The future of material sustainability

Holger Frauenrath

Associate Professor at LMOM
EPFL

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Holger intends to save the world from plastic pollution but has to realize this won’t work without data sciences he does not understand

Sustainable Materials by Supramolecular Modification of Biodegradable Polyesters

Prof. Holger Frauenrath

Associate Dean for Industry & Innovation
School of Engineering

Director of the Laboratory of Macromolecular and Organic Materials (LMOM)
Institute of Materials (IMX)

Ecole Polytechnique Fédérale de Lausanne (EPFL)

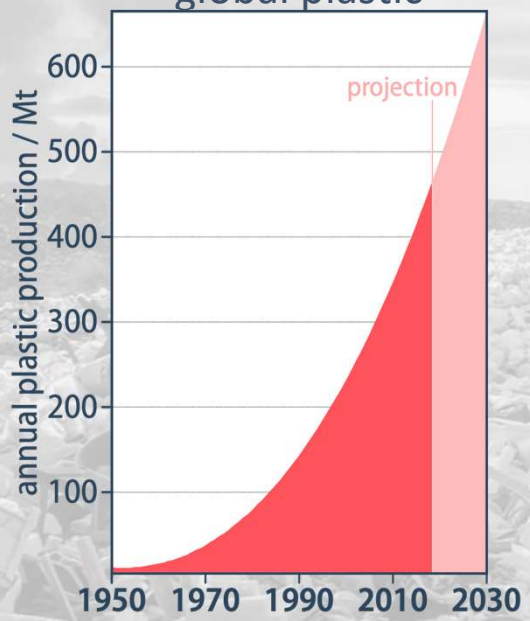
daniel.gorl@epfl.ch

EPFL

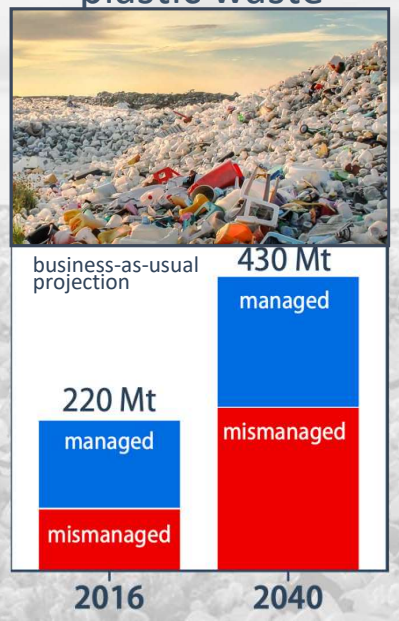
Sustainability Challenges of Plastics

- continued plastics proliferation driven by low cost, light weight, performance, durability, design freedom

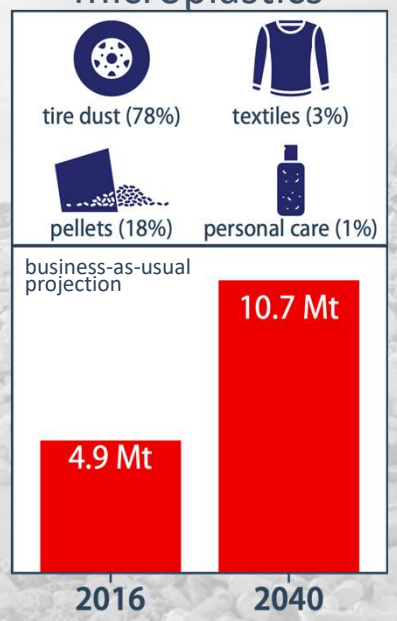
global plastic



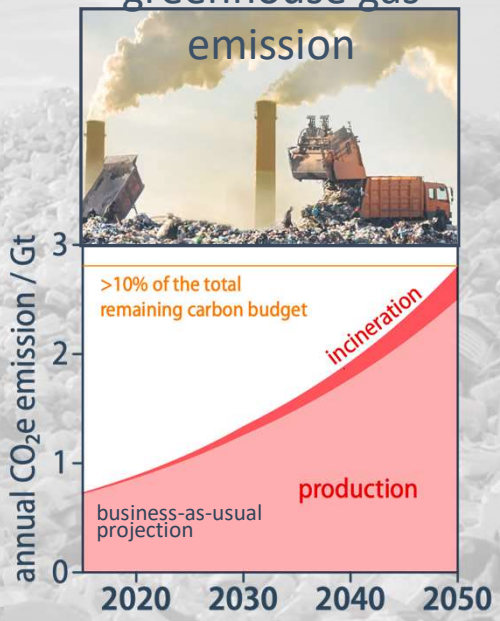
plastic waste



microplastics



greenhouse gas emission



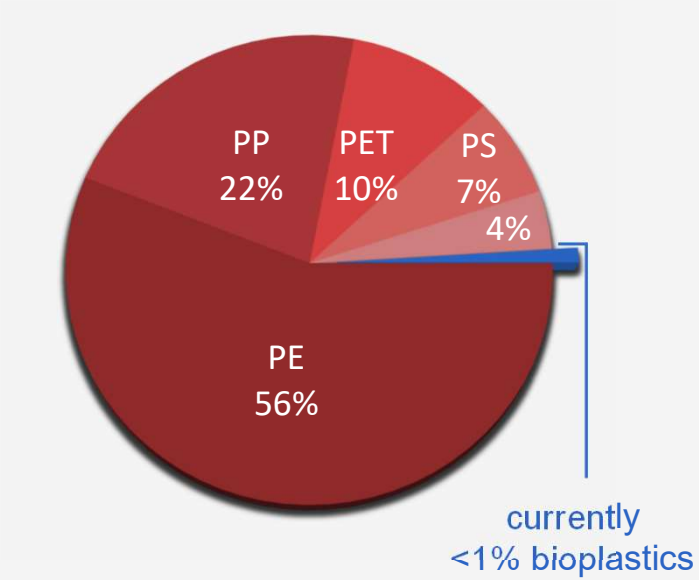
- **socioeconomic & environmental challenges require a complete rethinking of the plastics economy**

Plastikatlas, **2019**; *Breaking the Plastic Wave*, **2020**; CIEL, *Plastic & Climate*, **2019**.

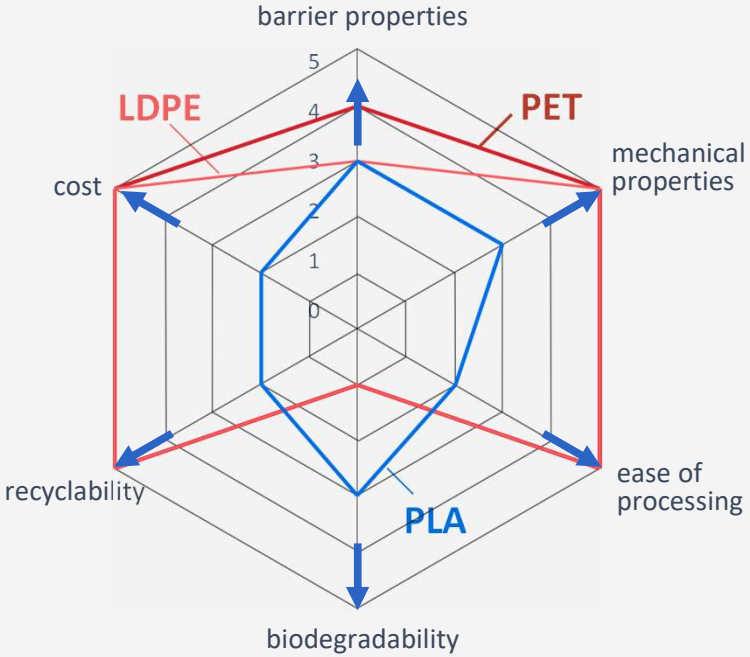
Example: Bioplastics for the Packaging Market

- bioplastics provide additional end-of-life options, but account for < 1 wt% of global market share

global packaging market



trade-offs in materials replacement by PLA



- **limitation of bioplastics & biodegradable polymers: inferior processing & mechanical performance**

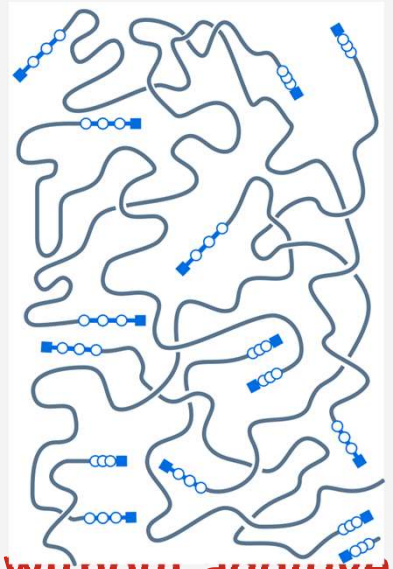
LMOM Technology for the Supramolecular Modification of Polymers

- **Challenge: more efficient recycling requires standardization of materials**
  - property profiles compliant to a broad variety of processing methods
  - match or exceed the final product performance of materials to be replaced
  - bioplastics often exhibit inferior processability and mechanical performance

- **Solution: supramolecular modification of polymers to match their thermal, mechanical, rheological properties to processing & application demands**
  - strength, stiffness, ductility & toughness at operating temperature
  - fatigue behavior, long-term embrittlement
  - dimensional stability at operating temperature
  - thermal transitions & operating/processing temperature range
  - melt viscosity & elasticity for better processing options & design flexibility

Concept: Modified Polymer + Additive

- Problem: high polymer molecular weight and supramolecular structure formation are mutually exclusive
- Solution: reinforcement by co-assembly of polymer end groups and a matching additive

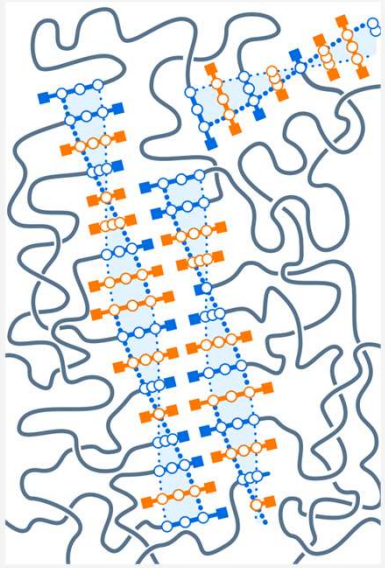


without additive
poor network formation

a network forming polymer of desired molecular weight

+

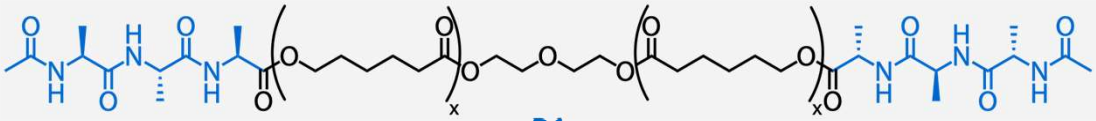
a network reinforcing additive

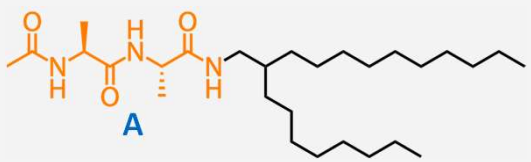


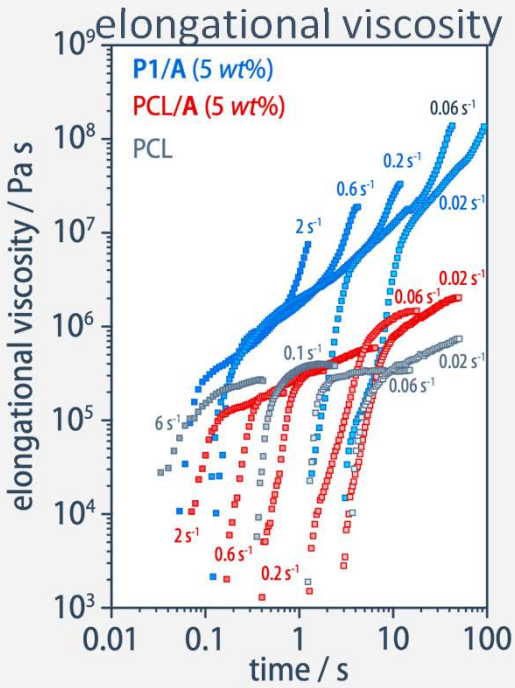
co-assembly into reinforced nanostructures

- tailorable property profiles based on networks that are independent of the polymer chain length

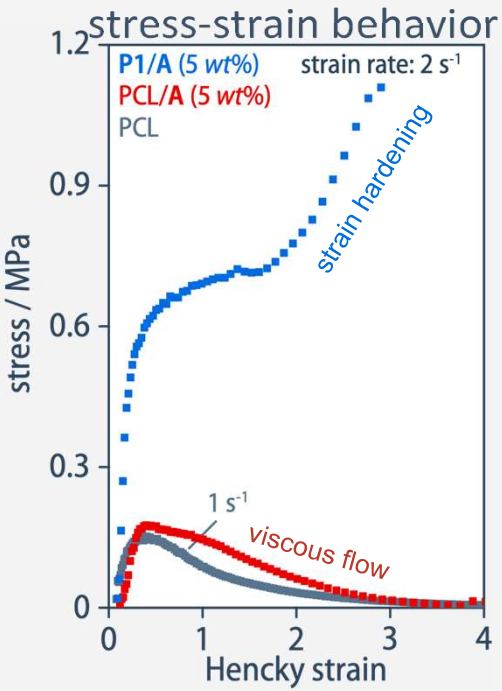
New Melt Properties



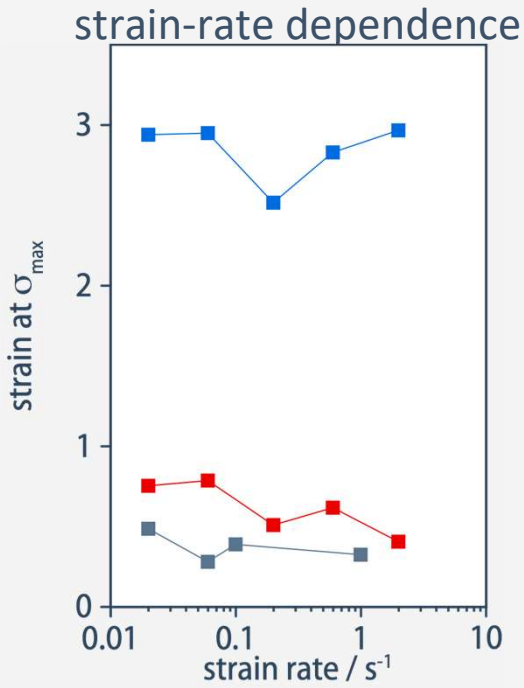




high transient viscosity



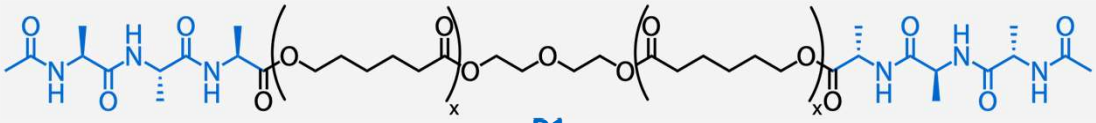
strain-hardening

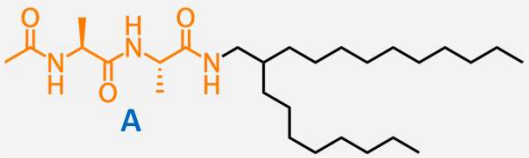


improved extensibility

- **initial high stiffness, yielding, and strain hardening translate into improved melt extensibility**

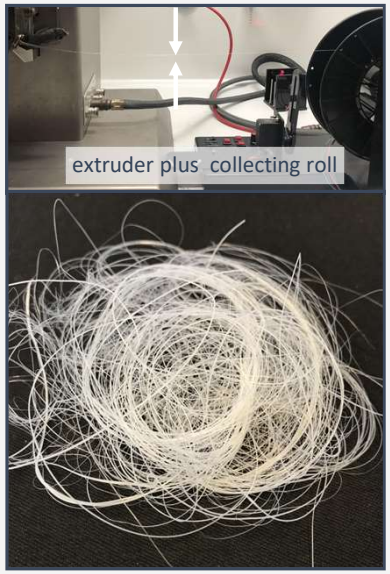
Facilitated Melt Processing and New Products





film blowing

film stretching

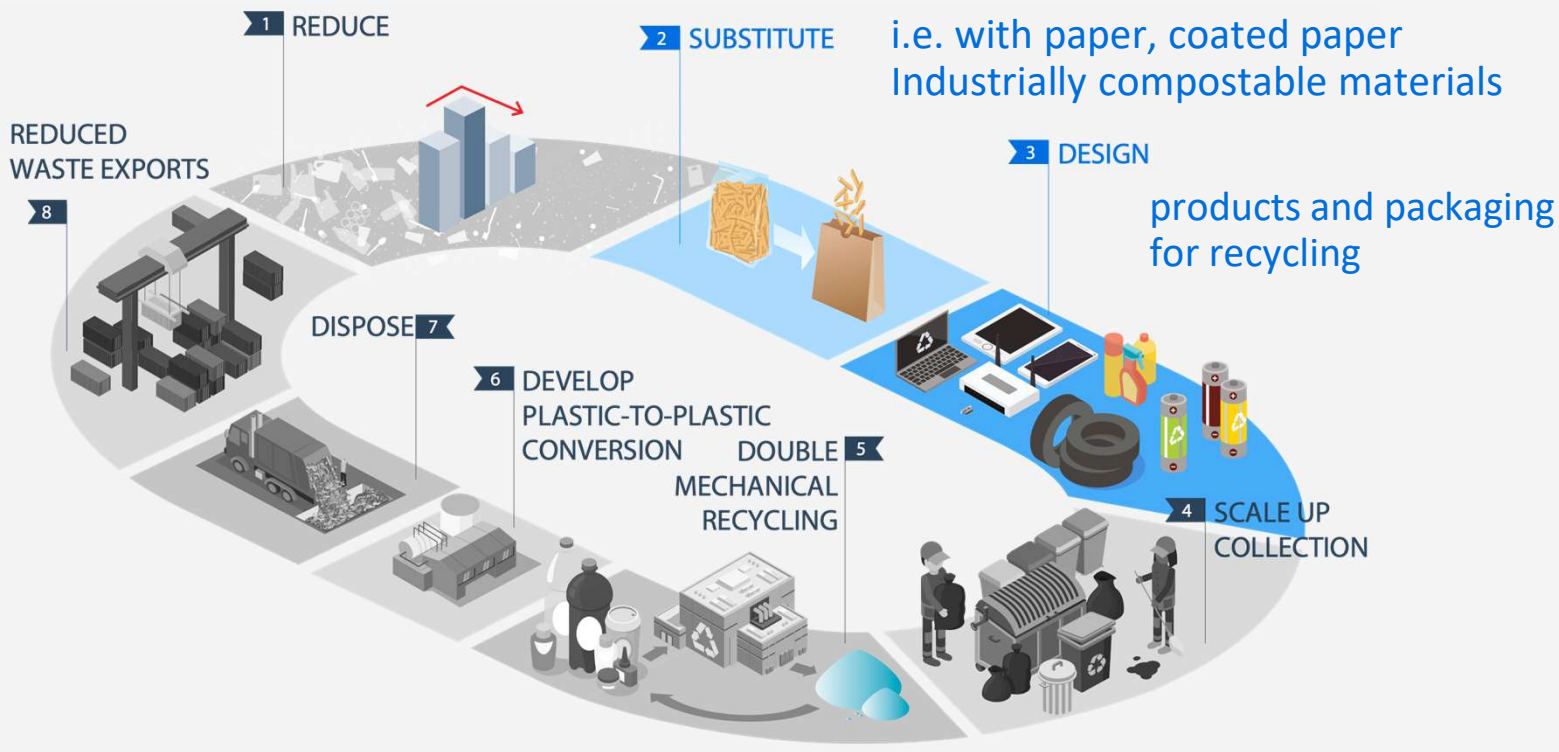


high performance fibers

- **new melt properties are relevant for melt processing methods that proceed under deformation**

Interventions Across the Plastics Value Chain

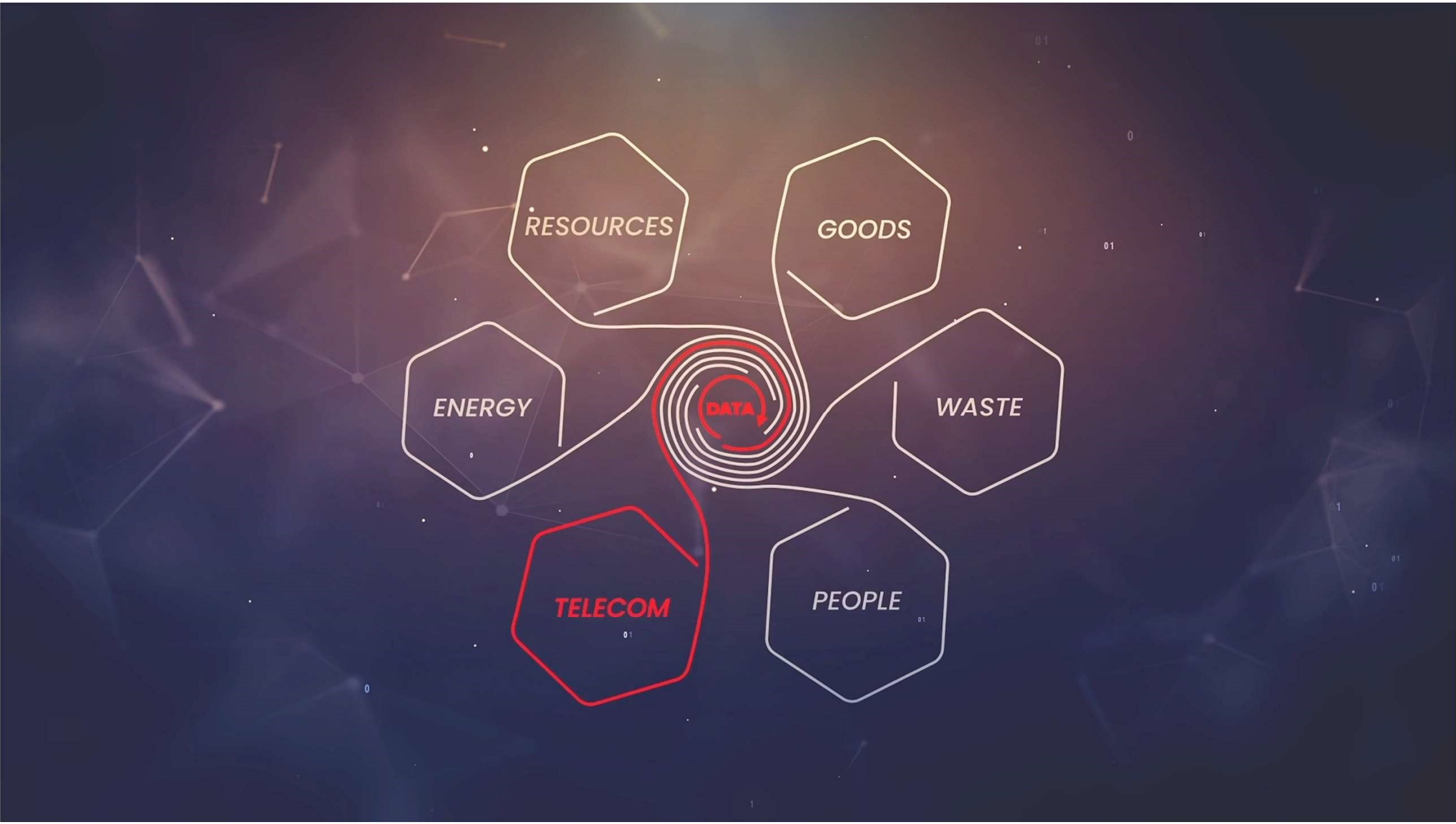
- up to 80% reduction in projected plastic leakage, without compromised societal and economic benefits



- **new sustainable materials are needed to lead the transition to a new circular plastics economy**

Grand Challenges Towards a Sustainable Society

- **grand challenges due to economy having grown beyond the limits of our planet:**
  - climate change and greenhouse gas emissions
  - use of energy and materials resources
  - waste and pollution
  - population growth and urbanization
  - human health and sustainable food chain
- **socioeconomic system of many independent but highly integrated circular streams**
  - energy, materials resources, products, and waste
  - transportation and distribution systems for people, goods, and waste
  - telecommunications & information systems


RESOURCES
GOODS
ENERGY
DATA
WASTE
TELECOM
PEOPLE

Understanding Product Life Cycles and Value Chains

- **limitations of current materials life cycle assessment (LCA)**
  - available data is scarce and unsystematic
  - manual analysis fails for more complex interdependencies
  - interdependent models and assumptions result in arbitrary final results
- **LCA from a scarce data problem to a big data opportunity to product knowledge**
  - abundant, low-cost, low-power, micromanufactured, intelligent tags & sensors
  - *Internet of Materials* as a data-centric and AI-driven approach to LCA
  - *Product Passport* based on rich data on the path through the entire value chain
- **life cycle management and understanding of value chains for a circular economy**

Materials and Product Design for a Circular Economy

- **environmental impact largely defined in the product design process**
  - design is not informed by alternatives required for a circular economy
  - design alternatives can only compete on full socioeconomic cost basis
- **data-enabled engineering for a durable product design**
  - *Internet of Materials* for feedback from entire life cycle and value chain
  - including use, failure, customer satisfaction
  - development of data-driven durable product design tools
  - standardization of materials, intelligent manufacturing processes
  - novel key performance parameters for measuring circularity & sustainability

Infrastructure for Complex Interconnected Circular Systems

- **radical infrastructure changes required for a circular economy**
  - competing with low-cost linear models economically “not viable”
  - lack of reliable data hinders investments into infrastructure

- **integrated infrastructure for electricity, transportation, reverse logistics systems**
  - intelligent, autonomous, networked vehicles and robotic systems for transportation / distribution systems for people, goods, and waste
  - renewable energy refineries for carbon capture from industrial exhaust gas, integrated with energy, fuel, feedstock streams
  - smart grid for a decentralized and resilient energy generation, distribution, consumption, integrated with transportation systems

Sustainability Activities Across EPFL

NCCR Catalysis

- manufacturing emissions
- sustainable processes
- CO_2 capture & conversion

EPFL Energy Center

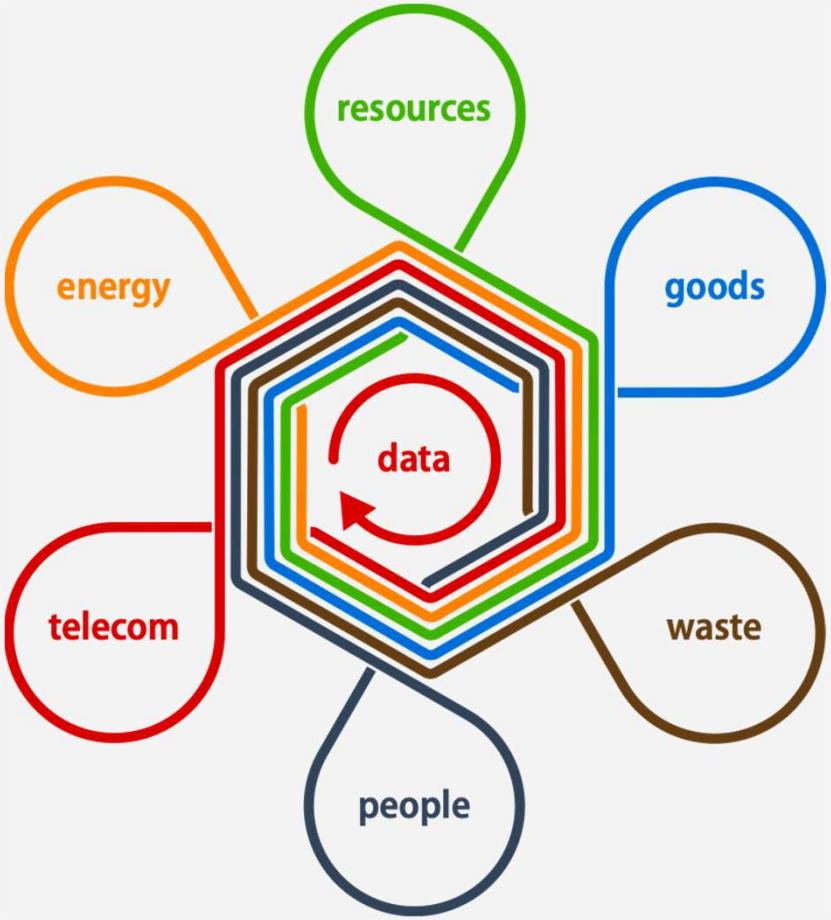
- smart grids
- energy storage
- renewable energies

Swiss Data Science Center

Data-Enabled Engineering

Center for Digital Trust

Intelligent Systems Center



EPFL Food Center

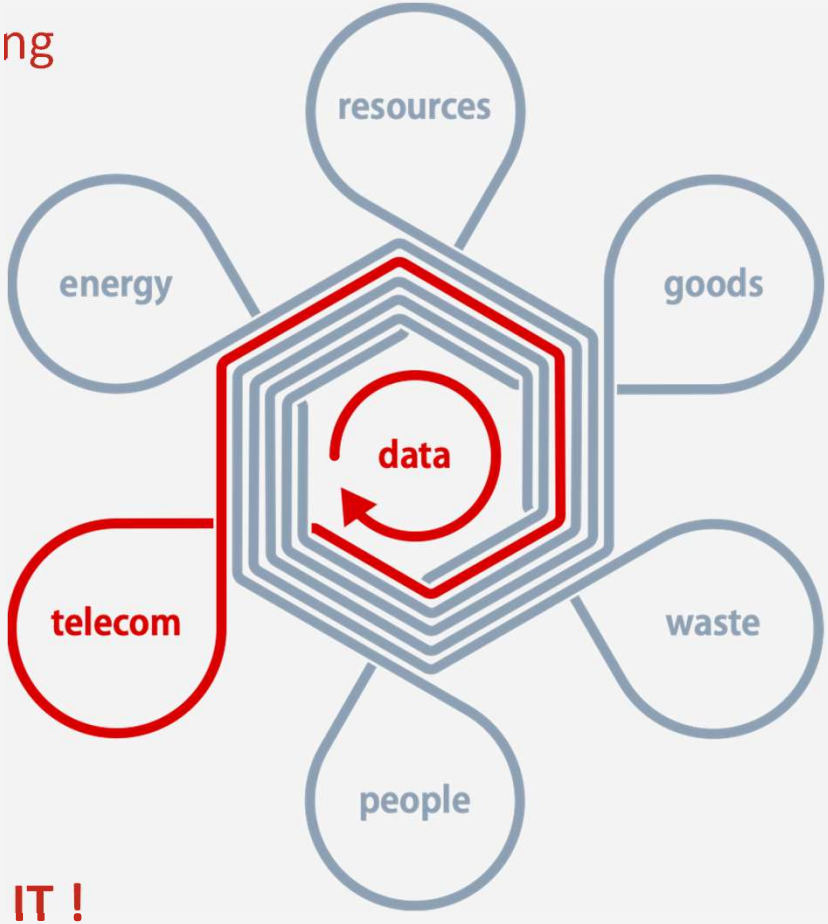
- food waste
- packaging materials
- sustainable agriculture

Materials & Recycling

- recyclable polymers
- biosourced materials
- cementitious materials

EPFL Transport Center

- transportation systems
- interconnected traffic
- autonomous vehicles

Sustainability of Data-Driven Sustainability Approaches

- **physical circular flows interconnected by digital data flows**
  - abundant intelligent tags, sensors, networking
  - edge & cloud computing
  - putting the *Internet of Things* to good use
  - from information models to knowledge
- **requirements for sustainability**
  - data must be open and privacy-aware
  - edge computing must be sustainable
  - data processing must be energy efficient
- **data-driven sustainability requires sustainable IT !**