7.2 Manufacture, Use, and Disposal of Electronic Systems in the Circular Economy

The greatest technical challenge posed by the circular economy is to develop environmentally compliant systems with the following characteristics:

- Waste is practically eliminated altogether during manufacture, usage, and disposal,
- Materials used in the products are almost completely recycled after usage.

The standards and criteria applicable to the circular economy also apply to the entire life cycle of an electronic system: to the manufacturing steps, to system operation and use, and to its disposal. The three relevant recycling loops for industrial waste, product, and material recycling are depicted in Fig. 7.4.

The manufacturing phase that is comprised of material processing and fabrication forms the *production waste recycling* loop (I). Industrial waste materials are fed back into, and reused in, the same production process. Because of the extensive use of chemical processes, every effort should be made during electronic assembly to deploy technologies that generate little or no waste. The aim here is to put in place closed manufacturing processes. As these issues are more in the realm of production and assembly than in the realm of electronic systems design, production waste recycling will not be dealt with further below.

There is typically no waste produced during the period of electronic system operation, so that there is no need for a recycling loop associated with system usage. That said, any ensuing waste material, such as data storage devices, should be integrated in higher level recycling loops. Energy losses during system operation and use, in the form of electromagnetic radiation and power consumption, for example, should be considered during design and development. Obviously, it is wise to design systems for minimum energy consumption. This includes the power consumed in standby mode. Here, for example, one energy-saving option is to have

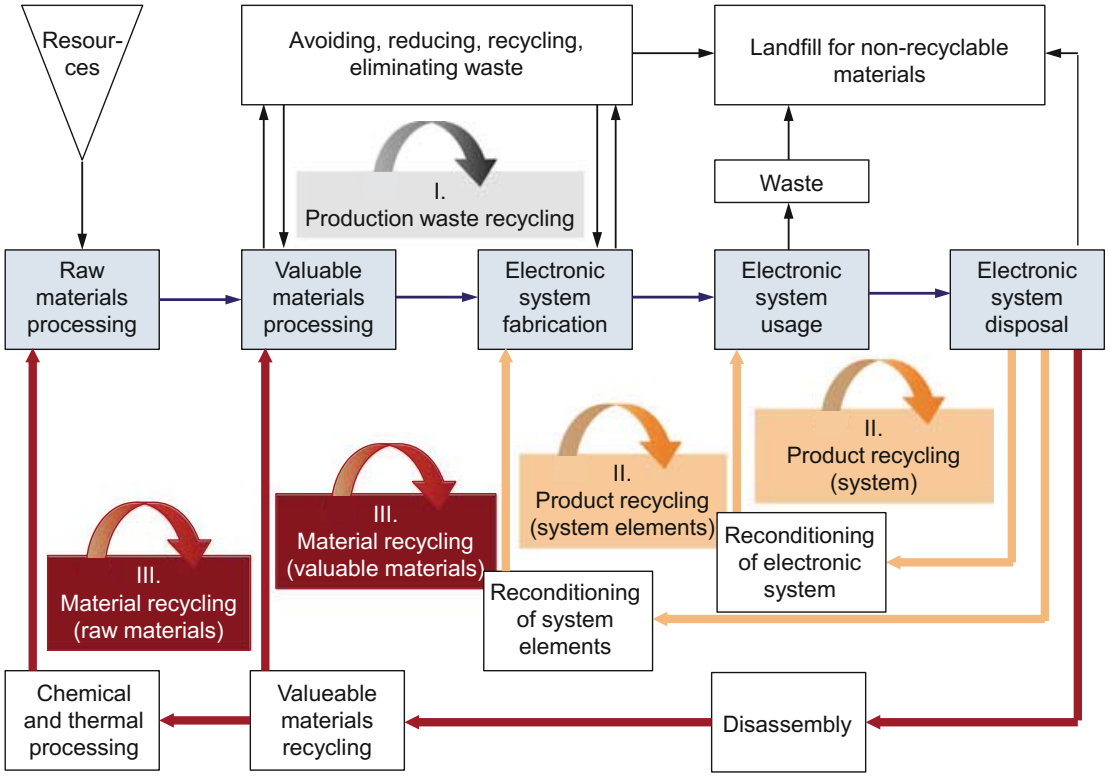

Fig. 7.4 Recycling loops for manufacture (production waste recycling) and disposal (product and material recycling) that electronic system design should aim for [3]

a power switch, which is easily accessible, and which allows the user to disconnect the system completely from the power source.

The system disposal process requires two recycling loops: *product recycling* (II) and *material recycling* (III).

The product (for product recycling at the system level) or product parts (for product recycling at the element level) are reused in the *product recycling* phase. This happens in one of two ways: (1) the product is used retaining the product functionality (reuse) or (2) the product continues to be used but with altered functionality (further use). The product design is unmodified, or only slightly modified, in both scenarios.

Product disassembly requires *material recycling*. Here, product materials are recovered and recycled in the material recycling loop. The materials are processed so they can flow back into the production process as valuable materials (valuable material recycling) for a similar (internal recycling) or different manufacturing process (further use). Alternatively, one can deconstruct them into raw materials in chemical and thermal processes and recycle them in a raw materials processing step (raw materials recycling).

Finally, we would like to point out that these recycling loops are supported by the maintenance operations covered in Chap. 4 (Fig. 7.5). While maintenance prolongs the life span of an electronic system (durability, see Sect. 7.3.2), recycling loops enable additional life cycles beyond the initial product. Both activities, while not always separable, are complementary and crucial in promoting ecological usage and disposal of electronic systems in a circular economy.