wholeSEM Whole Systems Energy Modelling Consortium, '*Hybrid Energy Modelling – Linkages and Interdisciplinarity*', Cambridge, 6-7 July 2015.

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ENVIRONMENTAL FOOTPRINT ANALYSIS AS AN INTEGRATING TOOL FOR EVALUATING THE *ENERGY-LAND-WATER* NEXUS

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THE ENERGY-LAND-WATER 'NEXUS'

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- The **energy-land-water [ELW] nexus:-**
  - Is a set of complex interactions, between energy requirements, land uses and water consumption levels.
  - It gives rise to multiple positive and negative impacts that have recently been widely debated in policy making circles.
- **Energy generation** is obviously the main driver for climate change, whilst there are competing demands on land use [both LUC and iLUC] for both food and biofuel production.
- **Water** is needed for drinking, irrigation, food and biofuel crop production, hydro-electric dams, and various leisure pursuits.
- A strategy which focuses on just one element of the nexus is likely to lead to **major unintended consequences**. Thus, a number of specialists have advocated an **integrated approach** to the modelling of all ELW impacts.

THE ENERGY-LAND-WATER NEXUS – A PICTORIAL REPRESENTATION

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Source: US Roundtable on Science and Technology for Sustainability [The National Academies, 2013].

ENVIRONMENTAL FOOTPRINTING: THE BASICS - 1

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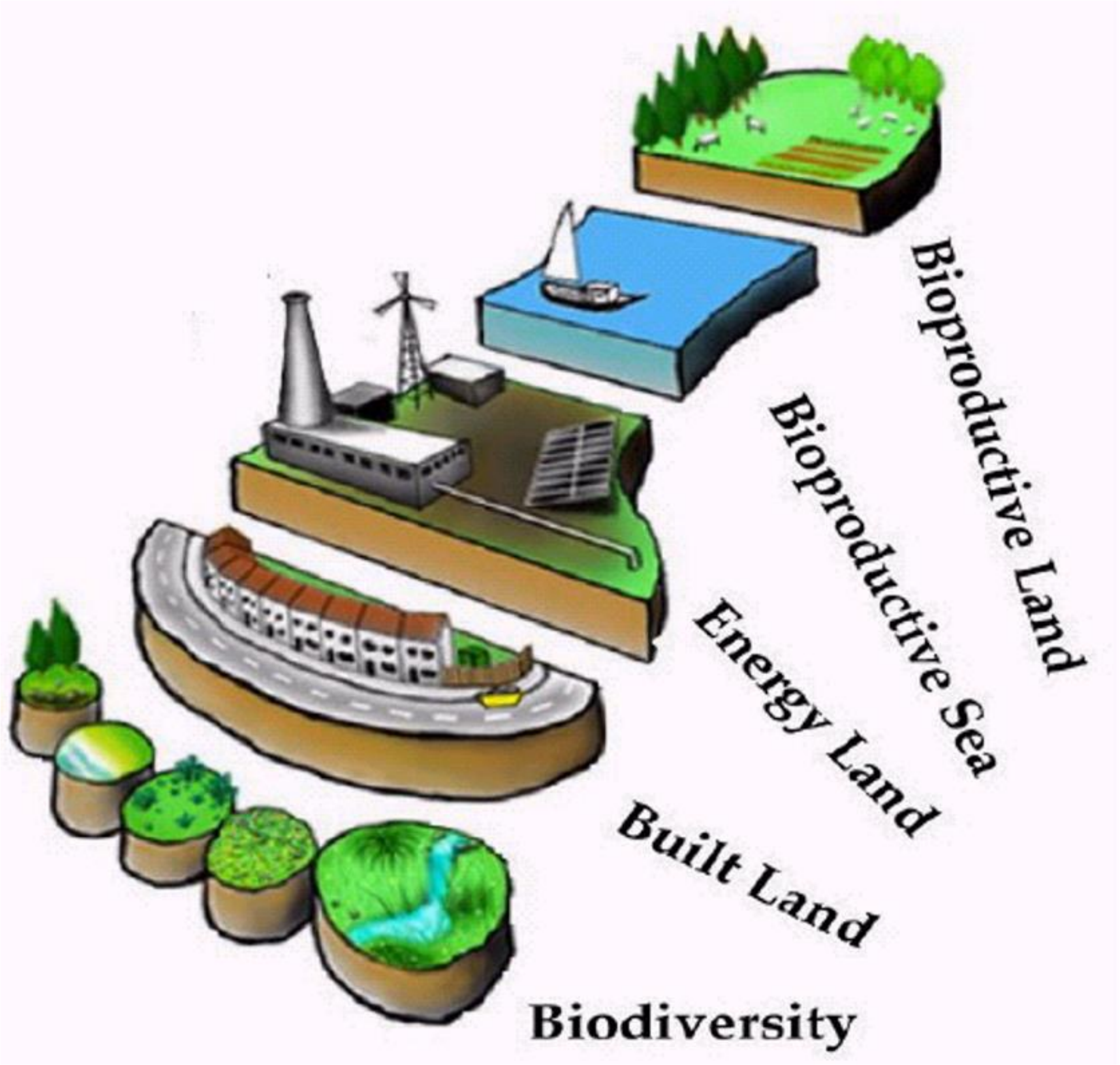
- **Footprint Units: GLOBAL HECTARES (gha)**
  - **Common unit used to standardize footprints worldwide**
- **Equivalence Factors**
  - **Convert land types into global hectares, so that they account for differences in 'bioproductivities'**
- **Biocapacity**
  - **Available bioproductive land**
  - **Measured again in global hectares**
- **Functional Unit: GWh for the related study of electricity or litre of biofuel**

THE ENVIRONMENTAL FOOTPRINT, AND ITS LAND TYPES

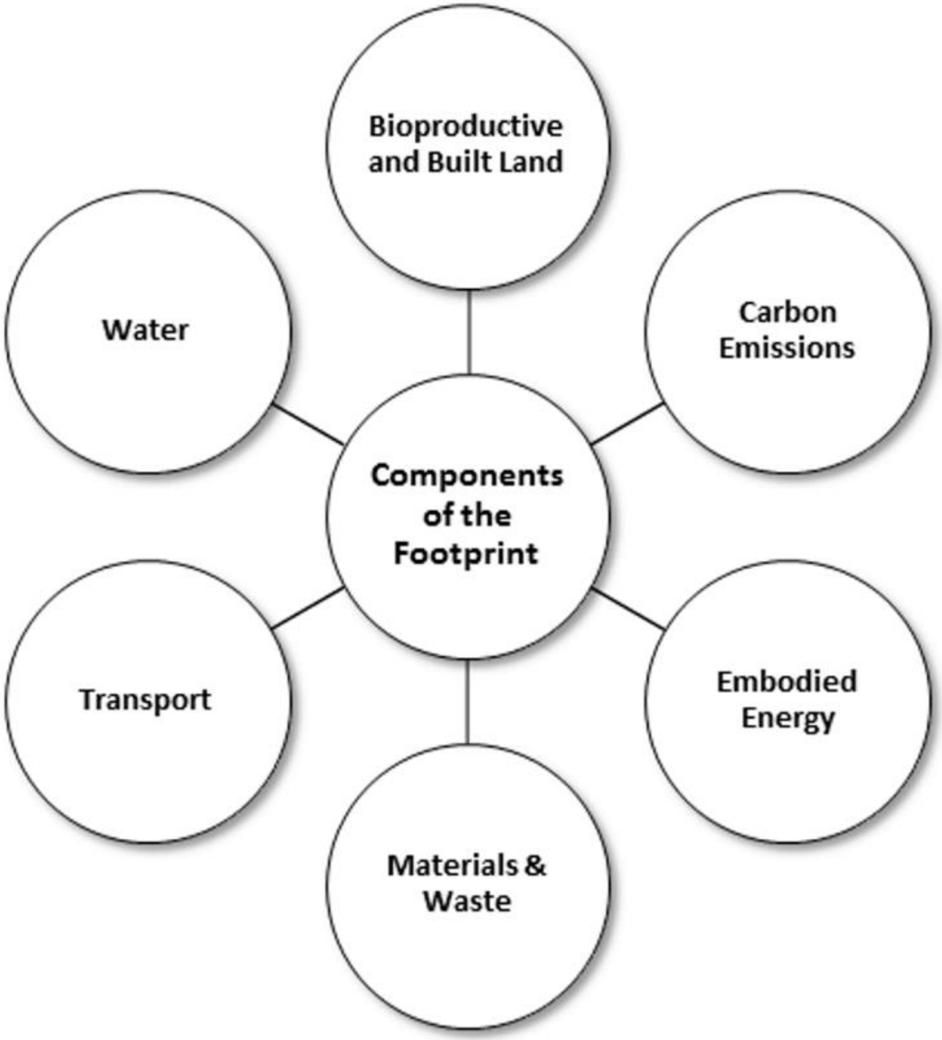


Source: adapted from Chambers, Simmons & Wackernagel, *Sharing Natures Interest*, 2000; and Eaton, Hammond & Laurie*, Landscape and Urban Planning* [2007; **83**(1): 13-28].

ENVIRONMENTAL FOOTPRINTING: THE BASICS - 2

- **The method of calculating the ecological or environmental footprints -**
  - **Estimate resources used and wastes produced within the defined boundary [here for the *UK transition pathways* or *global biofuel production*]**
  - **Snapshot approach – one year, one footprint**
  - **Consumption converted into equivalent land area**
    Area = Resource Consumption (unit) /Average Yield (unit/ha)
  - **Land areas into global hectares (gha)**
    Footprint = Area x Equivalence Factor
  - **Sum components and normalise**

THE COMPONENT-BASED APPROACH TO ENVIRONMENTAL FOOTRINT ANALYSIS



Source: adapted from Eaton, Hammond & Laurie, *Landscape and Urban Planning* [2007; **83**(1): 13-28]; based on the method of Simmons, Lewis & Barrett , *Ecological Economics* [2000; **32** (3): 375-380].

ENVIRONMENTAL FOOTPRINT COMPONENTS ASSOCIATED WITH THE ENERGY SECTOR

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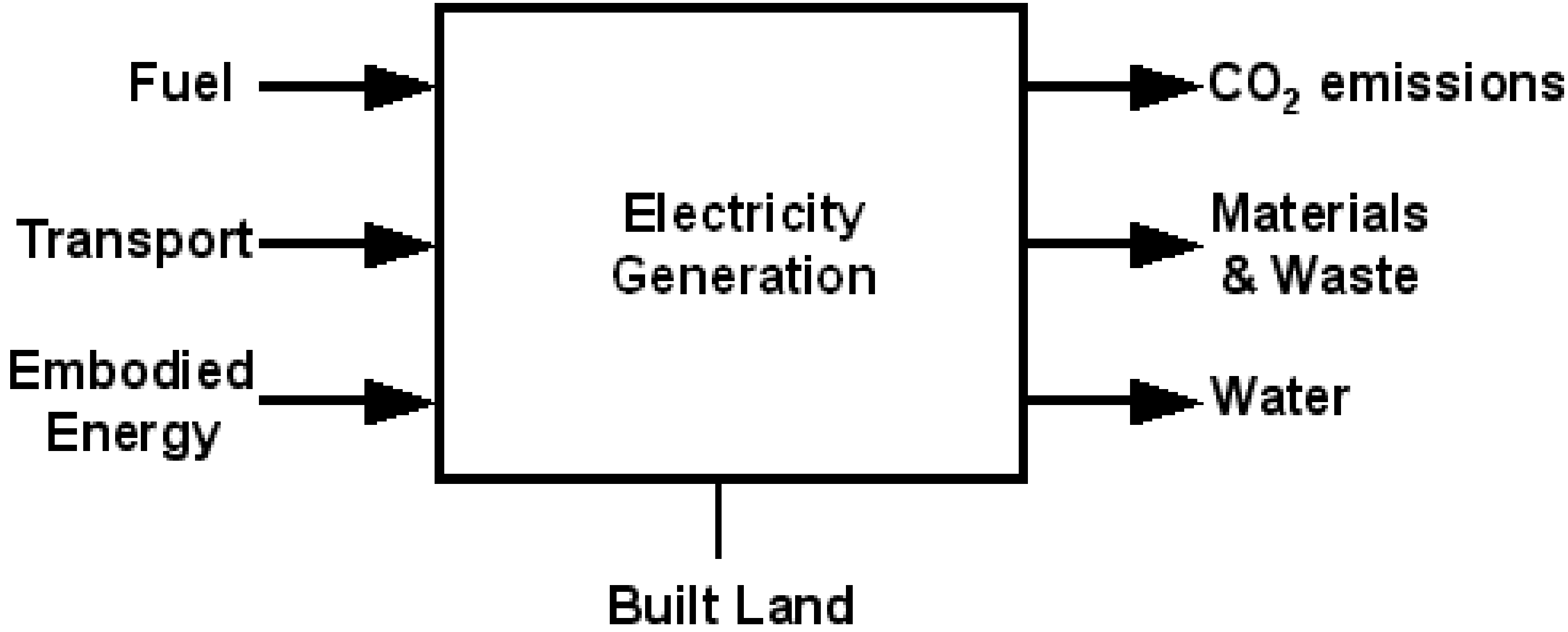
- **BIOPRODUCTIVE AND BUILT LAND:** Land appropriated for energy use.
- **CARBON FOOTPRINT:** The total amount of CO_2 emissions that are directly and indirectly associated with energy use.
- **EMBODIED ENERGY:** The quantity of energy required for processing equipment or to produce primary and secondary energy vectors.
- **MATERIALS AND WASTED:** Material and product use, along with waste arisings, from the energy sector.
- **TRANSPORT:** 'Full fuel cycle' transportation requirements.
- **WATER:** The use of water associated with energy use.

ELECTRICITY SECTOR PHYSICAL INPUTS AND OUTPUTS



Source: Alderson, Cranston & Hammond, *Energy* [2012; **48** (1): 96-107].

ENVIRONMENTAL FOOTPRINTS OF VARIOUS POWER GENERATORS (2010)

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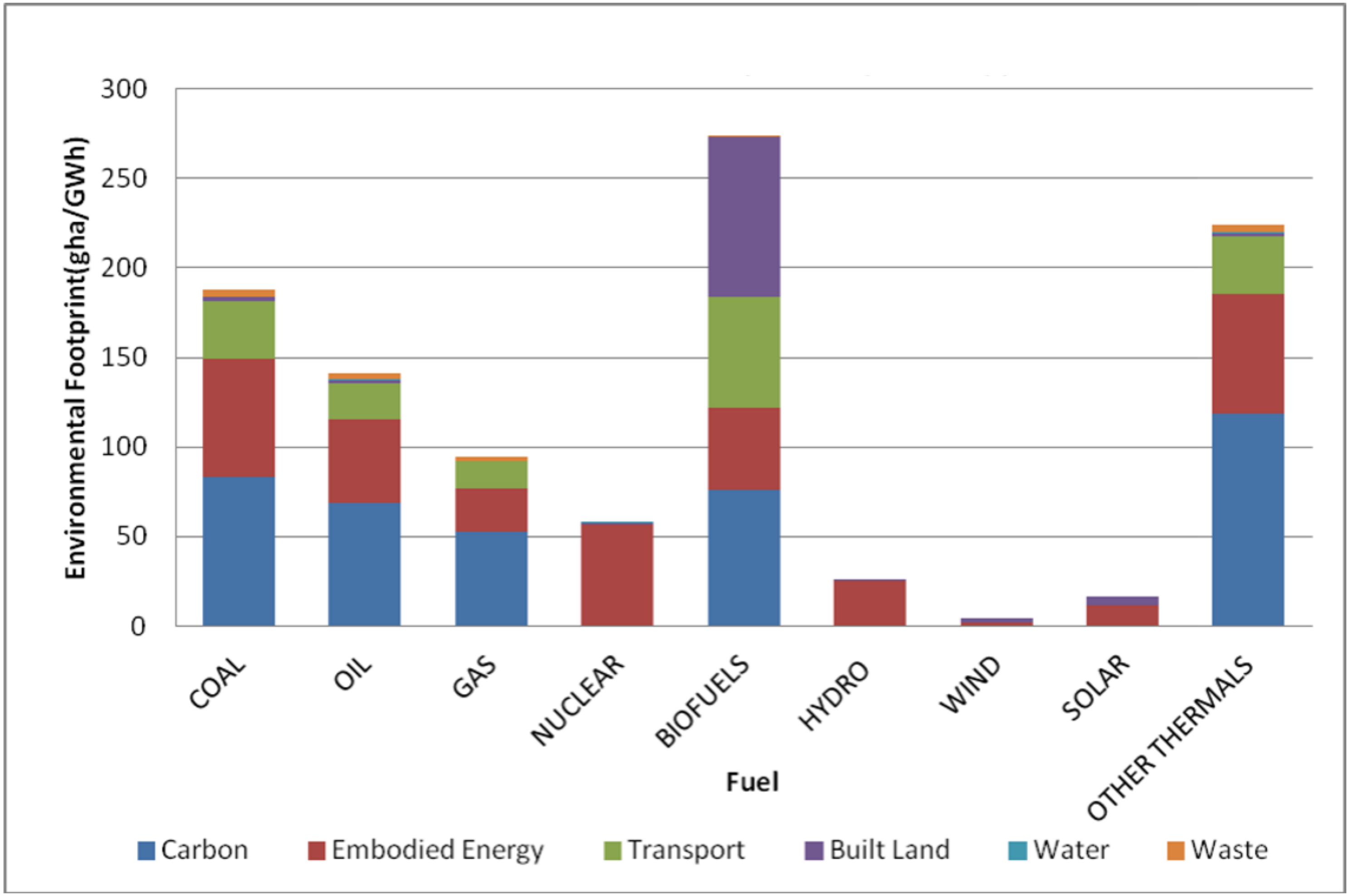
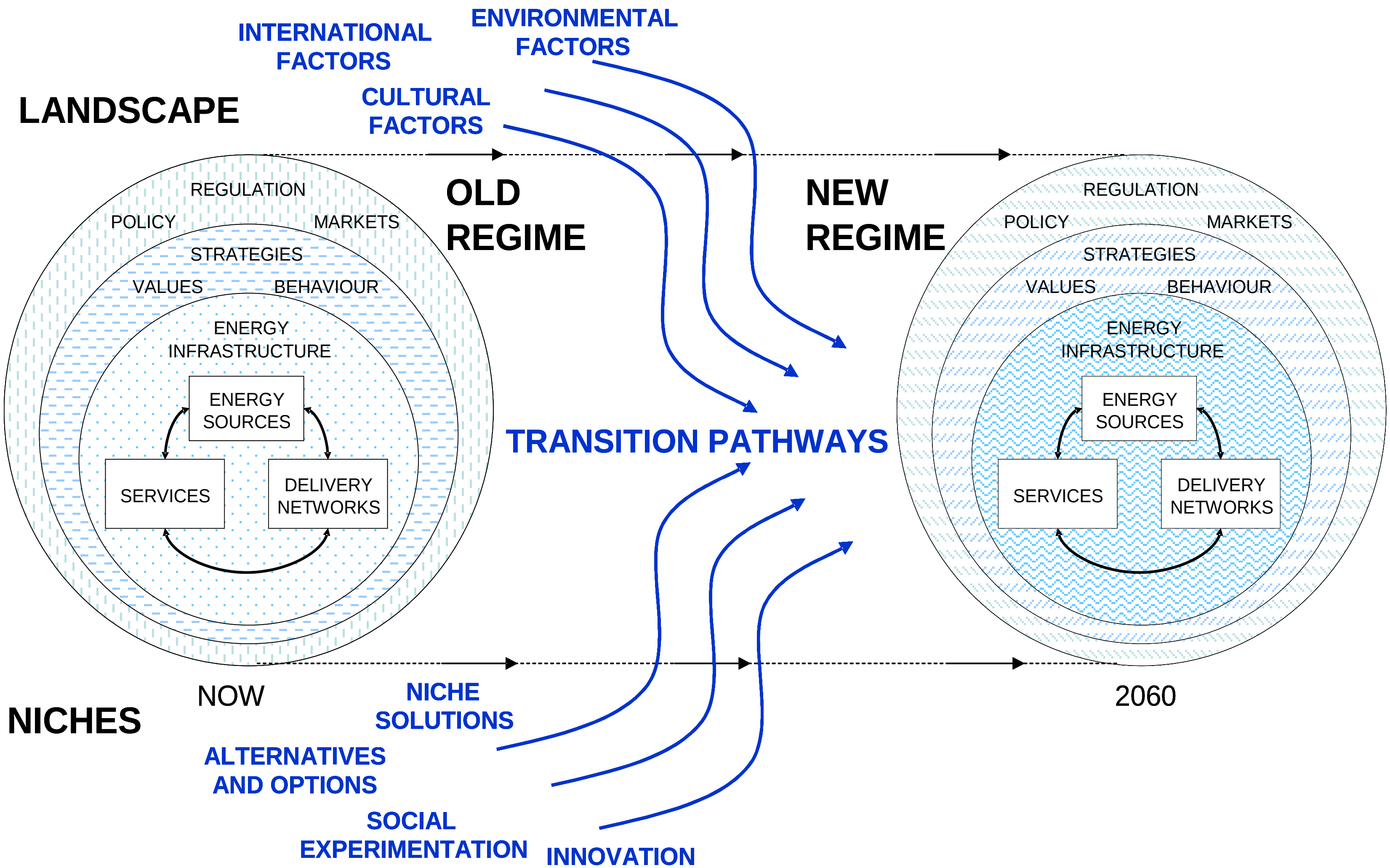


Source: Hammond, Howard & Rana [2015; in review].

TRANSITIONS APPROACH OR 'THEORY'



Source: Foxon, Hammond & Pearson, *Technological Forecasting & Social Change* [2010; **77** (8): 1203-1213].

THREE UK LOW CARBON, MORE ELECTRIC TRANSITION PATHWAYS

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- ***Market Rules (MR) -***

- Energy companies focus on large-scale technologies: nuclear power, offshore wind & capture-ready coal
- Minimal interference in market arrangements

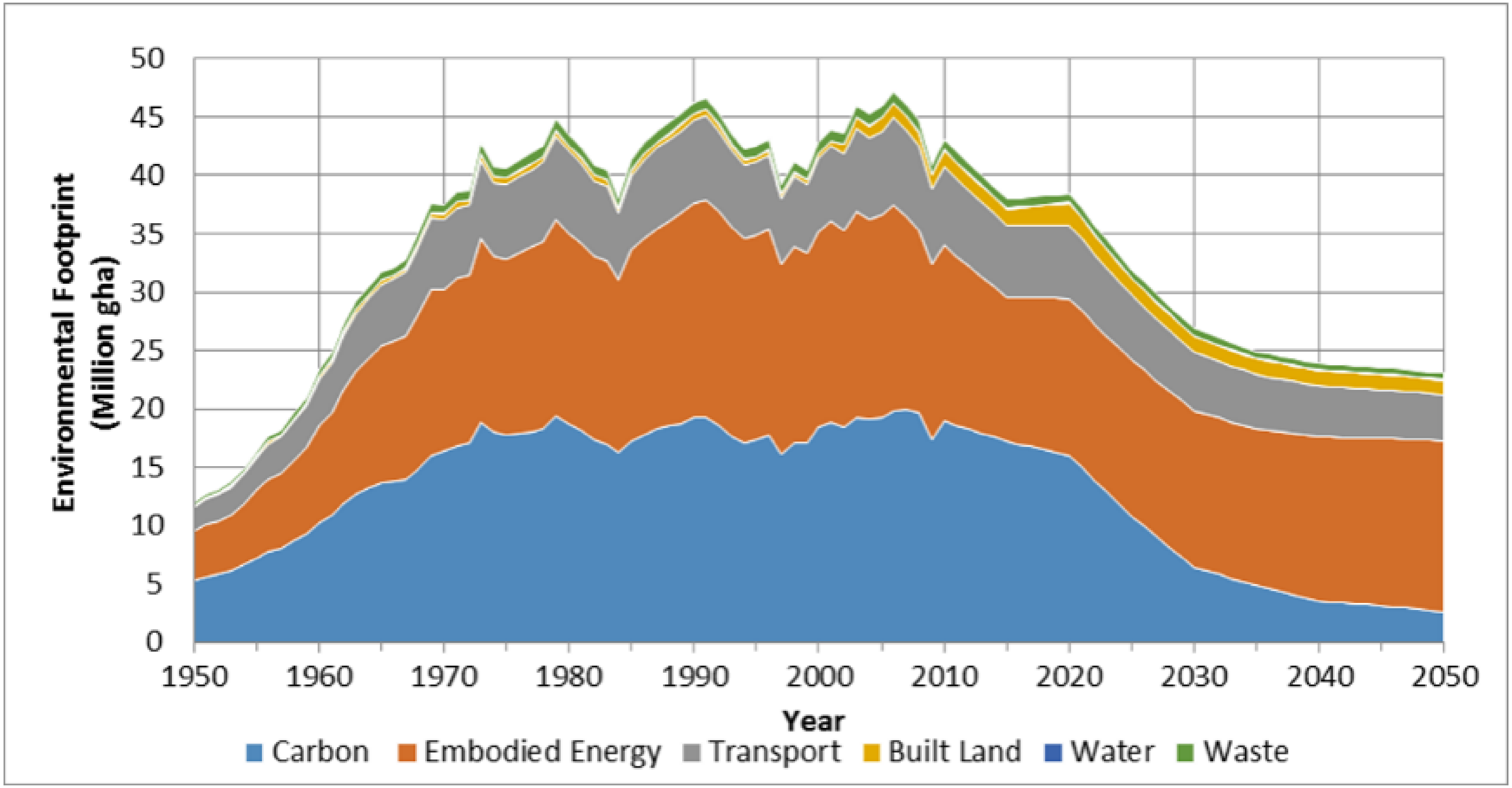
- ***Central Co-ordination (CC) -***

- Greater direct government involvement in governance of energy systems, e.g., issuing tenders for tranches of low-carbon generation
- Focus on centralized generation technologies

- ***Thousand Flowers (TF) -***

- More local, bottom-up diversity of solutions
- Local leadership in decentralized options

TOTAL ENVIRONMENTAL FOOTPRINTS AND ASSOCIATED COMPONENTS OF THE ‘MARKET RULES’ PATHWAY



Source: Hammond, Howard & Rana [2015; in review].

TOTAL ENVIRONMENTAL FOOTPRINTS AND ASSOCIATED COMPONENTS OF THE 'CENTRAL CO-ORDINATION' PATHWAY

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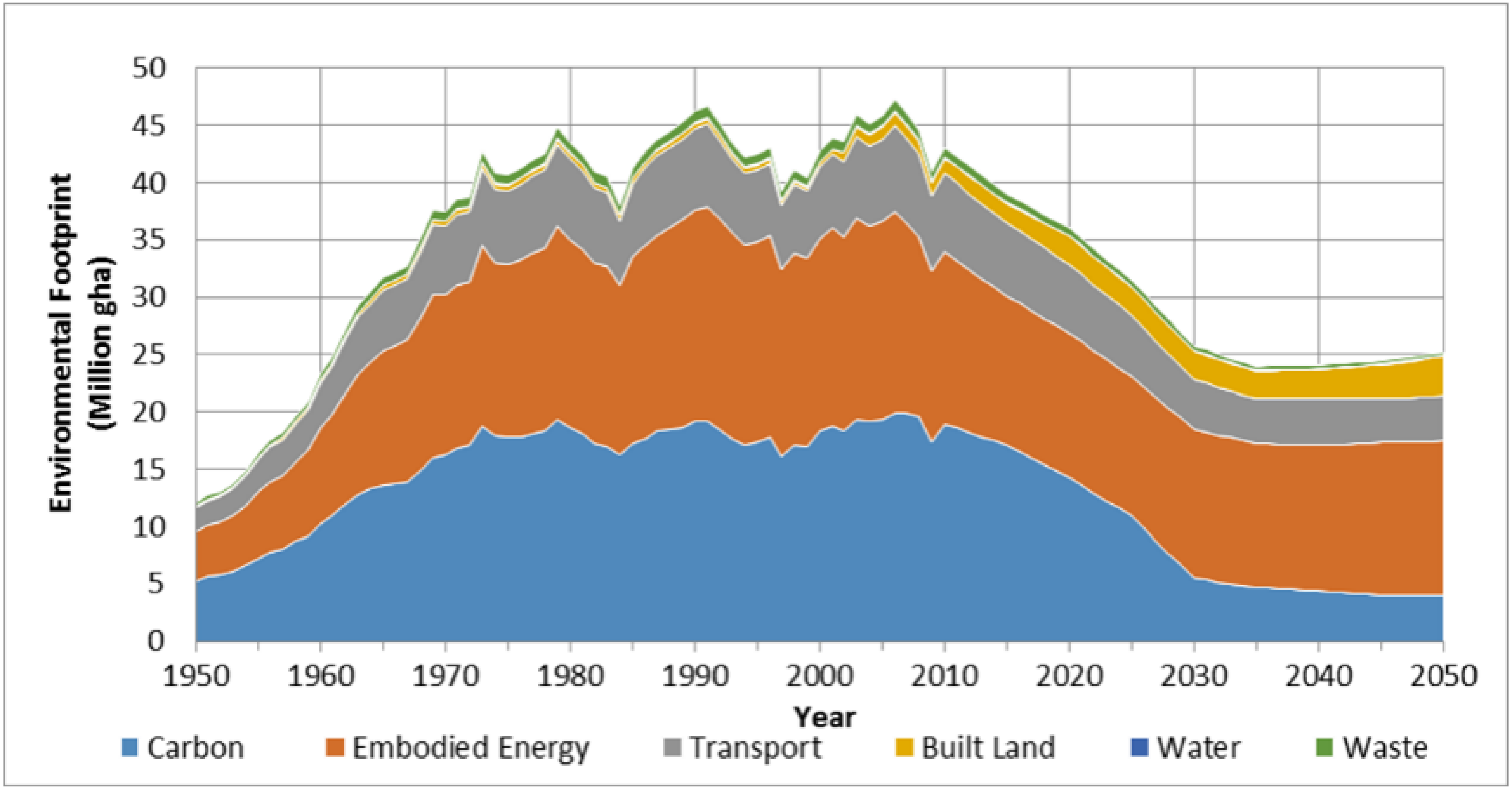
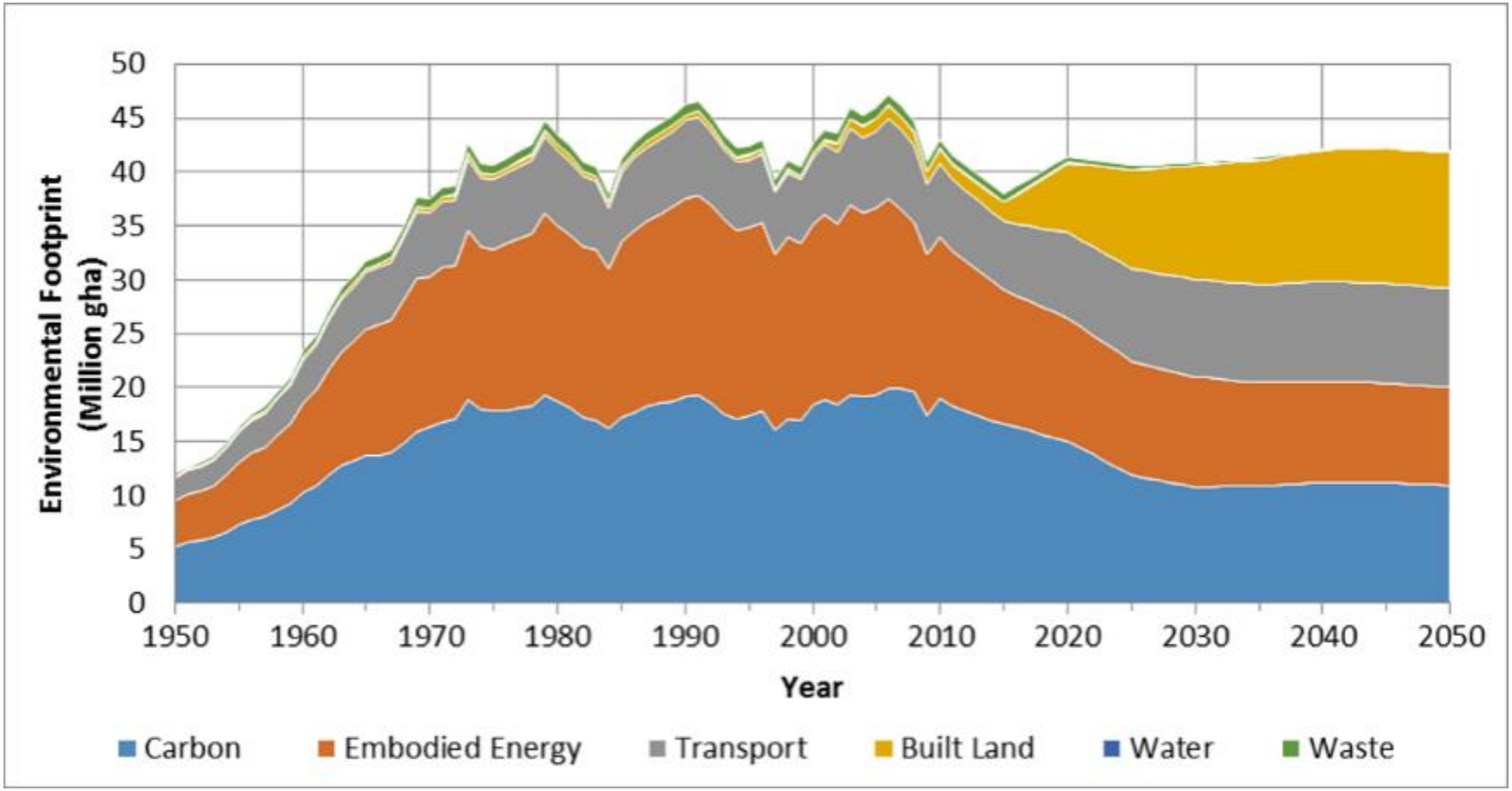


Source: Hammond, Howard & Rana [2015; in review].

TOTAL ENVIRONMENTAL FOOTPRINTS AND ASSOCIATED COMPONENTS OF THE 'THOUSAND FLOWERS' PATHWAY



Source: Hammond, Howard & Rana [2015; in review].

THE ENVIRONMENTAL FOOTPRINT AND ASSOCIATED COMPONENTS OF THE UK ELECTRICITY SECTOR IN 2050 UNDER ALL THREE TRANSITION PATHWAYS.

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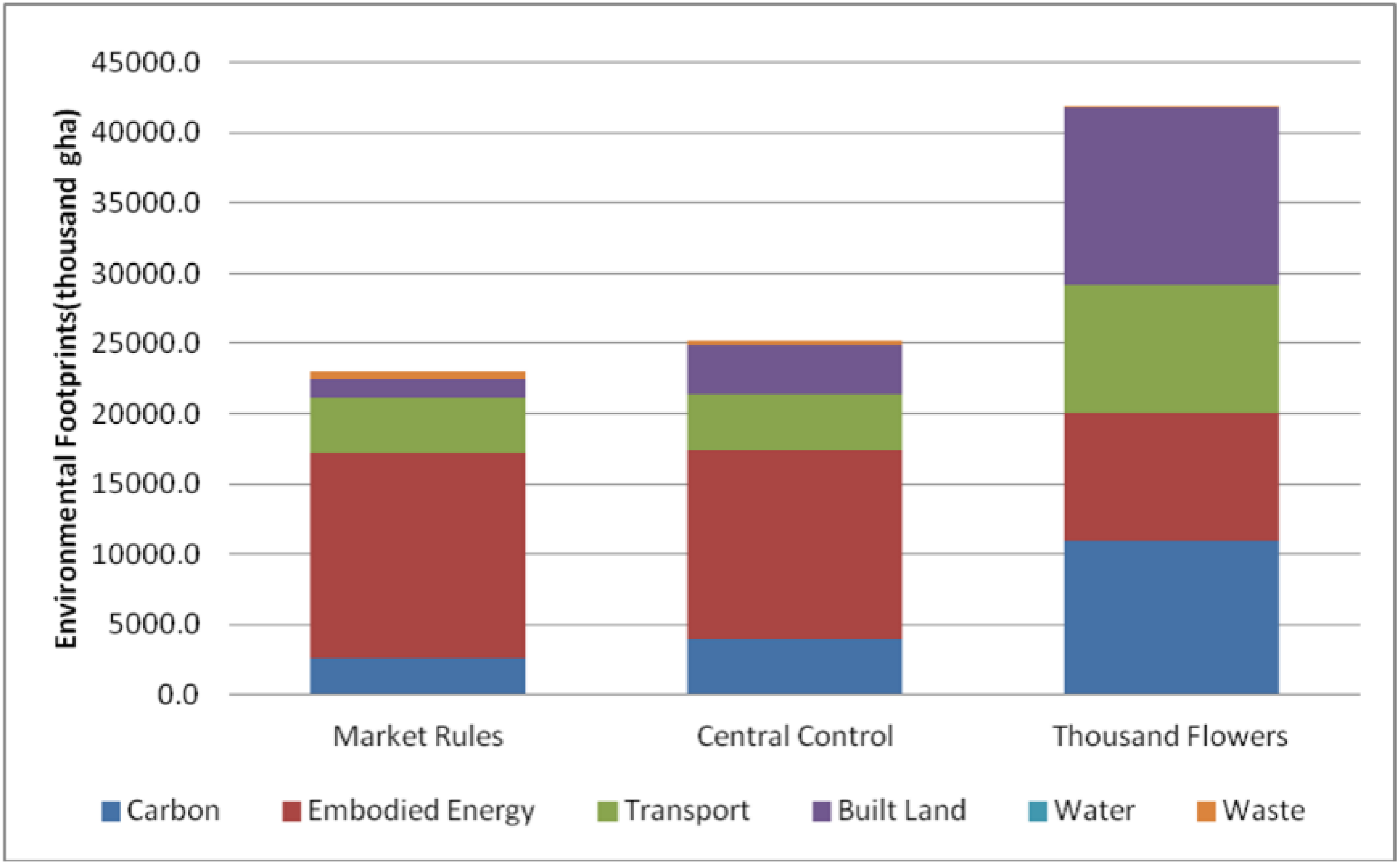
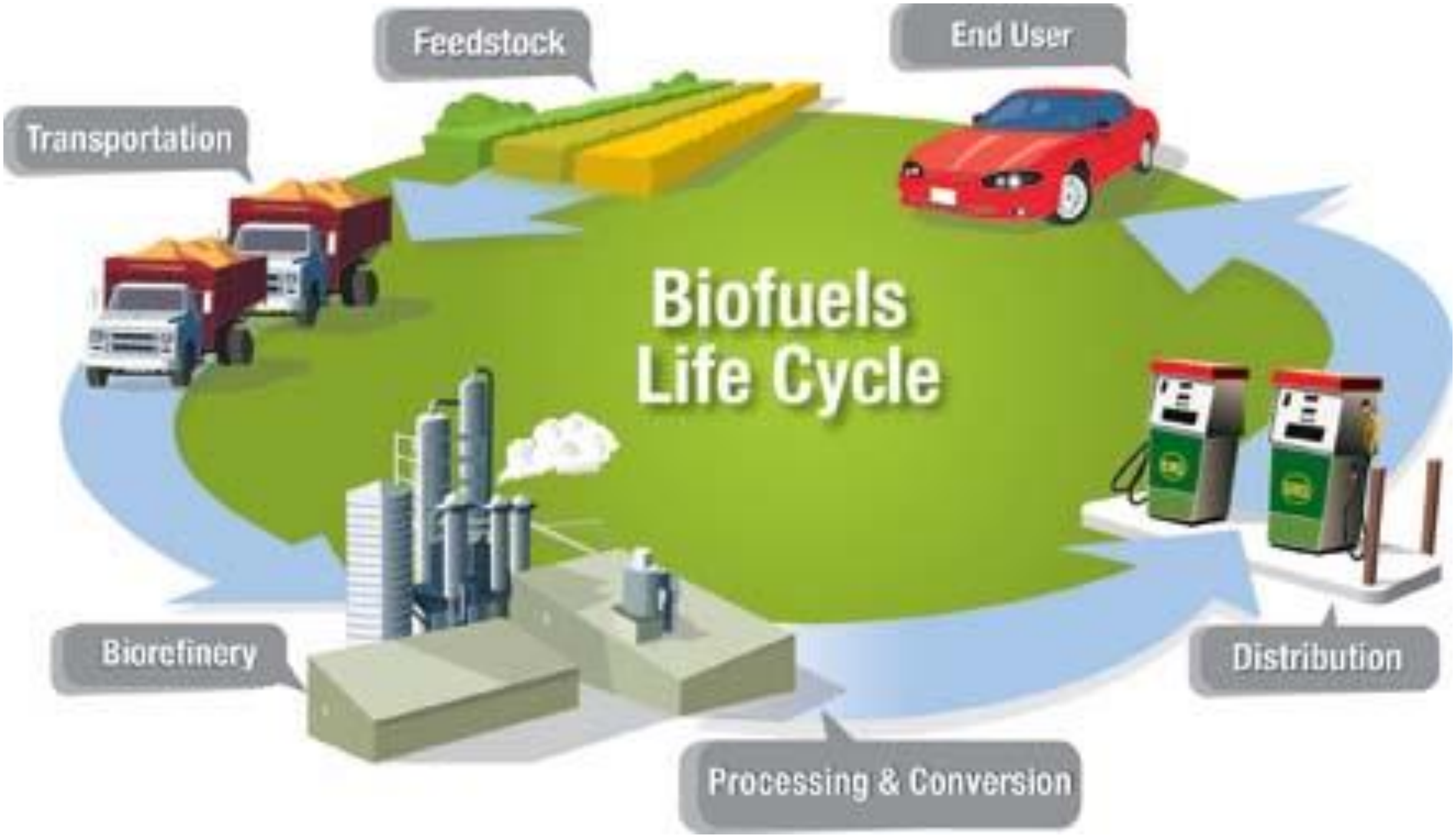


Source: Hammond, Howard & Rana [2015; in review].

THE BIOFUELS LIFE CYCLE



Source: US Department of Energy, Biomass Program, 2012 (http://www1.eere.energy.gov/biomass/).

BIOFUELS, FEEDSTOCKS AND UPSTREAM IMPACTS

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- ***FIRST GENERATION BIOFUELS* (FGB) -**

- Typically produced from food crops, and are limited in terms of achieving oil-product substitution [without threatening food supplies and biodiversity] and in securing ‘greenhouse gas’ (GHG) reductions.

- ***SECOND GENERATION BIOFUELS* (SGB) -**

- Generally produced from agricultural or crop ‘wastes’ (such as straw) and from non-food crops, which significantly reduces negative impacts. SGB can, for example, reduce life-cycle GHG emissions because of their high yields per hectare (ha) and the potential of the remaining material that can be employed as process energy.

- **UPSTREAM IMPACTS –**

- The greatest source of GHG emissions are from the upstream stage of the life-cycle: land-use changes and cultivation, fuel production, feedstock recovery, fertilizer manufacture, and ‘displaced’ emissions .

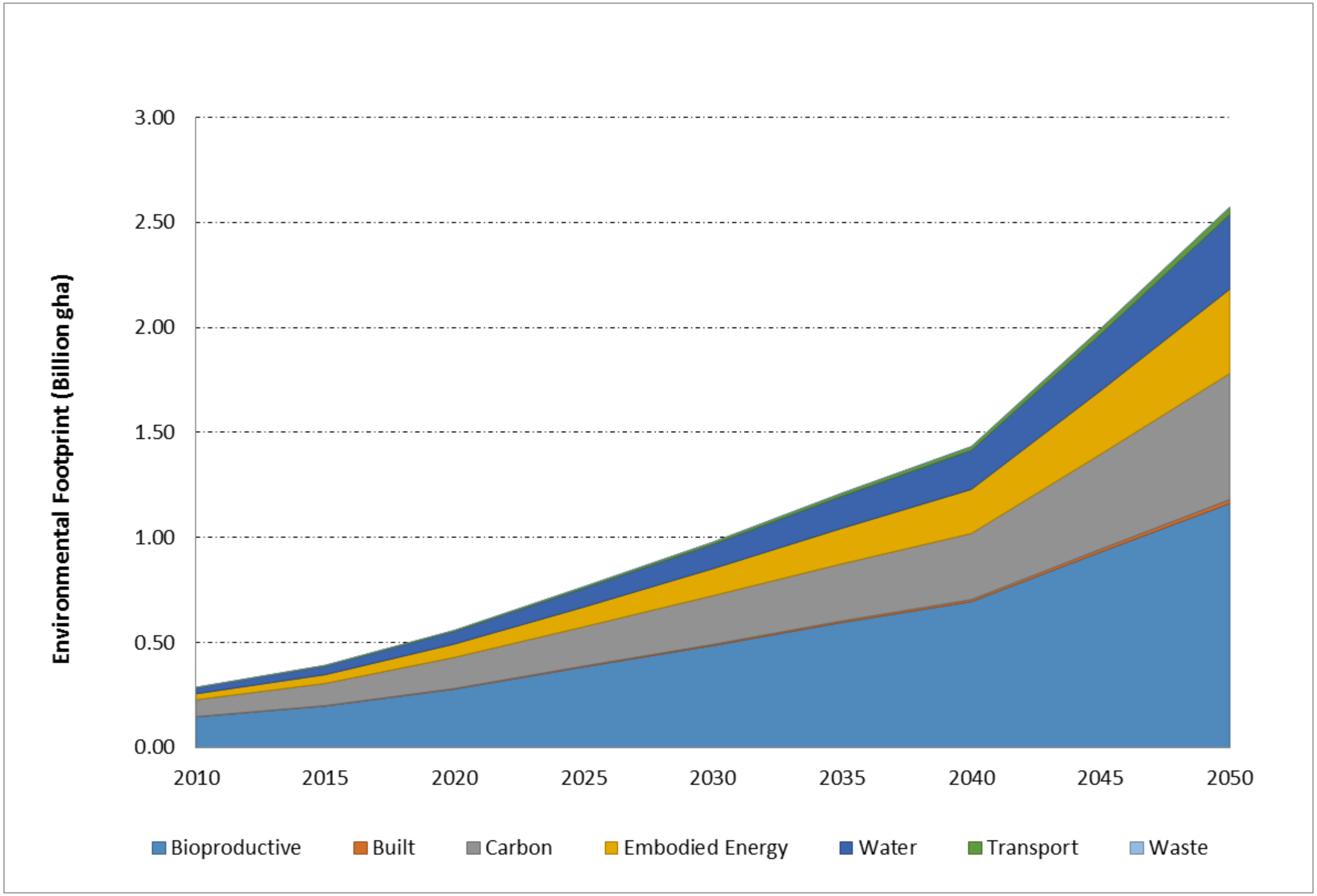
WORLD BIOFUEL PROJECTIONS AND ASSOCIATED FOOTPRINTS OUT TO 2050

- The component-based EFA approach was has been employed to calculate *ef* on an annual basis from 2010-2050 using projections of world biofuel production published by the *International Energy Agency* (IEA) as part of their 2011 'technology roadmap' for transport biofuels.

- The present results account for:-
  - The growing impact of advanced (SGB) biofuels.
  - The water footprint of liquid biofuels; determined using the recent work of Hoekstra and his co-workers (their **blue, green and grey water requirements**).

- The relative shares of the footprint components have been estimated for the different biofuels out to 2050.

ENVIRONMENTAL FOOTPRINTS OF GLOBAL BIOFUEL PRODUCTION TO 2050



Source: Hammond & Li [2015; in review].

CONCLUDING REMARKS – 1: The Power Sector

- Environmental footprinting provides an, albeit imperfect, approach to evaluating **‘*manufactured*’** and **‘*natural capital*’** elements of the **‘*five capitals model of sustainability*’** that arise from the ELW demands of humanity.

- An estimate of the environmental footprint components has been computed for each of all **three UK more electric, low carbon transition pathways to 2050**:-

❖ Water and waste footprint components made almost negligible contributions - with the water footprint having a share of the total environmental footprint (EF) of only ~1%**.**

❖ This is recognised as probably being an **artefact of the EFA methodology** and assumptions adopted.

CONCLUDING REMARKS – 2: Biofuels

- The IEA projection of global biofuel production, together with conversion (or 'equivalence') factors, have been used to determine the footprint components from 2010 to 2050.

- The total water footprint for global biofuel production was found to rise by an *order of magnitude* over 40 years (2010-2050), and will account for around **14% of total environmental footprint by 2050**.

  - Significantly higher contributions emanated from **bioproductive land use and carbon emissions** (45% and 23% respectively).
  - **Advanced (SGB) biofuels result in just half the water footprint of FGB**, because only 50% of the SGB feedstocks were obtained from waste and residues.

- Effective ways of **reducing the water footprint** associated with world biofuel production out to 2050 include (i) advanced biofuels from wastes and residues, (ii) the planting of crops that require only a minimal amount of fertilizer, and (iii) the promotion of rain-fed biofuel feedstocks.

END OF PRESENTATION

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ANY QUESTIONS?