Die Kreislauffähigkeit von Energiesystemen

Fallbeispiele: Transport, Strom und Wärme

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Take Home Message on Circularity Assessment

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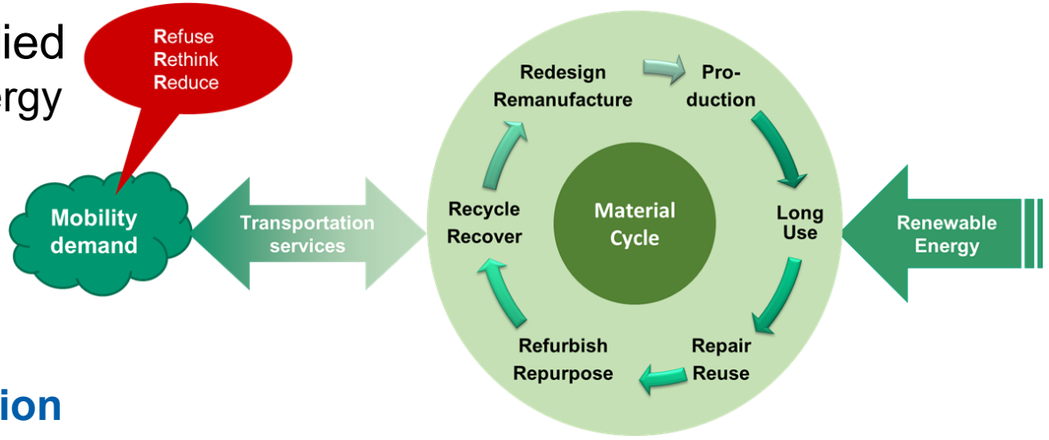
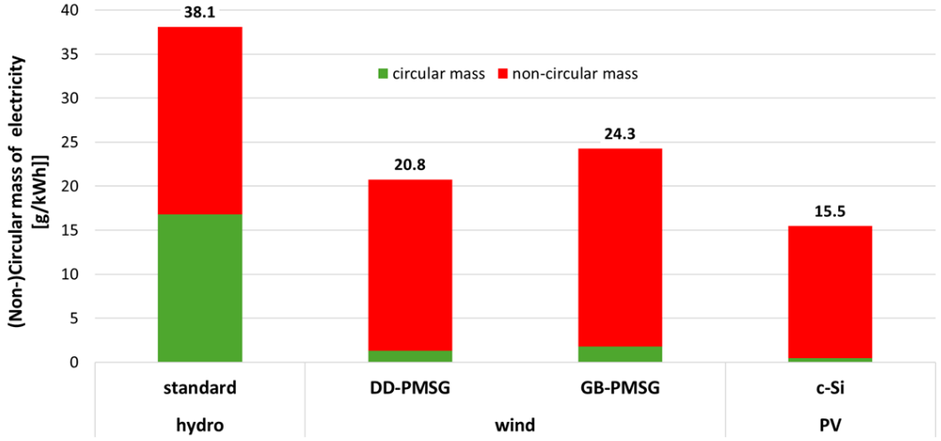
- Initial approach for **circularity assessment** developed & applied
  - **Definition** of Circularity Potential essential including primary energy
  - Methodological approach: dynamic **Life Cycle Assessment**
  - Mass balance of in- and outputs based on
    - **circular** and **non-circular** mass flows
    - **renewable** and **non-renewable** materials & energy
  - Practical application shown in case studies
  - **Energy consumption, types of materials, lifetime** and **utilisation** are essential for circularity
- **10 R-Principles** to improve Circularity with further challenges
- **Initial conclusions**
  - Only systems using **renewable energy have potential for circularity**
  - **Low mass but high circularity potential**
  - **Intensity of material use relevant**: lifetime, annual hours etc.
  - **Design** for 10 R-Principles in combination with new Circularity Business Models – Product-as-a-Service (PaaS)
  - Information exchange and collaboration in **supply networks:** e.g. towards **Digital Product Passport** (DPP)





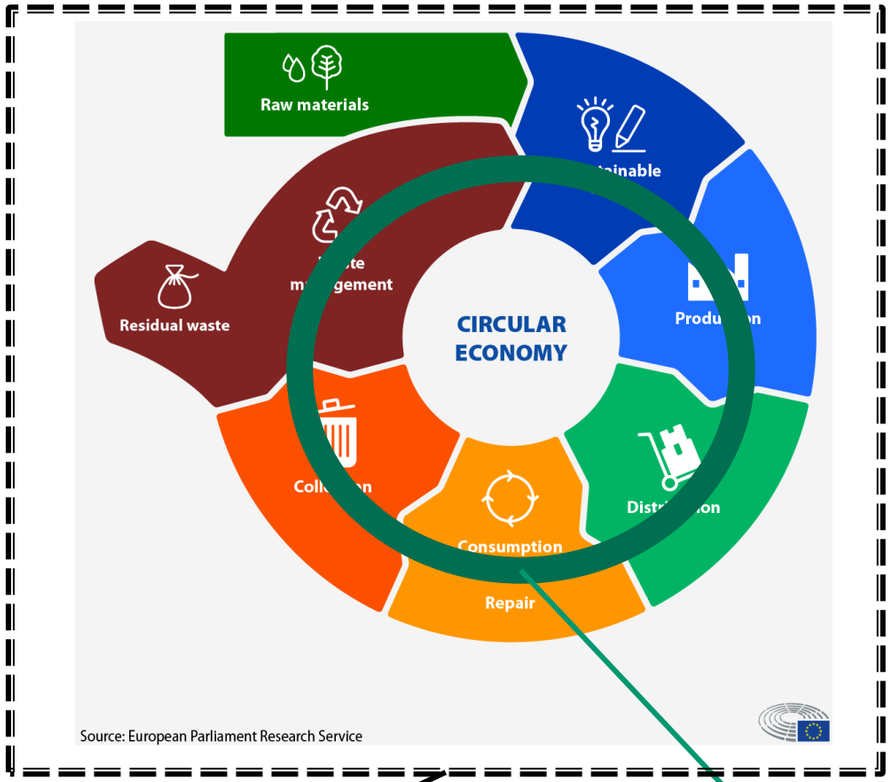
What is Circularity?

(1) Circularity (%) = circular mass / total mass

(2) Mass per product/service

Remarks

- ***Mass*** *is the sum of all materials in the total lifecycle*
- ***Primary energy*** *is counted as material (e.g. conversion from energy units in mass units using heating value of energy carriers)*
- *Total mass should be* ***minimized***
- ***Circular mass*** *should be increased*
- ***Non-circular mass*** *should must be reduced*



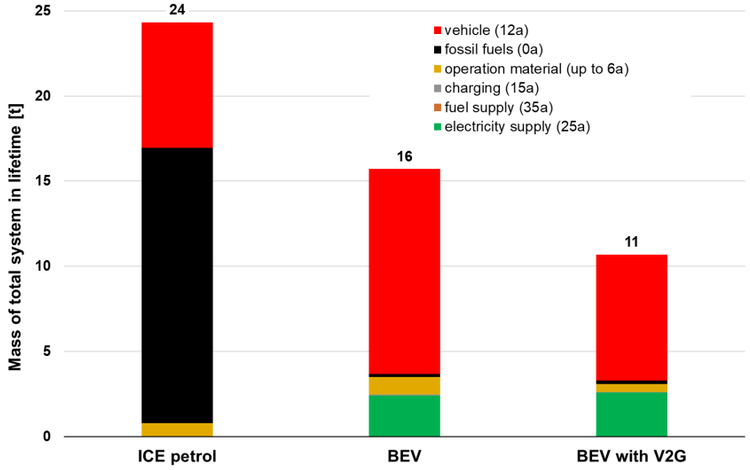
Total mass

Circular mass

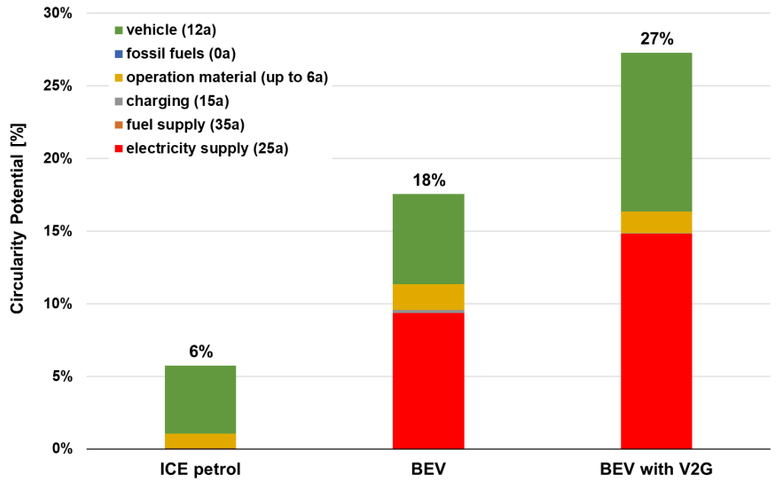
Passenger Car: Circularity Assessment

ICE/Petrol and BEV/Renewable Electricity

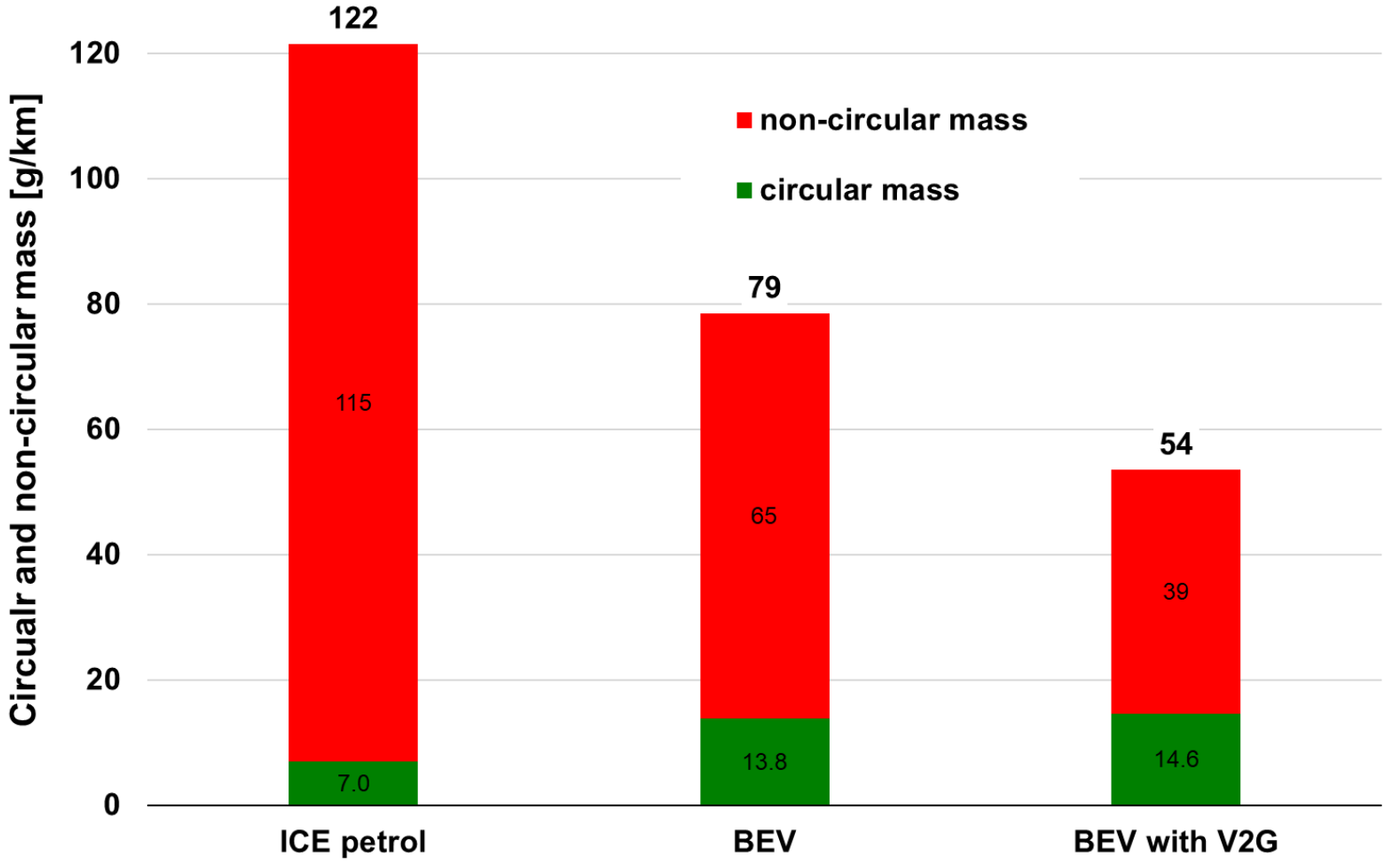
Inventory: Mass balance



Impact Assessment: Circularity Potential



Results: Circular and non-circular mass



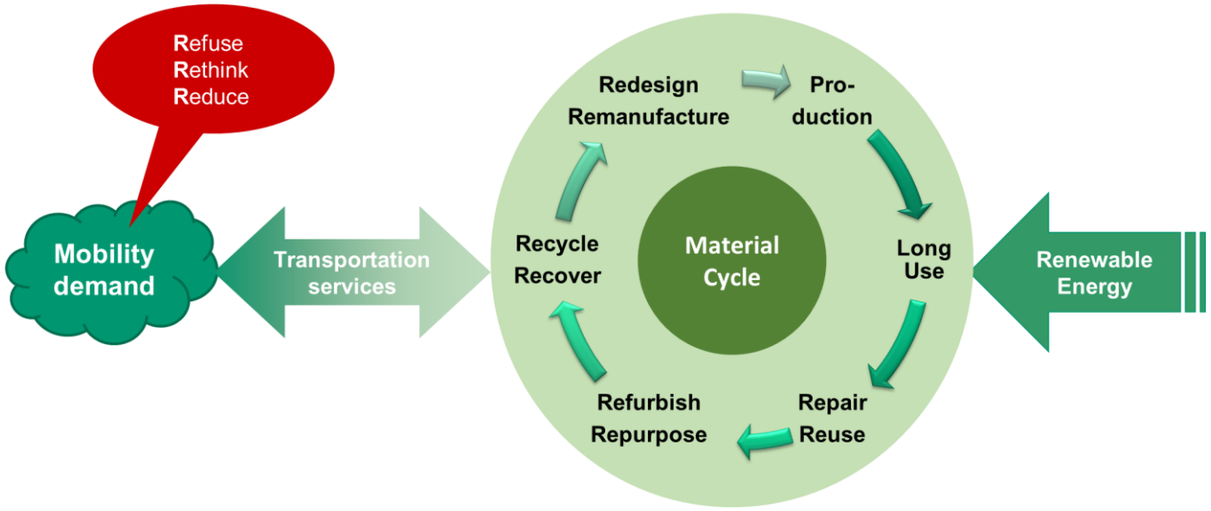
Lifetime mileage: 200, 000 km

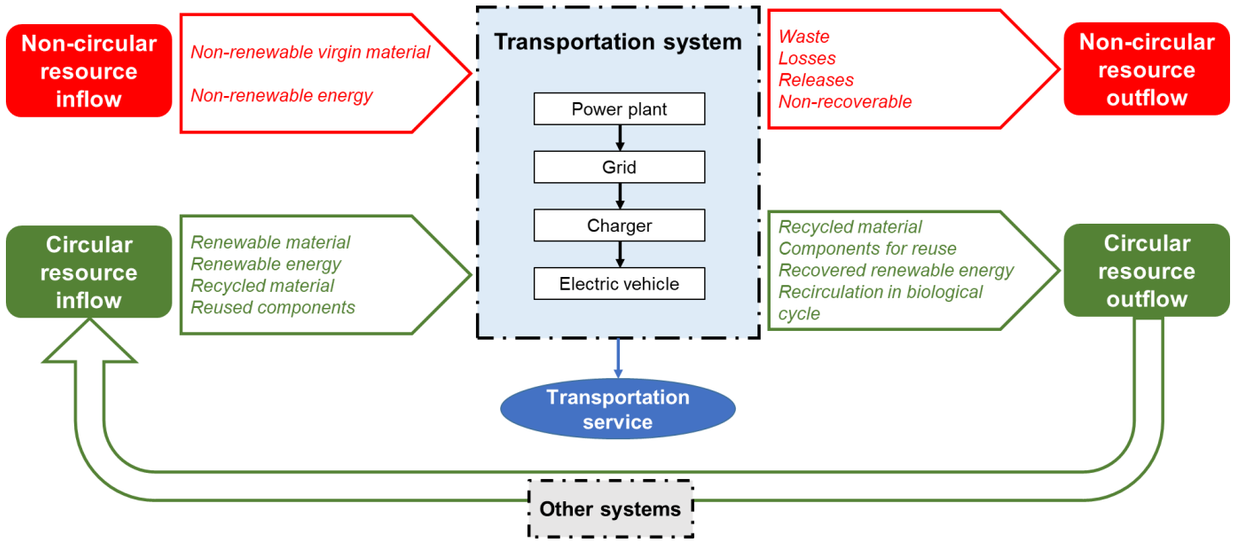
ICE: Internal Combustion Engine
BEV: Battery Electric vehicle
G2G: Vehicle-to-Grid Service

Source: JOANNEUM RESEARCH and IEA EV Partners

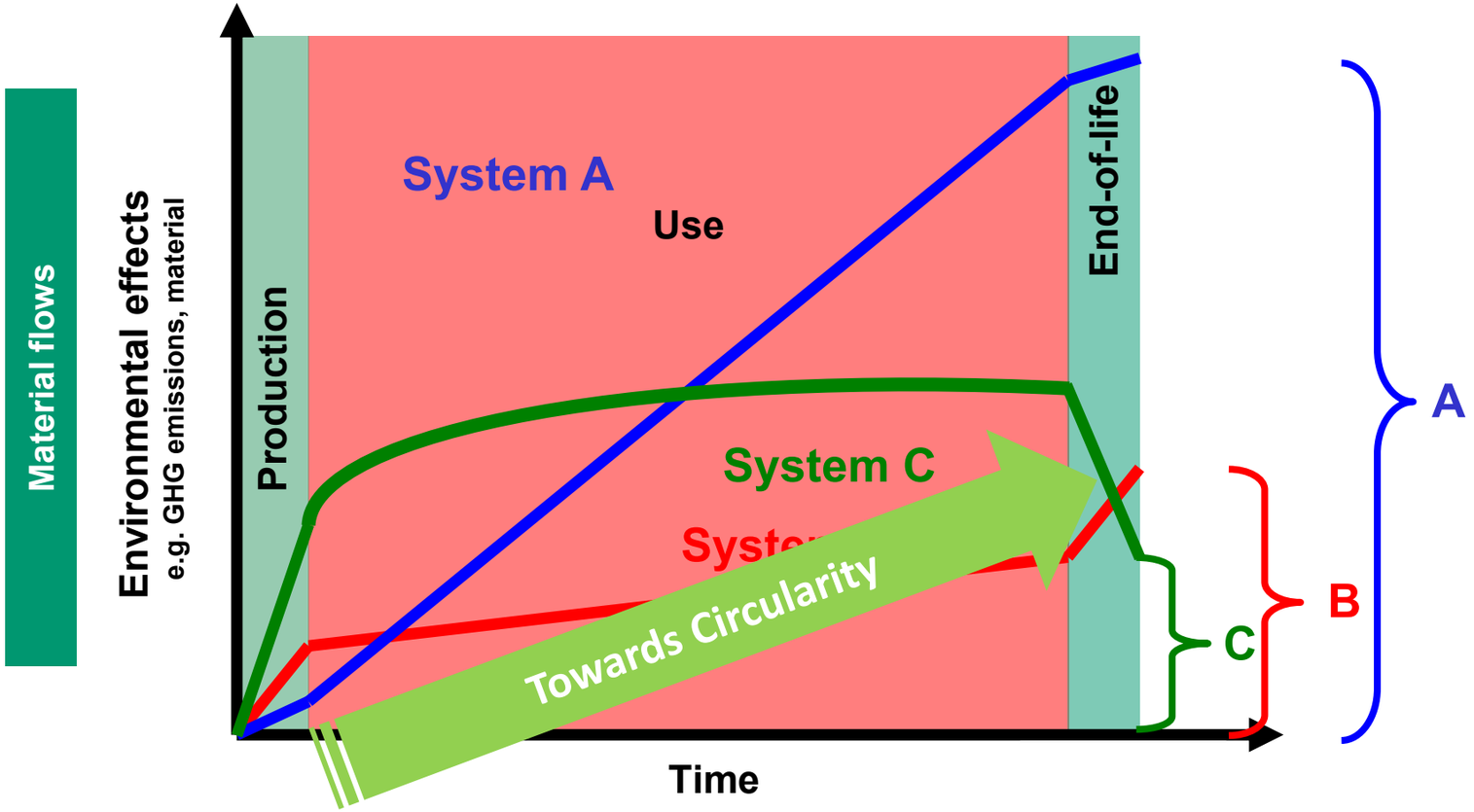
IEA EV Task 52: Definition of Circularity for LCA *(Status October, 2025)*

- *An energy service is "**100% circular**", if in the whole life cycle - production, operation & end-of-life – the total mass of used materials consists only of **reused components**, **recycled** and **renewable/bio-based materials** and **primary renewable energy** whereas no waste and no GHG emissions occur.*
- *That means **no primary material** (metal and minerals), **no primary fossil energy** (oil, gas and coal) and **complete recycling or reuse** of materials. A long lifetime and an intensive use in combination with high material and energy efficiencies are mandatory.*
- *The **10 R-Principles** of Circularity are applied consequently to further improve circularity - **R**efuse, **R**ethink, **R**educe, **R**euse, **R**epair, **R**efurbish, **R**emanufacture, **R**epurpose, **R**ecycle and **R**ecover.*
- *To assess circularity between 0% and 100% the **Circularity Potential** (CPO) is calculated with the lifecycle-based circular and non-circular mass of the system´s in- and outflows.*



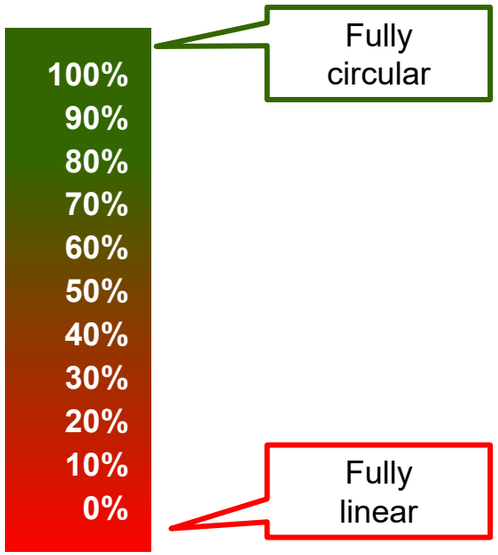


The Three Phases in Dynamic Life Cycle Assessment (dLCA)

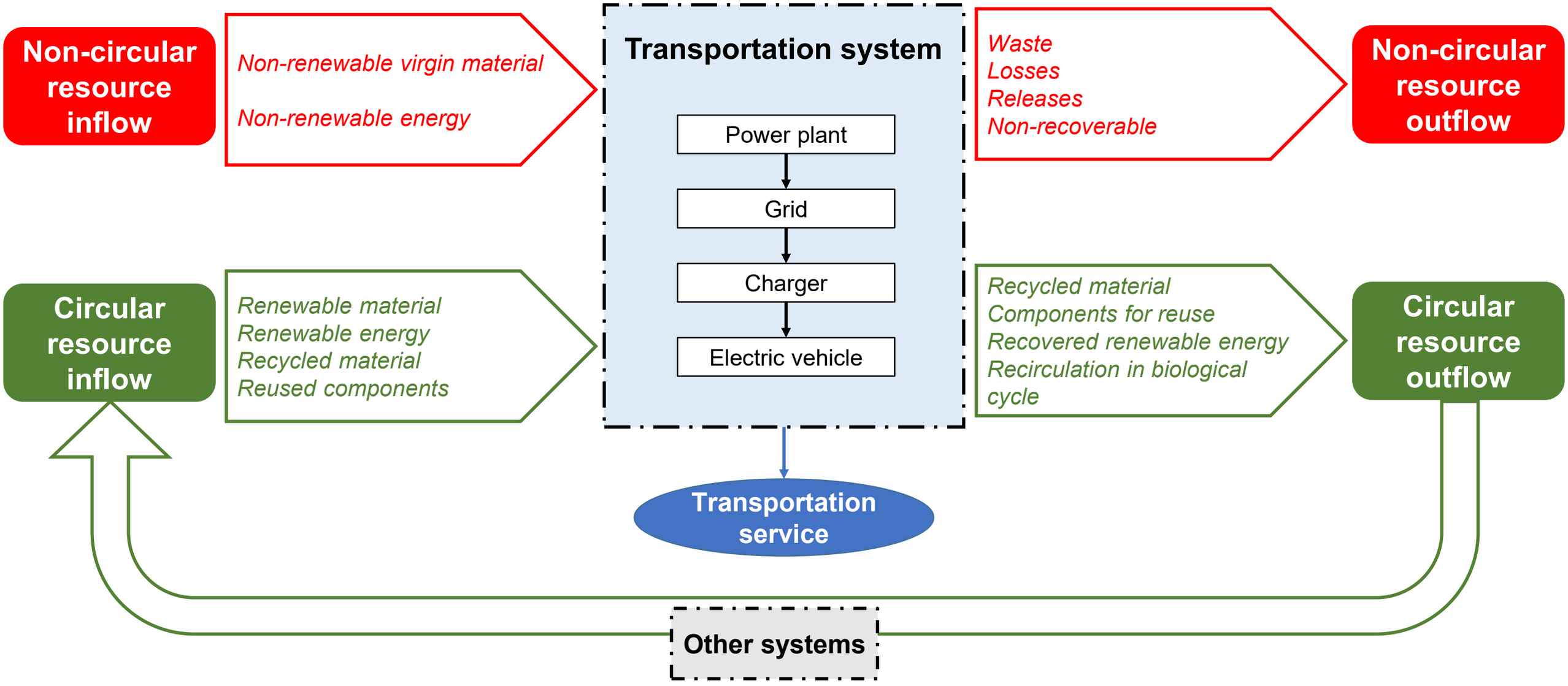


Assessment of Circularity Potential

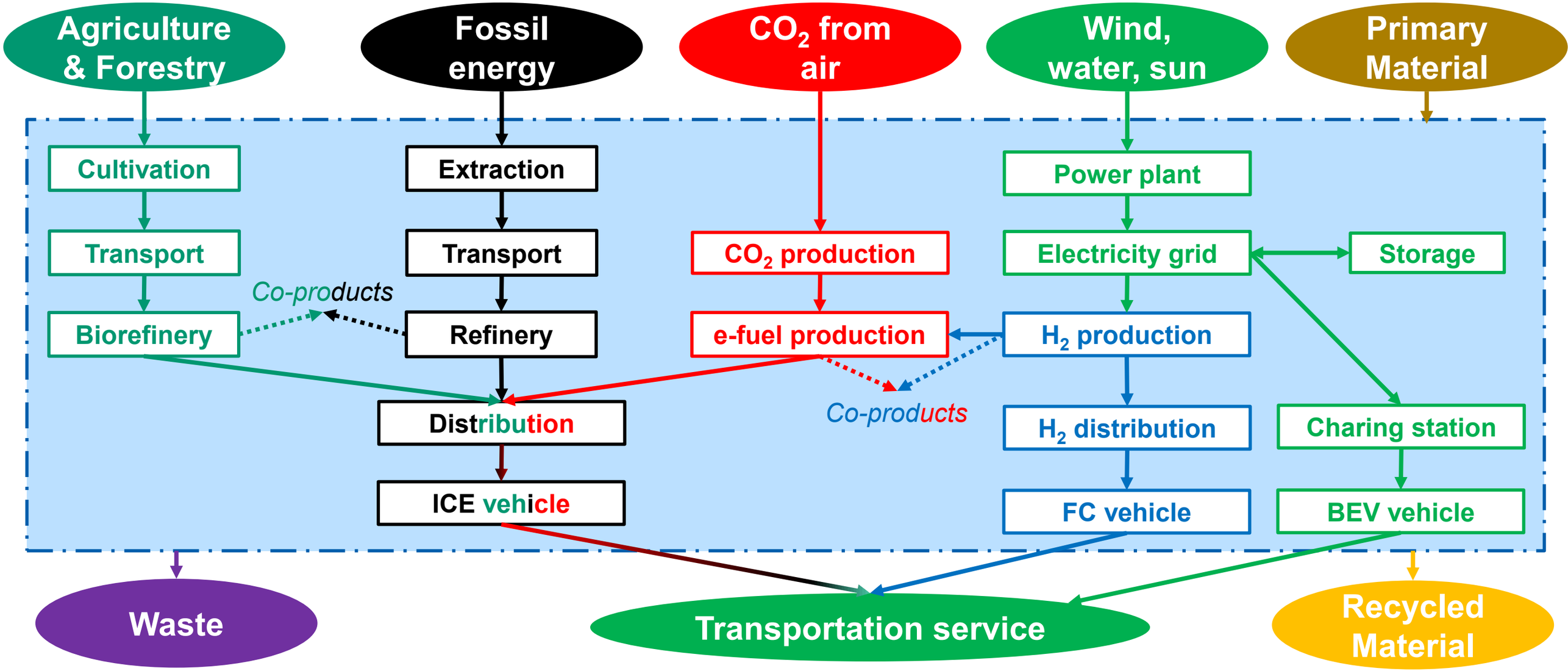
- Using the **Material Circularity Index** (MCI) developed by the Ellen MacArthur Foundation
  - Linear Flow Index ($LFI_{material}$): material specific
  - Utility Factor ($UF_{product}$): utilisation specific e.g. lifetime, payload
  - Material Circularity Index (MCI): MCI = $LFI_{materials}$ * $UF_{product}$
- **Calculating the Circularity Potential (CPO) (incl. core circularity indicators from ISO 59020)**
  - Apply dynamic LCA methodology with the time dependent mass flows
  - Setting of system boundary including production, operation & End-of-Life of vehicle & energy supply
  - Normalizing the MCI
    - 0% = fully linear
    - 100% = fully circular
  - Including cumulated primary energy demand in mass balance (Inventory)
  - Identifying circular and non-circular mass flows (Impact Assessment)
  - Calculating the circular and non-circular
    - total mass (e.g. g/km, g/component)
    - critical and non-critical mass (e.g. mg Sb_{eq}/km, mg Sb_{eq}/component)
    - renewable and non-renewable mass (e.g. $g_{renewable\ mass}$/km)
- **Remarks**
  - Primary energy is converted from MJ in kg using the heating value
  - Air, water and CO_2 are excluded as natural inputs (main focus on technical cycles)
  - Quality of recycled material is not considered, only useable mass: $Q_{virgin\ material} \geq Q_{recycled\ material}$ in open & closed loop recycling
  - Mass of primary energy for fuels occurs when heating value is extracted/made



Material Inventory and Assessment of Circular and Non-Circular Mass Flows



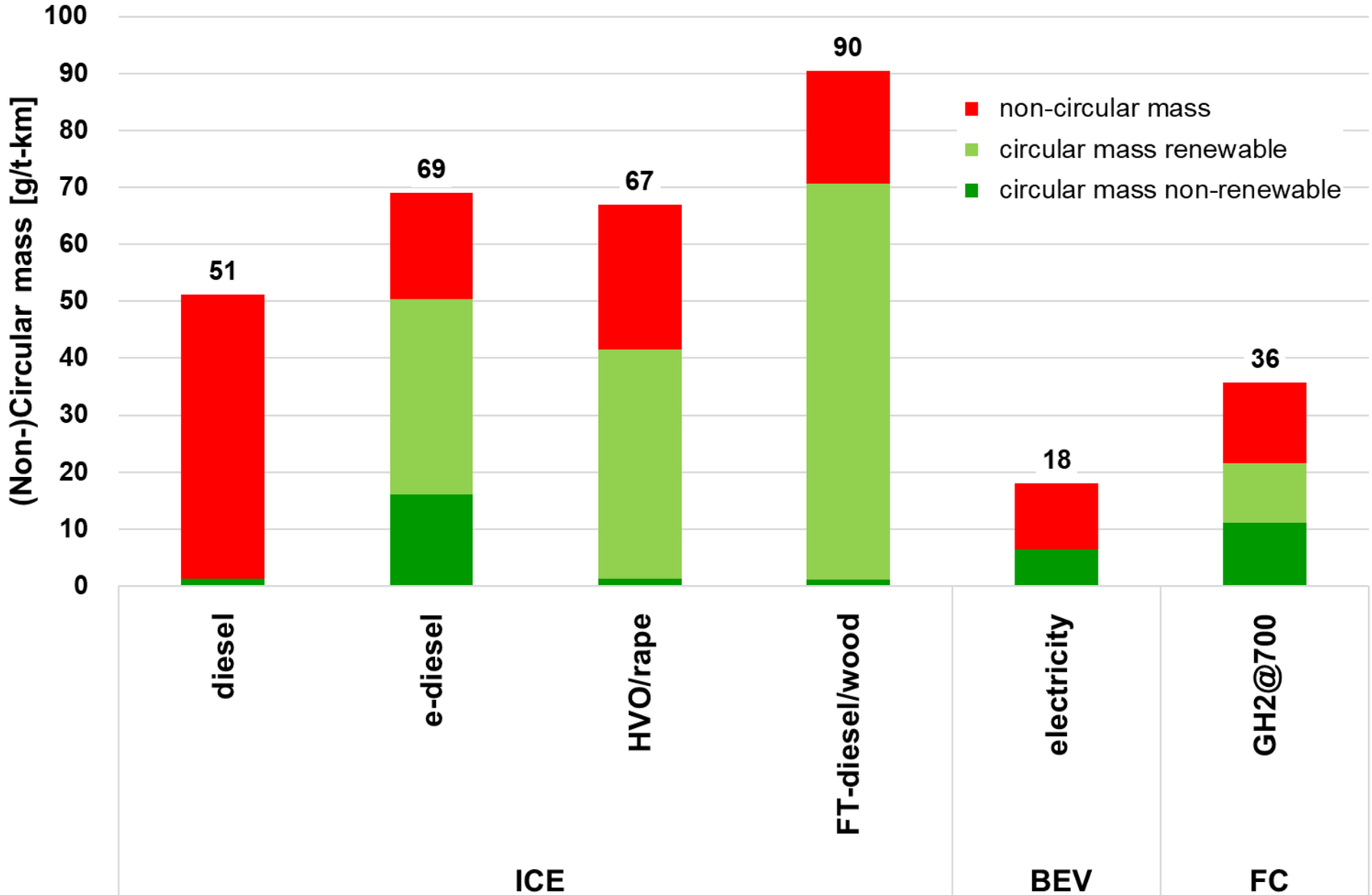
System Boundaries to Compare Transportation Systems



Circularity Assessment of Transportation Service: (Non-)Circular Mass per t-km of Truck

Trucks considered

- ICE (Internal Combustion Engine) using
  - Diesel
  - e-diesel with CO_2 from air and renewable hydrogen
  - HVO (Hydrated Vegetable Oil) using rape
  - FT-diesel using wood
- BEV (Battery Electric) using renewable electricity
- FC (Fuel Cell) using renewable gaseous hydrogen (@ 700 bar)

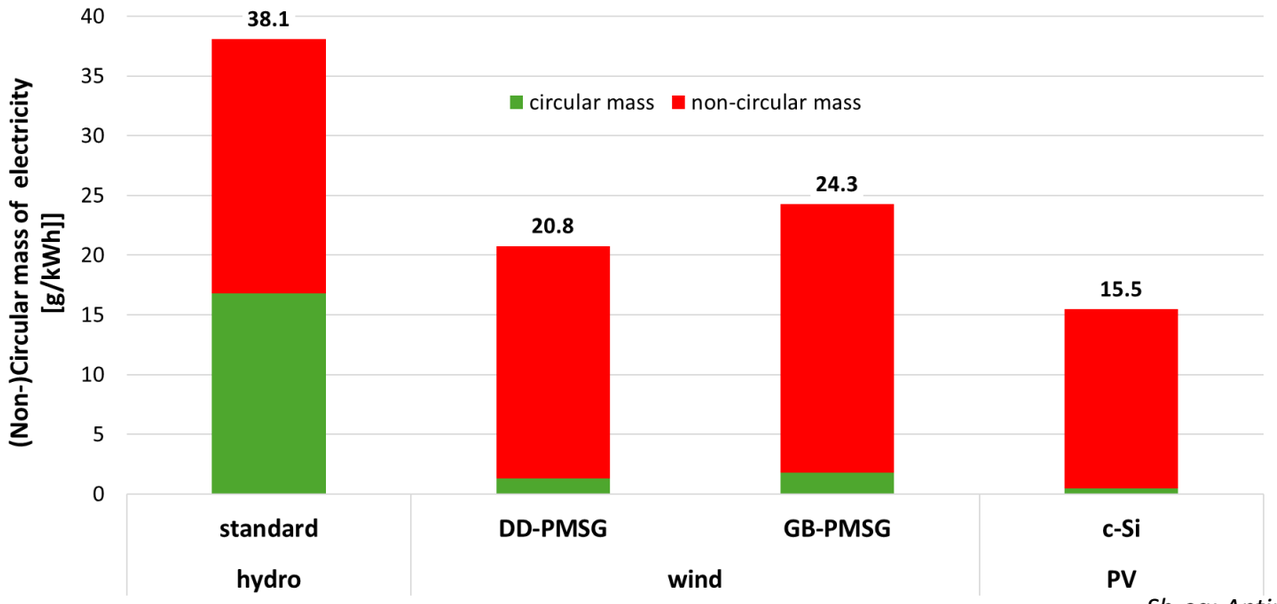


Circularity Assessment of Renewable Electricity: (Non-)Circular Mass per kWh

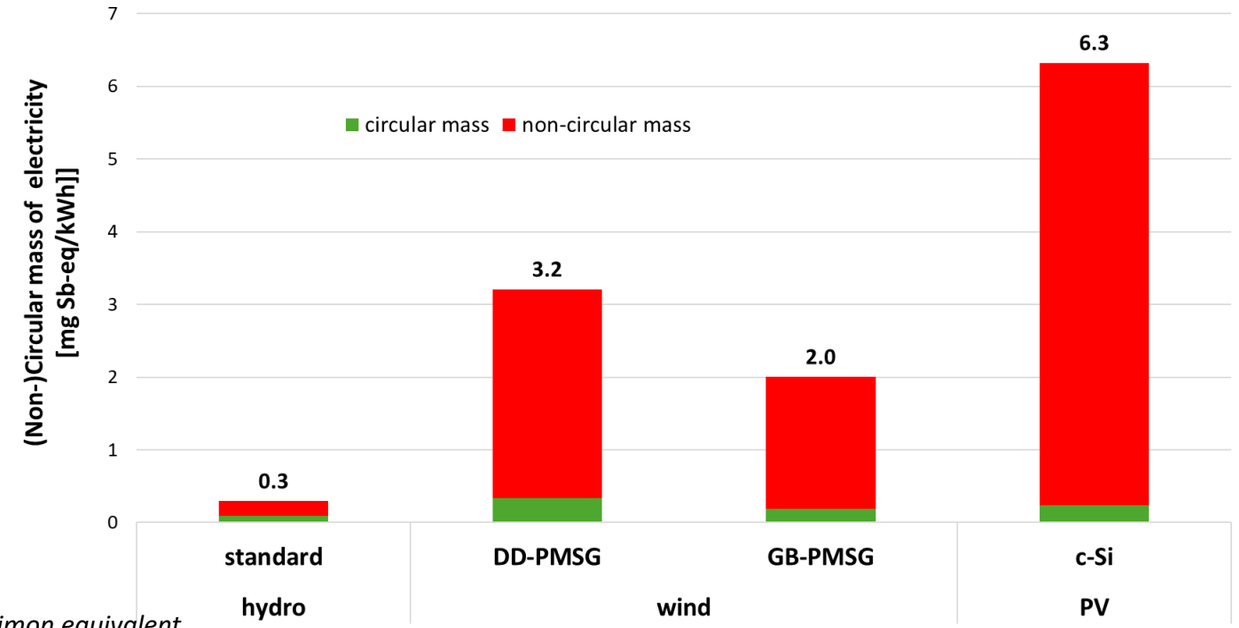
Circularity assessment: Utility Factor of material [h]: lifetime [a] x full load hours [h/a]

- Hydro: 35 x 4,500 = 157,000 h (100%)
- Wind: 20 x 2,200 = 44,000 h (28%)
- PV: 25 x 1,200 = 30,000 h (19%)

Mass



Critical mass

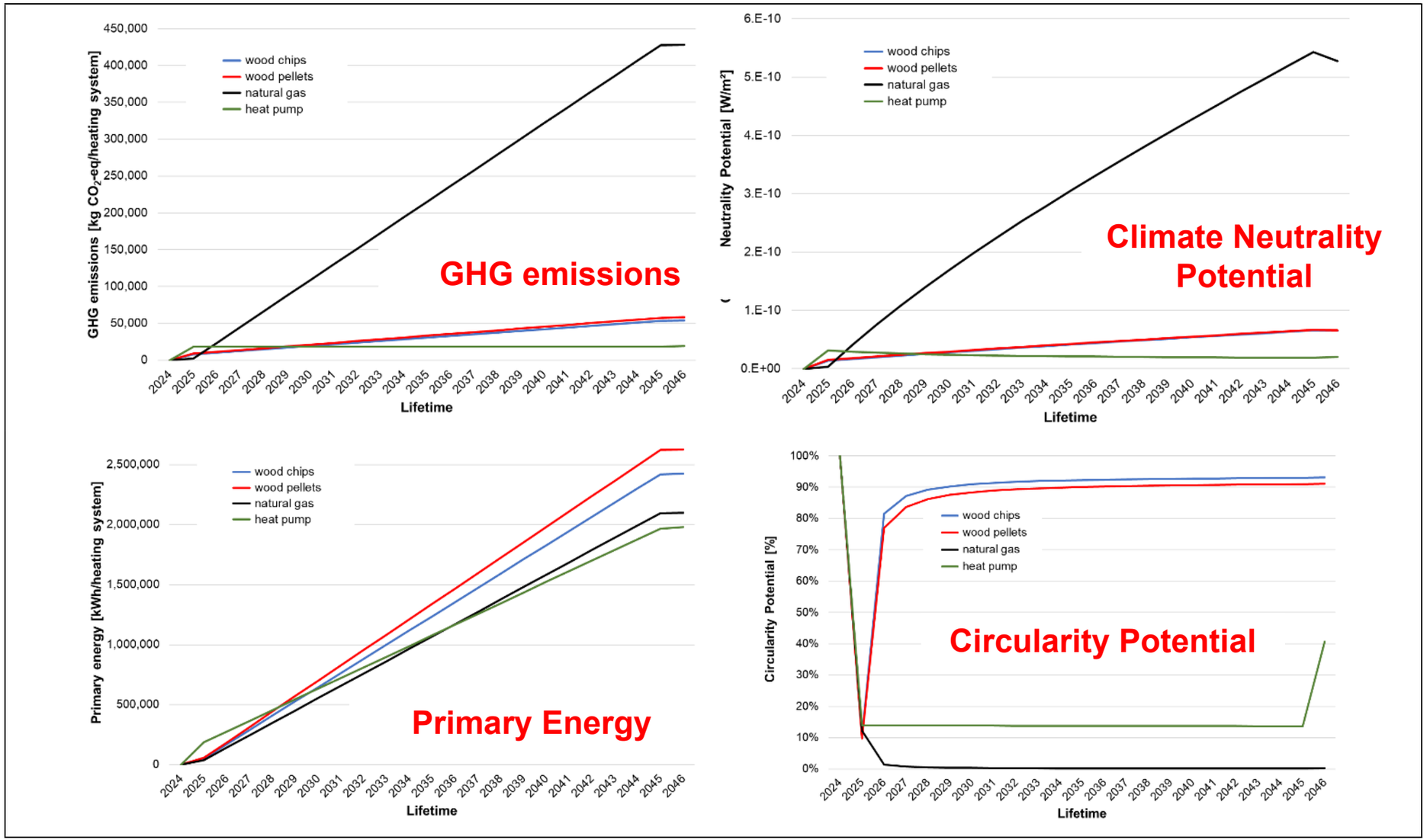


Sb-eq: Antimon equivalent
DD: Direct Drive; G: GearBox
PMSG: Permanent Magnet Synchronous Generator; C-Si: wafer-based crystalline silicon

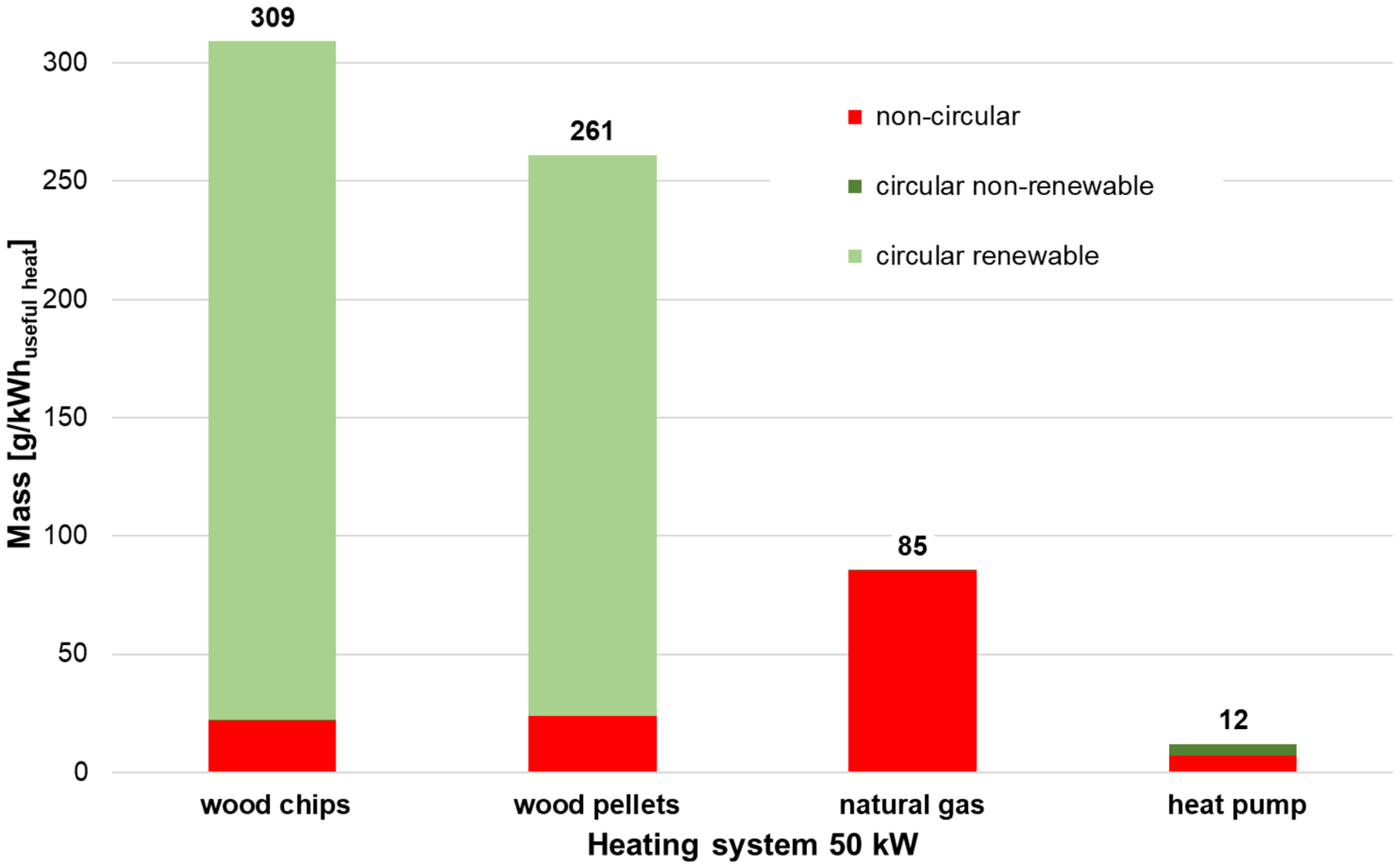
Assessing Heating Systems: GHG Emissions, Climate Neutrality, Primary Energy and Circularity Potential

Heating systems considered

- Wood chips
- Wood pellets
- Natural gas
- Heat pump using ambient air and renewable electricity



Circularity Assessment of Heating Systems: (Non-)Circular Mass per kWh



10 Partners from 9 Countries

- **Austria**: JOANNEUM RESEARCH: Task Manager (Gerfried Jungmeier)
- **Europe:** European Commission (Guido Sacchetto, Saki Gerassis Davite, Anne Bouter, Beatriz Ildefono)
- **Canada**: National Research Council Canada (Miyuru Kannangara)
- **France:** CEA (Anh-Linh Bui Van)
- **Germany**:
  - German Aerospace Center, Institute of Vehicle Concepts, vice Task manager (Stephan Schmid, Simone Ehrenberger, Jonas Peschke, Jannatul Ferdouse)
  - Fraunhofer (Charlotte Joachimsthaler, Jan-Phillipp Jarmer, Tim Hettesheimer)
- **Norway**: Institute of Transport Economics, Transport Technology and Environment Group (Rebecca Thorne, Babak Ebrahimi)
- **Spain**: IREC (Victor Jose Ferreira, Anna Sanchez Ballesta)
- **UK:** Minviro (Costanza Tinari) *tbc*
- **USA**: ARGONNE (Linda Gaines)

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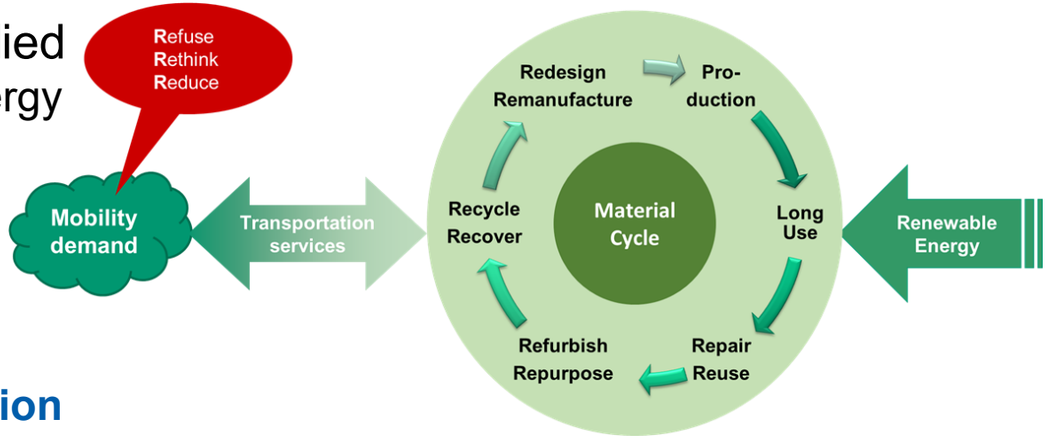

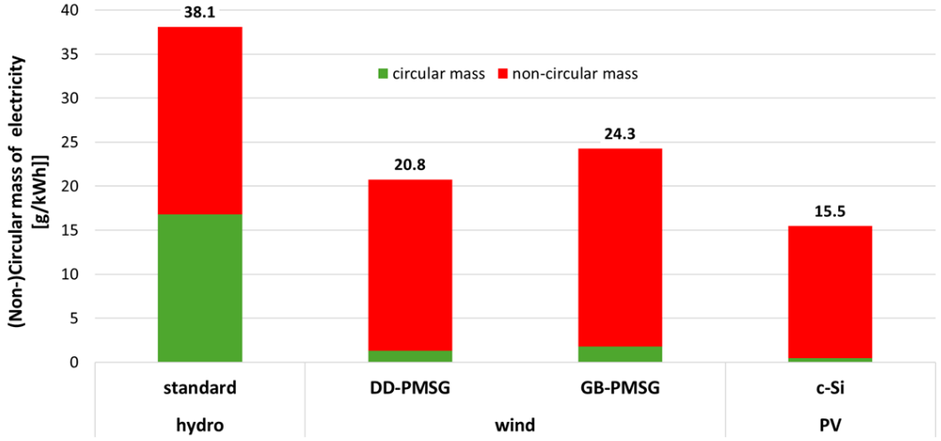

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