
- **Biodiversity in business model** Soil, landscape and natural biodiversity are prioritised and incorporated in the farm's business model.

<www.circle-economy.com/wp-content/uploads/2016/10/the-circular-dairy-economy.pdf> accessed 20/3/2018

Circular Economy in Transportation

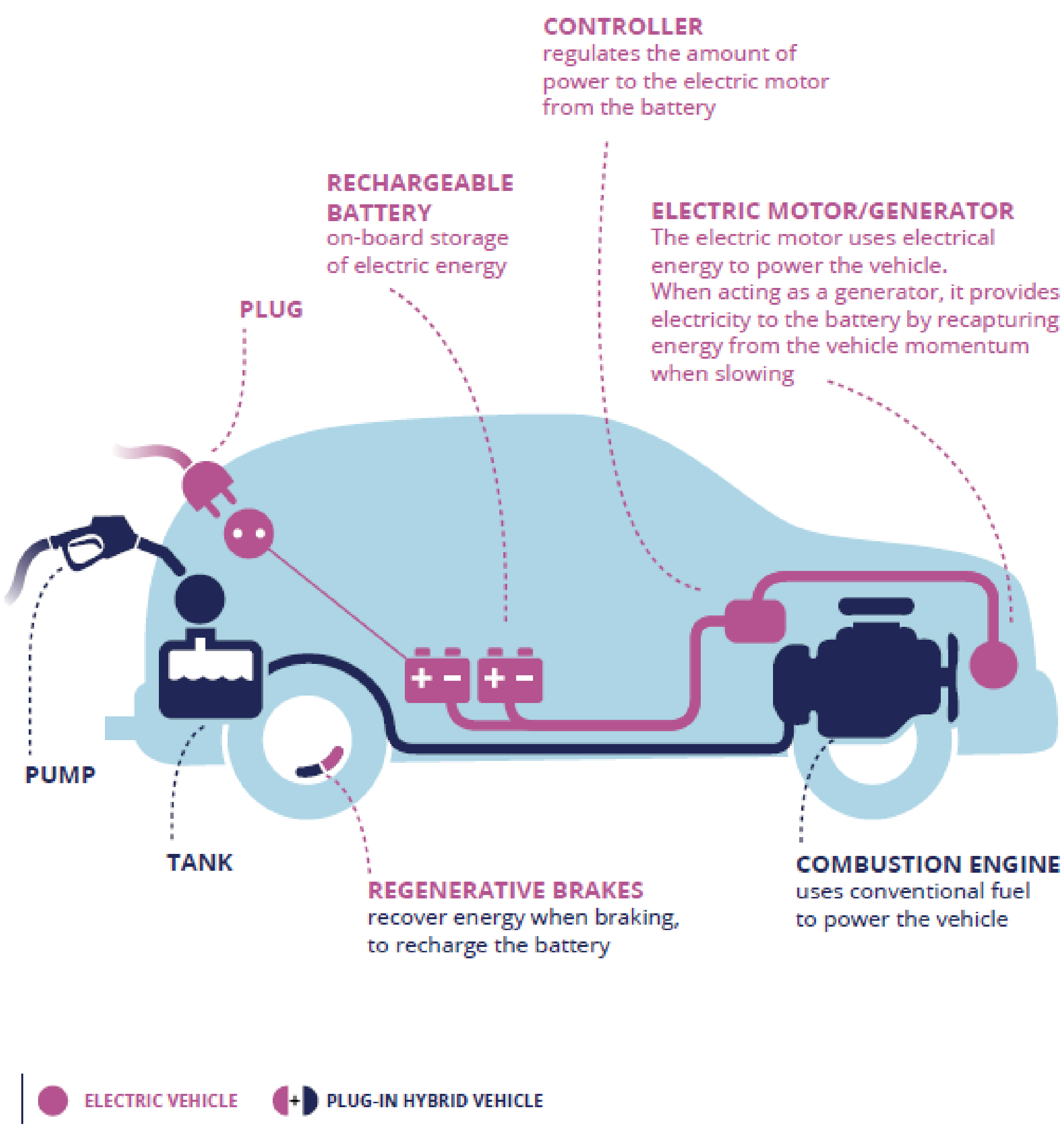
Circular economy in transport: electric cars, recuperation/recharging energy

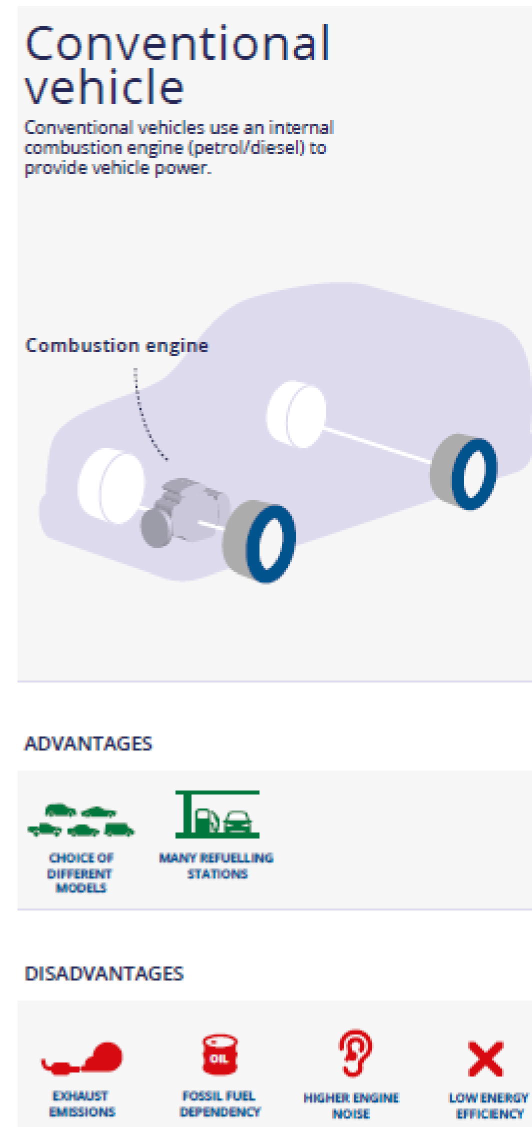
Vehicle Technologies

Vehicle	Initial cost (kUSD)	Power plant to wheel efficiency	Commercial availability	Main challenges
Electric	20	High (>50%)	Now	Chemical sustainability, battery cost, reprocessing
Hybrid electric	23	Moderate (≤50%)	Now	Chemical sustainability, battery cost, reprocessing
Hydrogen internal combustion engine	18 + H_2 Storage	**Low (<25%)**	In 2–3 y ??	Lack of infrastructure
Fuel-Cell	**40**	**Low (<25%)**	In 2–3 y ??	Lack of infrastructure, high cost
Biofuels	17.1	**Low (<25%)**	Now	**CO_2 fixation**, **NOx,** responsible farming

Calvillo, C. F., Sánchez-Miralles, A., Villar, J. (2016). Energy management and planning in smart cities. Renewable and Sustainable Energy Reviews, 55, 273-287.

The Main Part of E-car





EEA, 2016. Electric vehicles in Europe. EEA report, Luxemburg, Publication Office of the European Union.

Charging Time to Provide 100 km of Driving

POWER, CURRENT, MODE	TIME	LOCATION
120 kW DC (mode 4)	10 MINUTES	Motorway service area or dedicated charging stations in urban areas (future standard)
50 kW DC (mode 4)	20→30 MINUTES	Motorway service area or dedicated charging stations in urban areas (current standard)
22 kW AC, three-phase (mode 3)	1→2 HOURS	Most public charging poles
10 kW AC, three-phase (mode 3)	2→3 HOURS	Household, workplace wall box
10 kW AC, three-phase (mode 3)	2→3 HOURS	Household, workplace wall box
7.4 kW AC, single-phase (mode 1 or mode 2)	3→4 HOURS	Public charging poles
3.3 kW AC, single-phase (mode 1 or mode 2)	6→8 HOURS	Household, workplace wall box

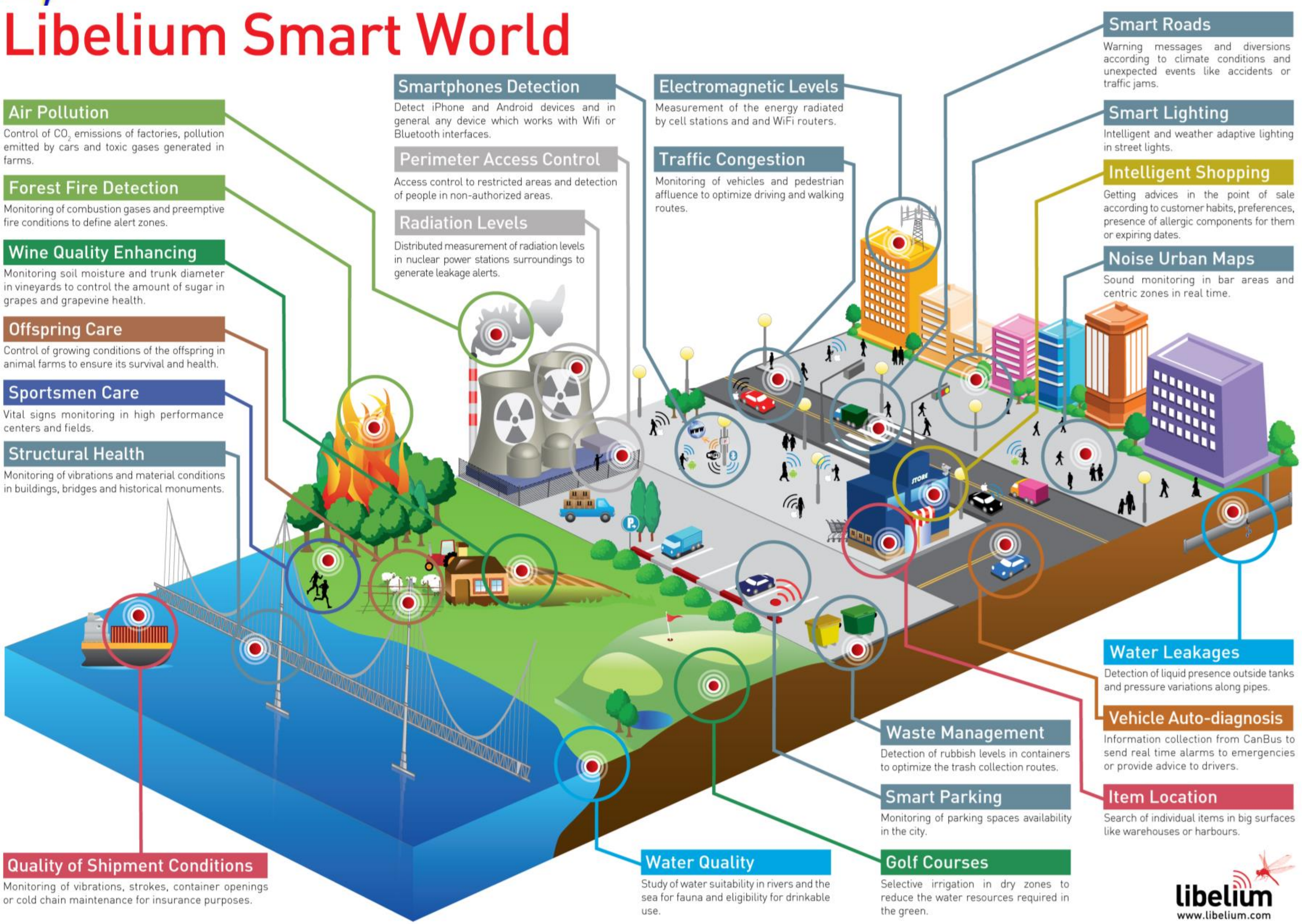
Source: E-Mobility NSR, 2013.

EEA, 2016. Electric vehicles in Europe. EEA report, Luxemburg, Publication Office of the European Union.

Smart Cities in CE

- The smart city concept goes beyond the use of ICT for better resource use and less emissions.
- It means smarter urban transport networks, upgraded water supply and waste disposal facilities, and more efficient ways to light and heat buildings.
- Encompasses a more interactive and responsive city administration, safer public spaces and meeting the needs of an ageing population.

<ec.europa.eu/digital-single-market/en/smart-cities>



<www.libelium.com/libelium-smart-world-infographic-smart-cities-internet-of-things/> accessed 2 May 2017

Cyber & IT for healthy living in smart cities – Climate Monitoring

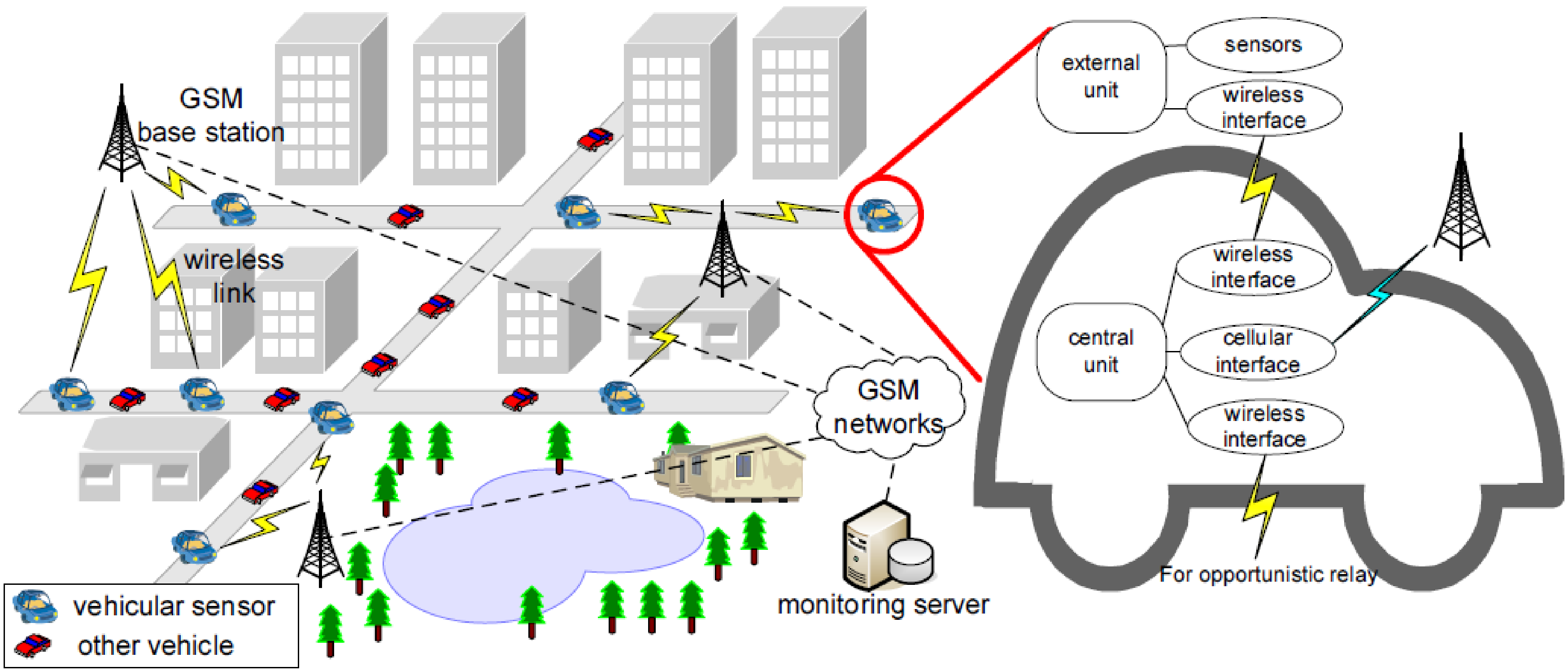


Fig. 1: The proposed VSN architecture for micro-climate monitoring.

VSN= Vehicular wireless sensor network

Hu, S. C., Wang, Y. C., Huang, C. Y., Tseng, Y. C. (2009). A vehicular wireless sensor network for CO_2 monitoring. In Sensors, 2009 IEEE (1498-1501). IEEE.

Specifics of the Description of the Spread of Pollutants

Brno

- **Current field**

- Heavily influenced by the terrain and vegetation coverage of the neighbourhood

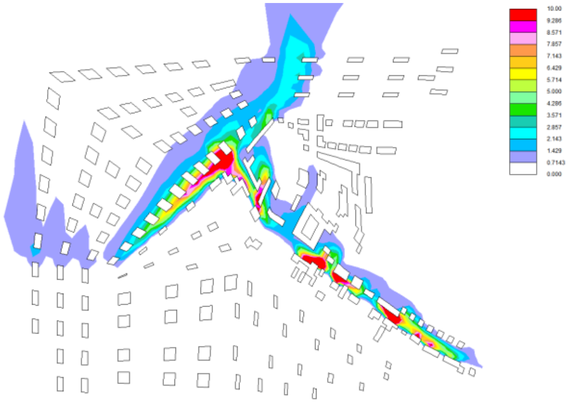
- Large differences in local speeds in the area

- **Sources of pollution**

- A limited number of significant line sources

- Great importance of background resources

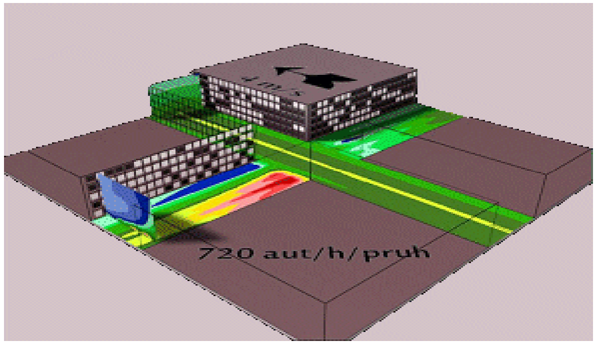
- Significant local sources from small furnaces

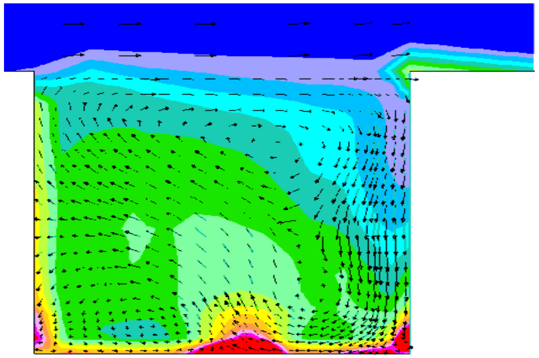


Need for a detailed solution

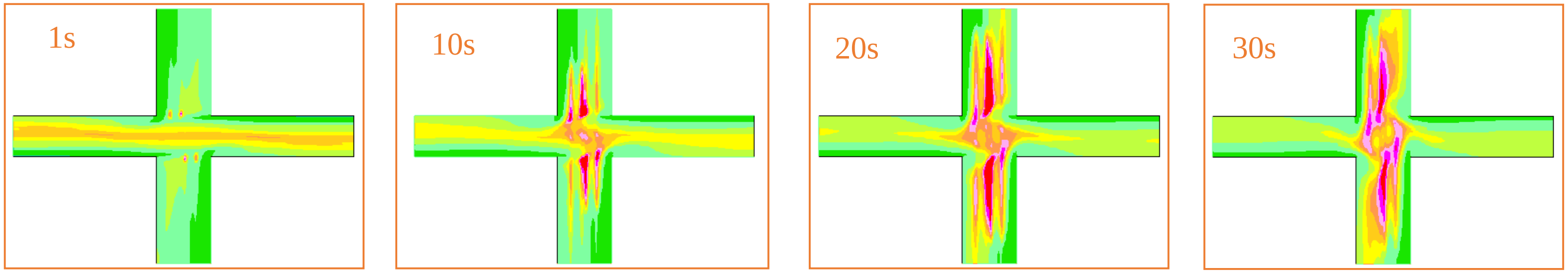
Pospíšil J, Huzlík J, Ličbinský R, Chaloupeck P.Spread of pollutants from line sources in small settlements. Center for Transport Research, Brno University of Technology, 10.11.2014

Appropriate / Inappropriate CFD Applications





Dynamics of contamination at junction space



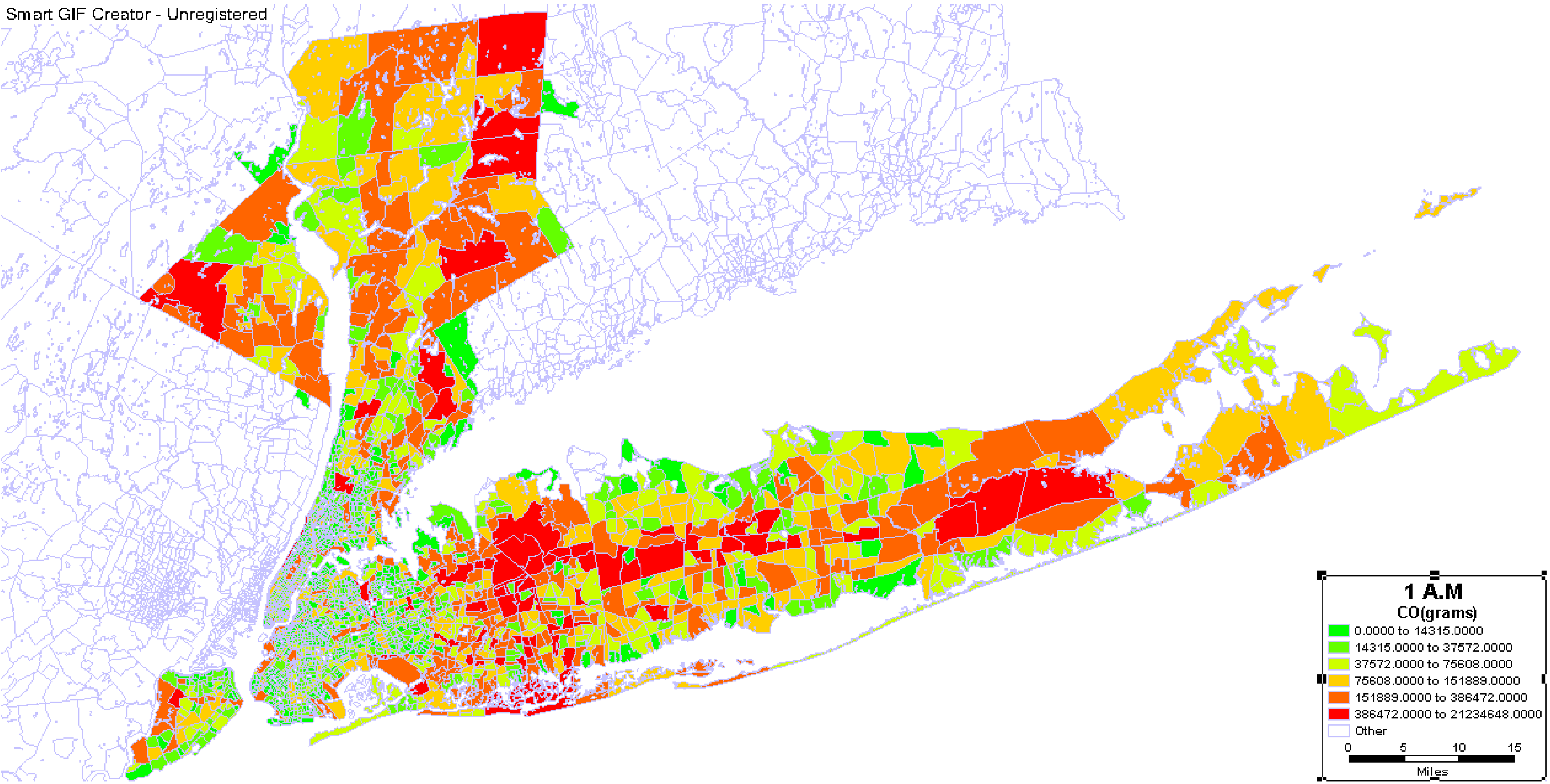
Jiří Pospíšil, Jiří Huzlík, Roman Ličbinský, Pavel Chaloupecký. Spread of pollutants from line sources in small settlements. Center for Transport Research, Brno University of Technology. 10.11.2014

Other Publication Sources

Pospisil, J., Jícha, M. (2008). Behavior of particulate matter produced by cars in a regional model of urban canopy layer. Transactions on Transport Sciences, 1(4), 157-164.

Pospisil, J., Jicha, M. (2010). Particulate matter dispersion modelling along urban traffic paths. International Journal of Environment and Pollution, 40(1-3), 26-35.

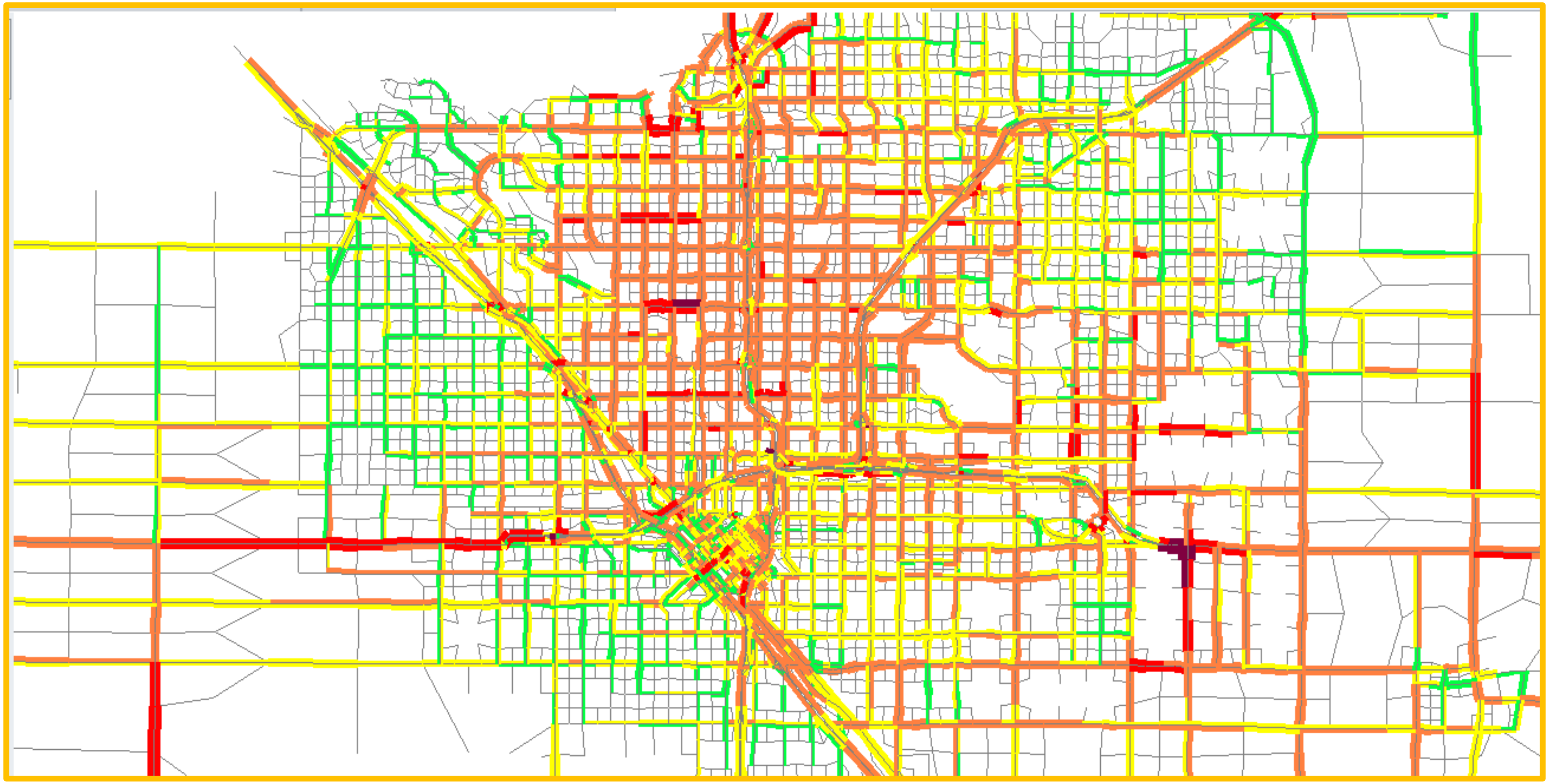
Transportation Emission Modelling in NYC



H. Oliver Gao (2017), Cornell University Centre for Transportation, Environment and Community Health (CU-CTECH). Cornell University.

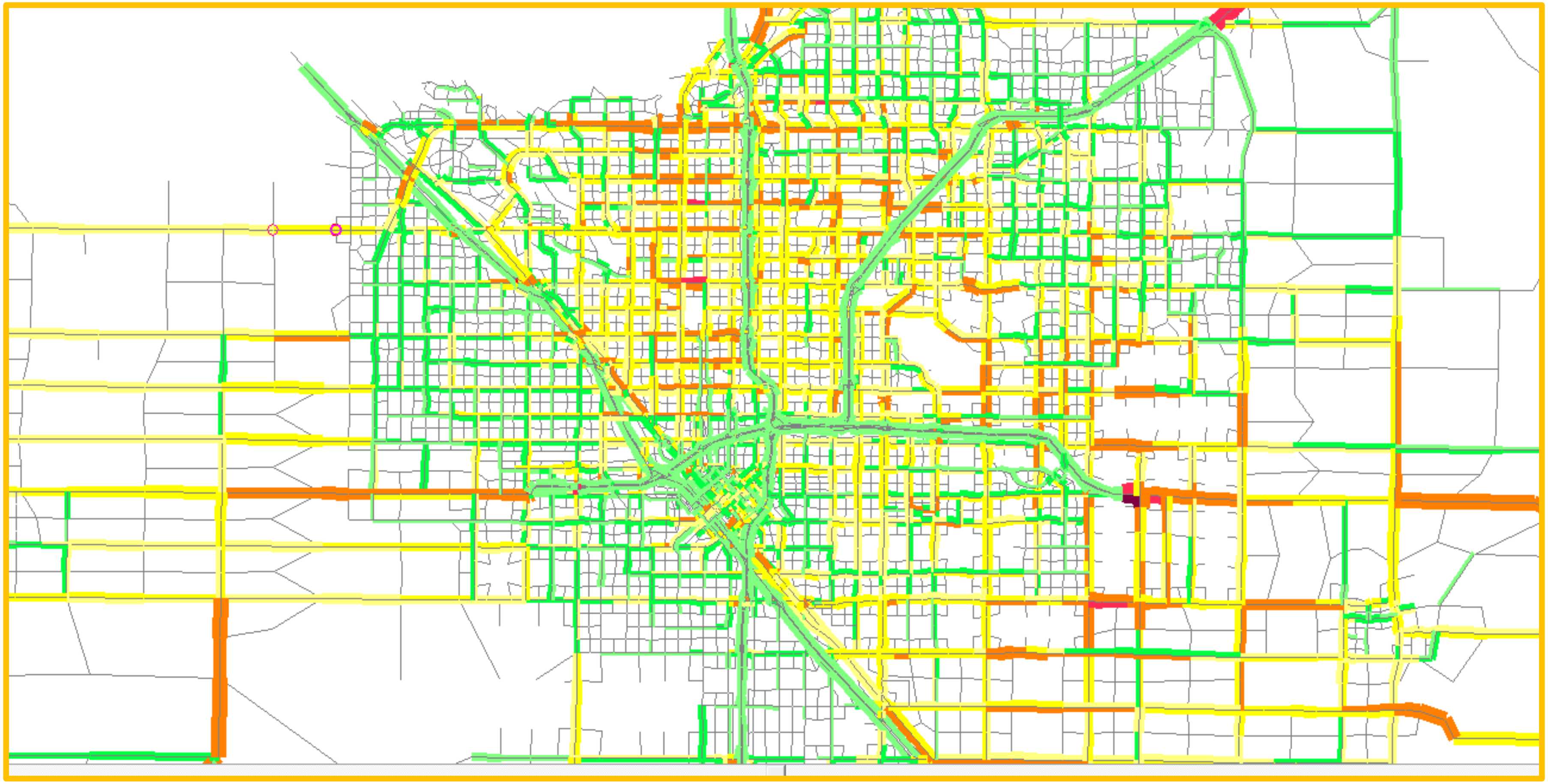
California

Traffic Behaviour Before (simulation)



Rouhani O M, Gao H. O (2014), An advanced traveler general information system for Fresno, California, Transportation Research Part A, 67, 254–267

Traffic Behaviour After (simulation)



Omid M. Rouhani, H. Oliver Gao (2014), An advanced traveler general information system for Fresno, California, Transportation Research Part A, 67, 254–267

Footprints from Shipping

Ideally

- Consuming less oil and releasing fewer pollutant for each unit of goods carried

However

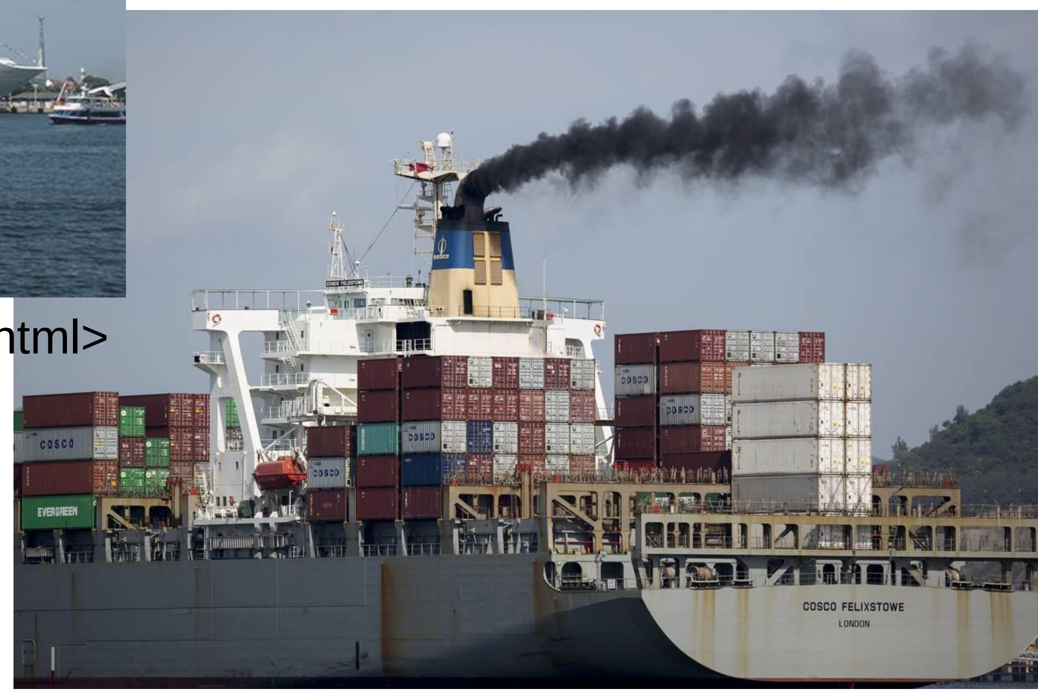
- Low grade marine fuel (3,500 times more S than road diesel). In Europe ships contributed 18% of NO_x, 18% of SO_x and 11% of $PM_{2.5}$.
- Ship scrapping - asbestos, heavy metals and oils are toxic
- Improper management (human activities)

<www.nature.com/news/pollution-three-steps-to-a-green-shipping-industry-1.19369> accessed 20.06.2017
Fan, Y.V., Perry, S., Klemeš, J.J., Lee, C.T., 2018. A review on air emissions assessment: Transportation. Journal of Cleaner Production, 194, 673-684.

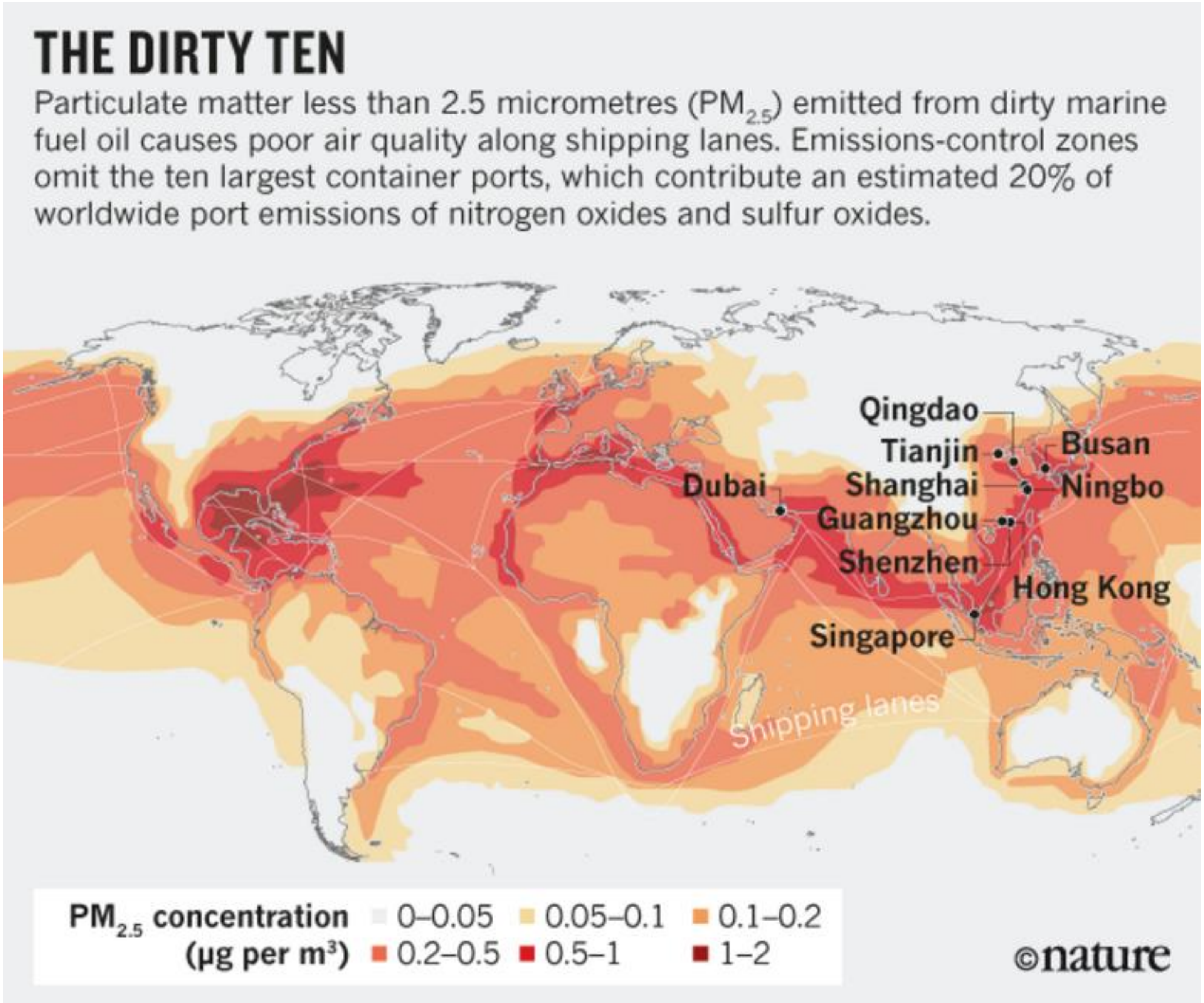
Cruising and International trade

AIR POLLUTION

<en.nabu.de/issues/traffic/cruiseships.html>



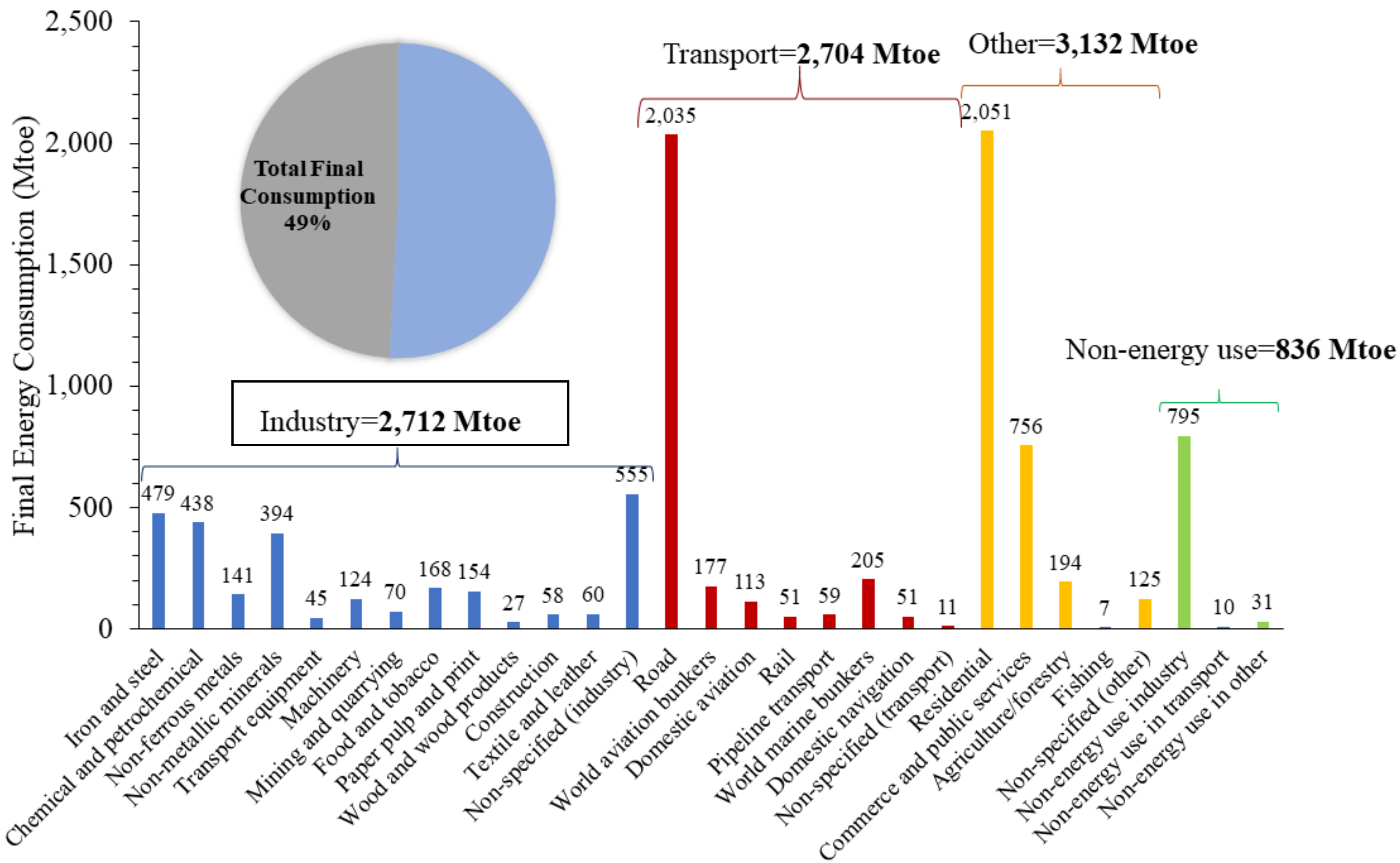
<www.wsj.com/articles/maritime-nations-near-big-cut-to-pollution-causing-sulfur-in-ships-fuel-1477058581> accessed 12 April 2017



<www.nature.com/news/pollution-three-steps-to-a-green-shipping-industry-1.19369> accessed 05.06.2017

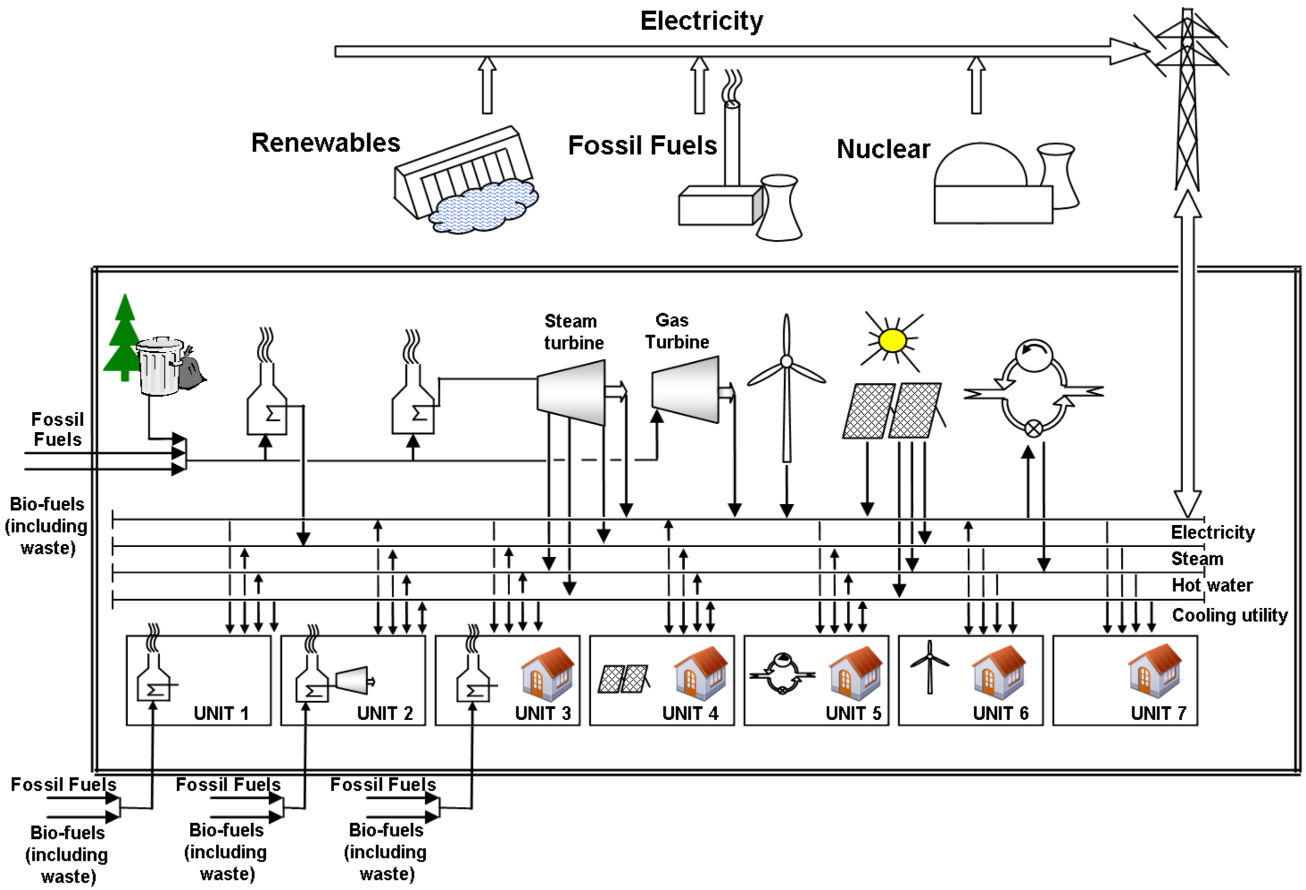
Circular Economy in Industry

Global Energy Consumption by Sector (year 2015)



Fan, Y. V, Varbanov, P. S., Klemeš, J. J., Nemet, A. (2017). Process efficiency optimisation and integration for cleaner production. Journal of Cleaner Production, 174, 177-183.

Integrating Renewable Energy Sources into Extended Total Sites



Perry, Klemeš, Bulatov, Chemical Engineering Transactions, 12, 2007, 593-598

Perry, Klemeš, Bulatov, Energy, 33, 1489-1497, 2008

Conclusion

- More **development is needed** to secure that the actual environmental impacts of circular economy work toward sustainability

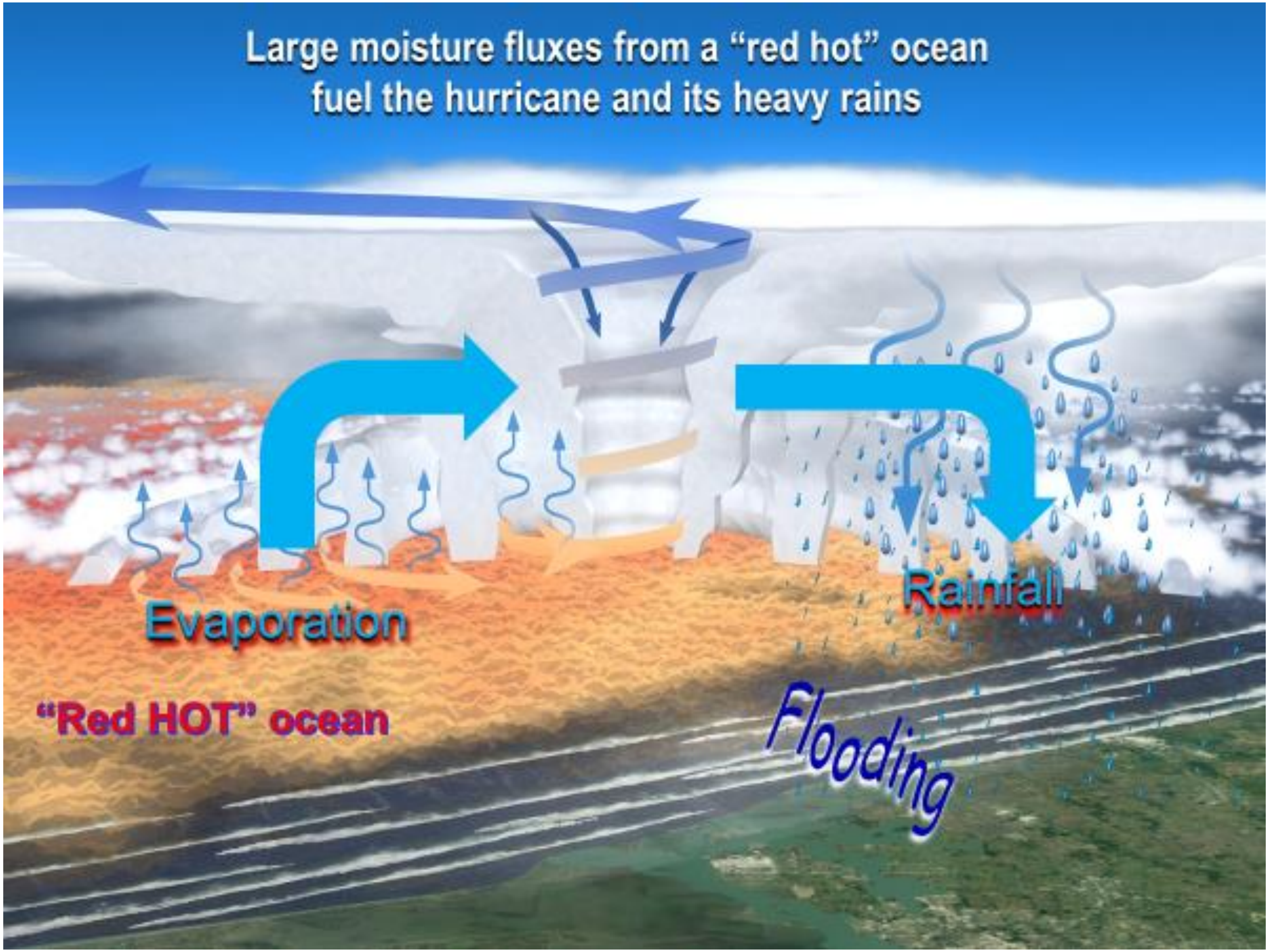
- Improve the **efficiency/design of waste minimisation, management and treatment**

- Rather than having circularity as an ultimate goal, a more pragmatic vision for a material future would be **aim to meet human needs (demand) while minimising the environmental impact.**

What Can We Do

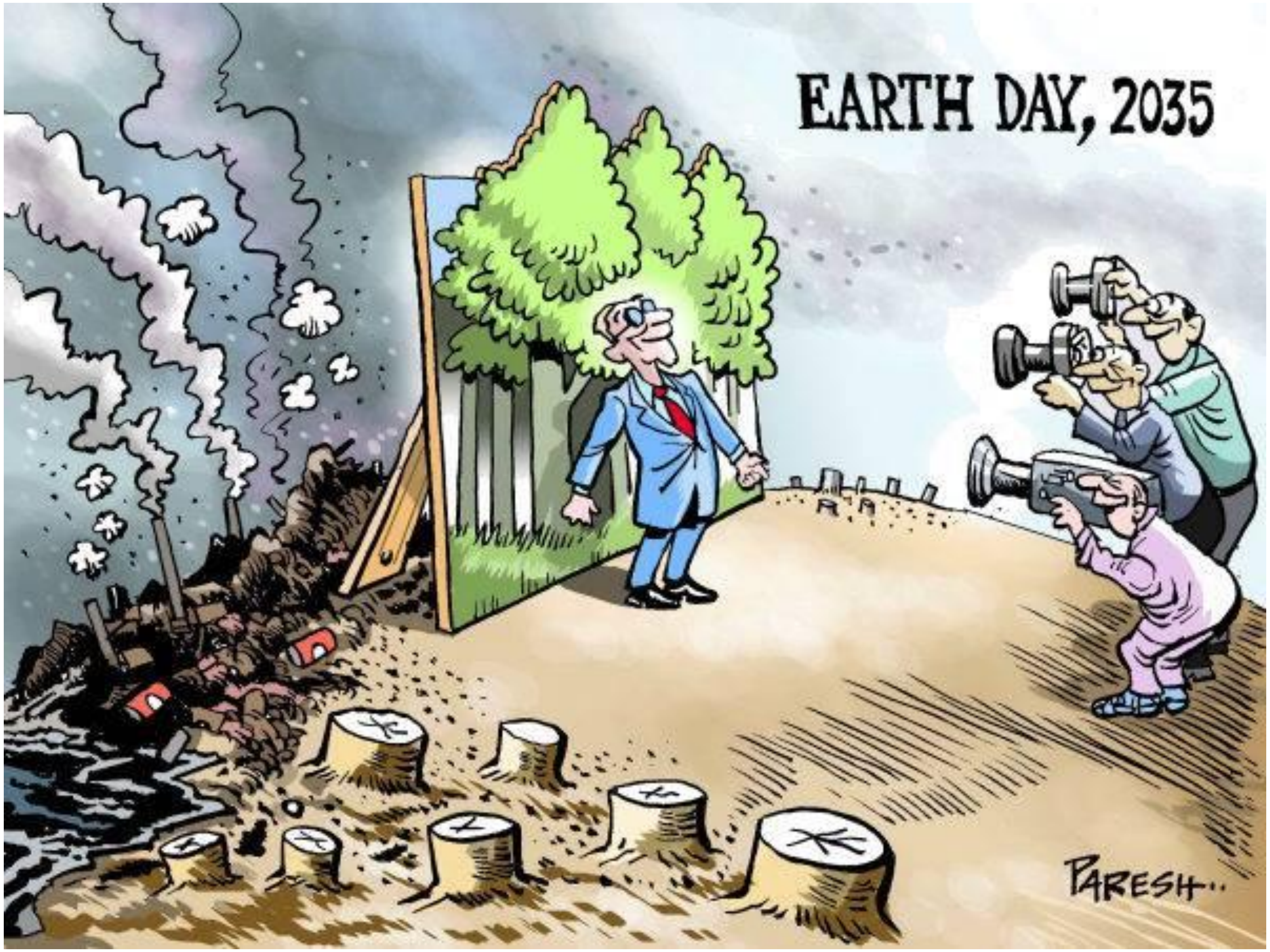
- Use energy efficient light bulbs and appliances
- Walk, bicycle
- Live where you work
- Drive less, and drive fuel efficient vehicles
- Eat less meat, change the diet
- Do not over-heat or over-cool, Increasing thermostat by 1^{o} in the summer & Decreasing it by 1^{o} in the winter (save 10% of energy consumption),
- Wear a sweater
- Reuse, reuse (shopping bag, bottles, packaging)
- Reduce your waste (incl. food waste), separation, composting
- Insulate your house etc:
- Use biofuels (?) – target biowaste
- Use a clothesline
- Vote!

Trenberth K E, NCAR, Extreme weather and the changing climate,
<www.cgd.ucar.edu/staff/trenbert/presentations.html> 2/7/2018



Trenberth K E, NCAR, Extreme weather and the changing climate, <www.cgd.ucar.edu/staff/trenbert/presentations.html> accessed 2/7/2018

The Need of Action and Appropriate Implementation



Acknowledgement

To the EC project Sustainable Process Integration Laboratory – SPIL funded as project No. CZ.02.1.01/0.0/0.0/15_003/0000456, by Czech Republic Operational Programme Research and Development, Education, Priority 1: Strengthening capacity for quality research and by the collaboration agreement with Universiti Teknologi Malaysia (UTM), The University of Manchester, UK, University of Maribor, Slovenia, Hebei University of Technology, Tianjin, China, Fudan University, China, The University of Waikato, New Zealand and Pázmány Péter Catholic University, Hungary based on the SPIL project.

Future Special Session: SDEWES 2018 Palermo

Proposed Special Session: SDEWES 2019 Dubrovnik



<dubrovnik2019.sdewes.org/>

Energy, Water and Resource Efficiency for Sustainable Future: Contribution to Circular Economy

Jiří Jaromír Klemeš: jiri.klemes@vutbr.cz
Petar Sabev Varbanov: varbanov@fme.vutbr.cz
Yee Van Fan (Ms): fan@fme.vut.br

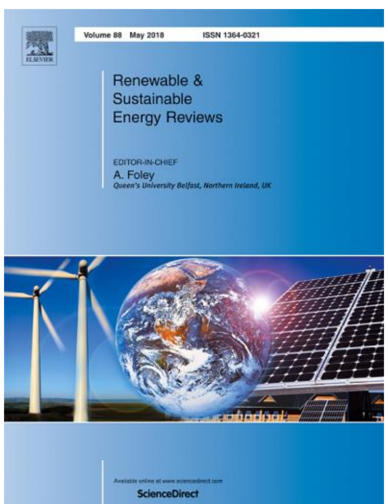
22nd Conference Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction

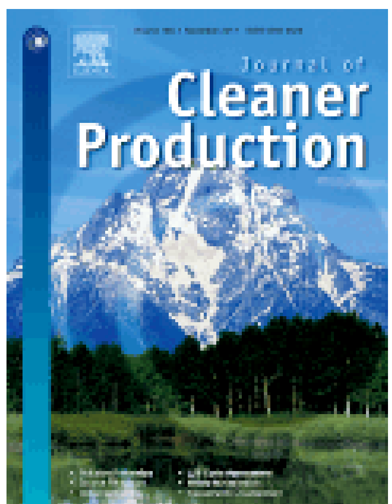
PRES'19

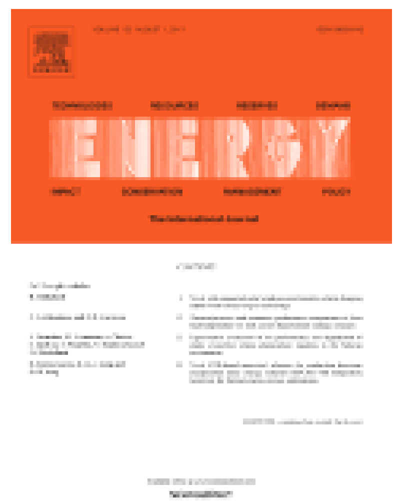
20–23 October 2019
Crete, Greece

MPORTANT DATES

30 November 2018, Abstract due
31 January 2019, Notification of abstract acceptance
16 March 2019, Full text submission due
30 April 2019, Full text revisions and final acceptance completed

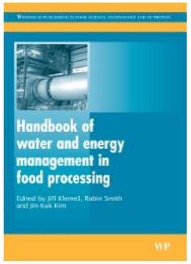


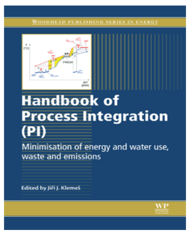


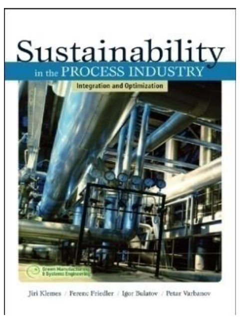


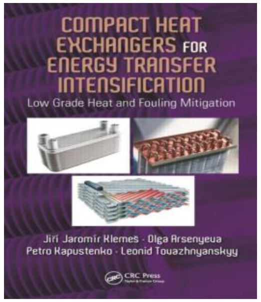
<conferencepres.com> | <pres2019.cperi.certh.gr>

Handbooks and the Textbooks

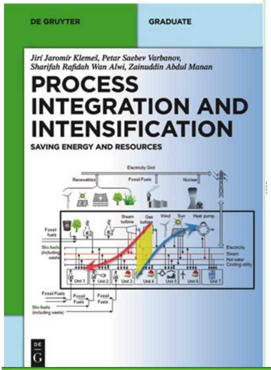


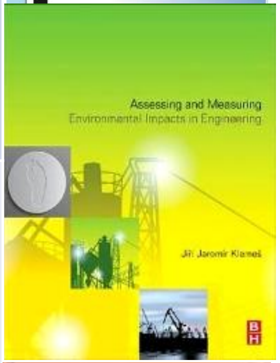


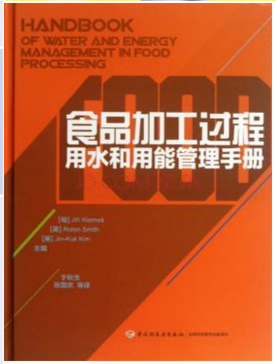




	Book Title	Editors	Publication
1	Handbook of water and energy management in food processing (English and Chinese version)	Jiří Klemeš, Robin Smith and Jin-Kuk Kim	Woodhead Publishing Ltd / Elsevier 中国轻工业出版社
2	Handbook of Process Integration (PI): Minimisation of energy and water use, waste and emissions	Jiří Klemeš	Woodhead Publishing Series in Energy No. 61
3	Sustainability in the process industry	Jiří Klemeš, Ferenc Friedler, Igor Bulatov, Petar Varbanov	McGraw-Hill Professional
4	Process integration and intensification	Jirí Jaromír Klemeš, Petar Varbanov, Sharifah Rafidah Wan Wan Alwi, Zainuddin Abdul	De Gruyter
5	Assessing and Measuring Environmental Impact and Sustainability	Jirí Jaromír Klemeš	Butterworth-Heinemann/Elsevier
6	Compact heat exchangers for energy transfer intensification: Low grade heat and fouling mitigation	Jirí Jaromír Klemeš, Olga Arsenyeva Petro Kapustenko, Leonid Tovazhnyanskyy	CRC Press/ Taylor and Francis Group







Thank you, comments welcome

感谢倾听，请多指导