Series Editor
Jean-Charles Pomerol

Process Engineering Renewal 2

Research

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Color Section

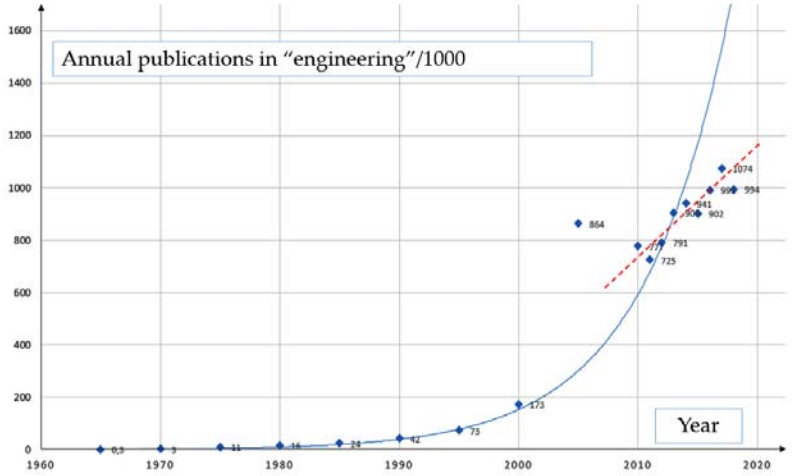


Figure I.1. *Evolution of the number of publications in the field of engineering (source: CNRS). The continuous curve in blue corresponds to an evolution respecting an exponential evolution; the red dotted line corresponds to a more modest increase obtained in recent years.*

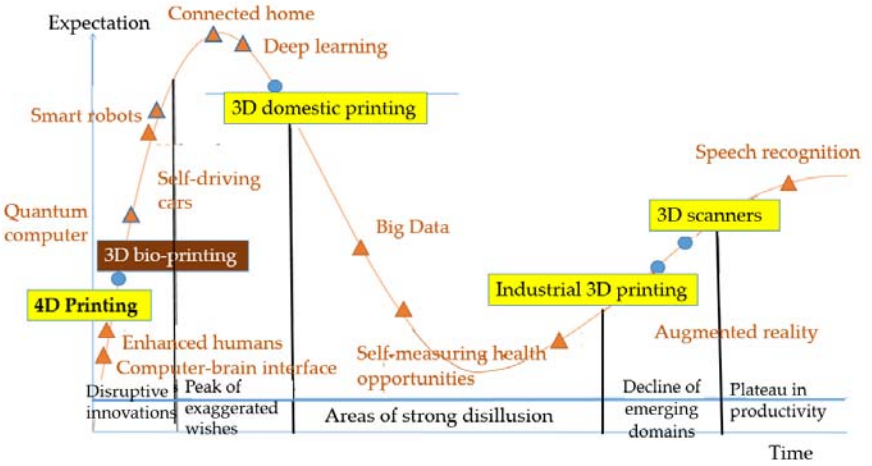


Figure 1.1. *Emerging technologies (with a specific focus on additive manufacturing).*

Figure 1.2. *Industry 4.0 (source: Audéoud 2017).*

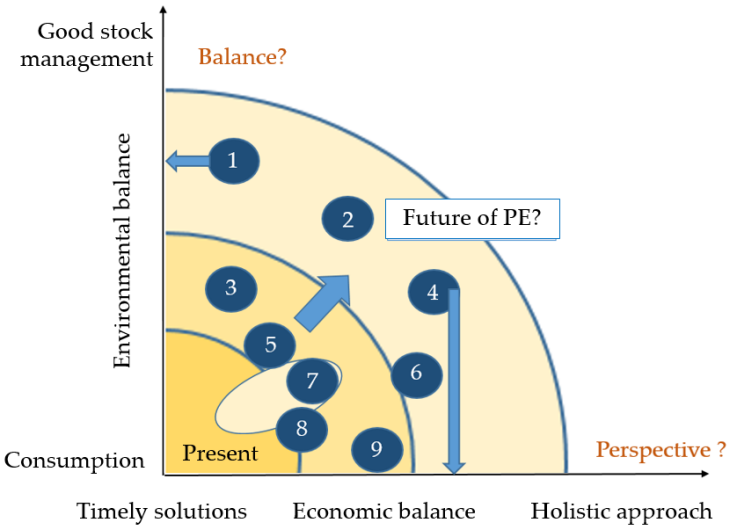


Figure 1.5. *Positioning of economic and ecological activities in the future of process engineering activities with two strategic directions.*

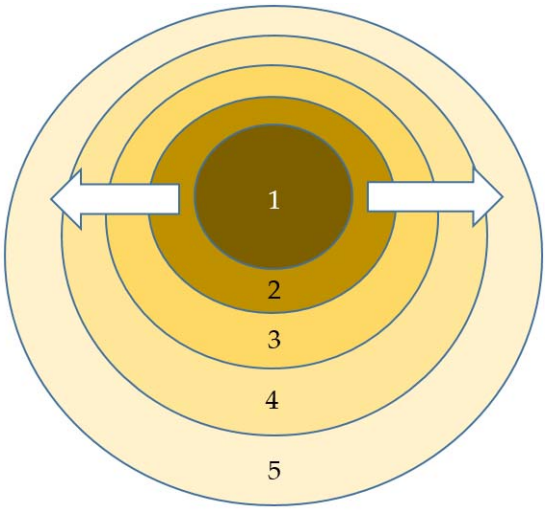


Figure 1.8. *The onion model in process engineering.*

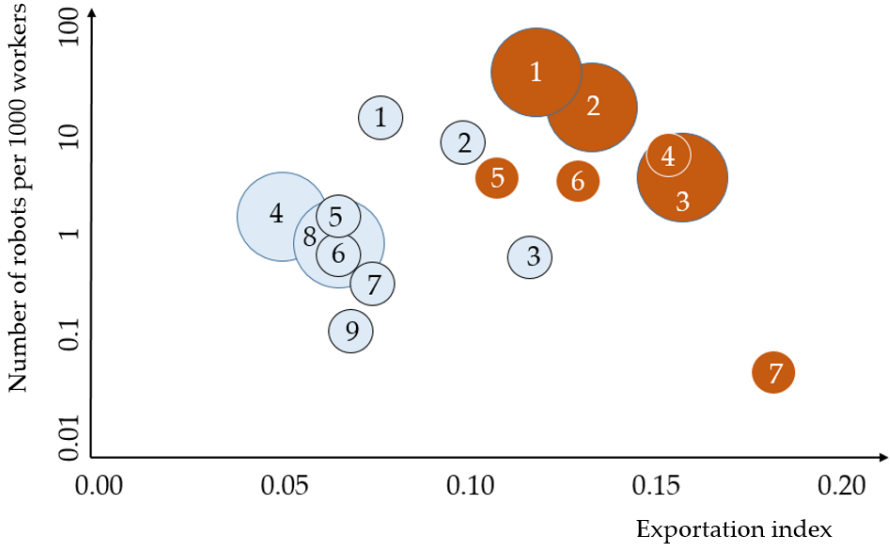


Figure 1.9. *Example of PE association with automation-robotization.*

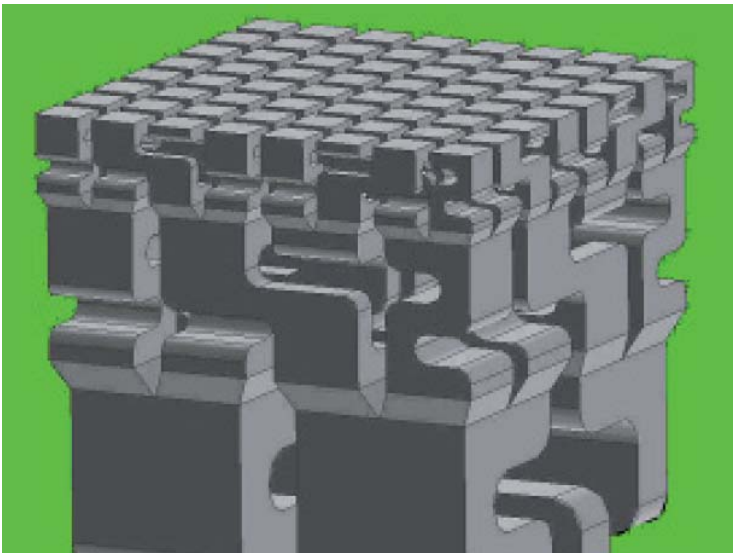


Figure 2.3. *Principle of a mixer using divided and interlaced channels (Baker's problem) (with Laurent Falk's agreement).*

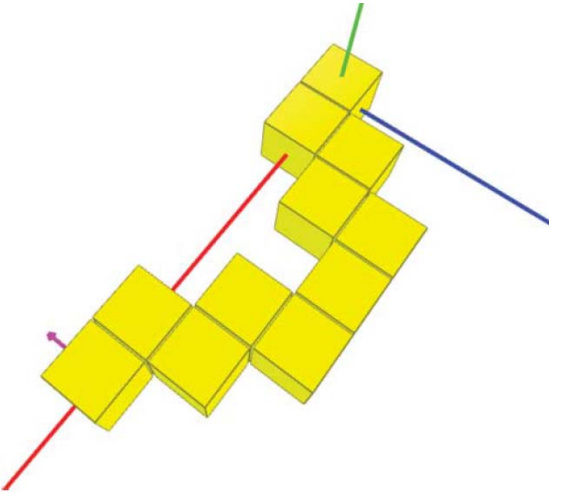


Figure 2.5. *Voxel construction.*

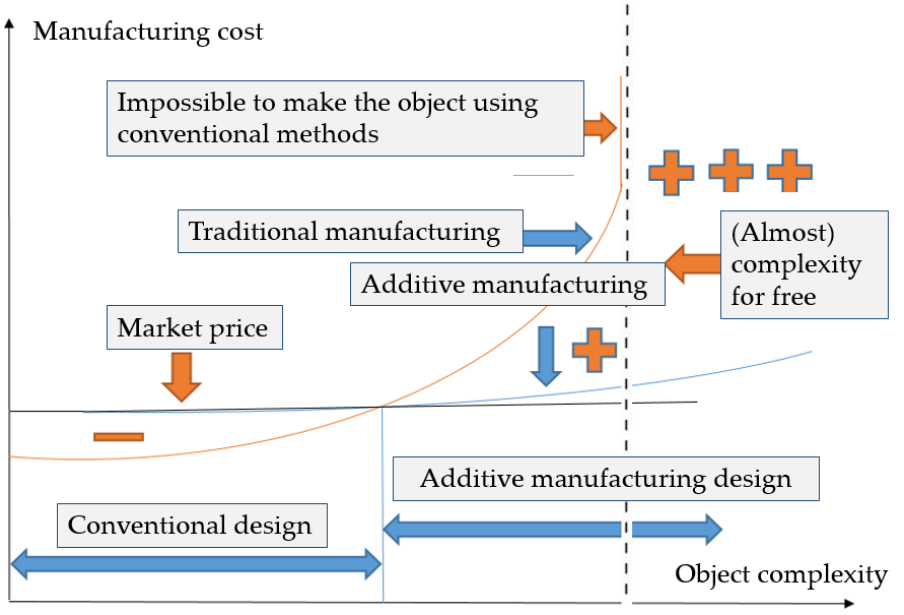


Figure 2.7. *Interests and limitations of 3D printing in relation to the design of an object (the sign - represents the domain that is advantageous for traditional design, the + for additive manufacturing design, which becomes +++ when the object is not achievable by conventional methods).*

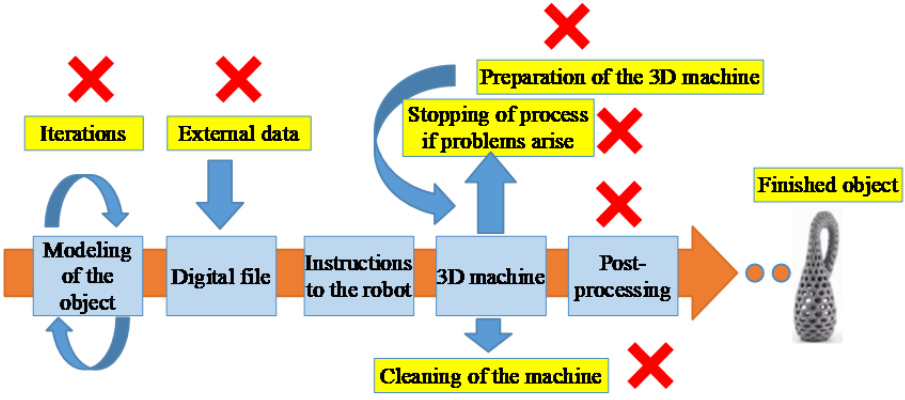


Figure 2.9. *Steps in the manufacture of an object by additive manufacturing (red cross: current human intervention in the process).*

Figure 2.10. *Heat exchanger made in additive manufacturing.*

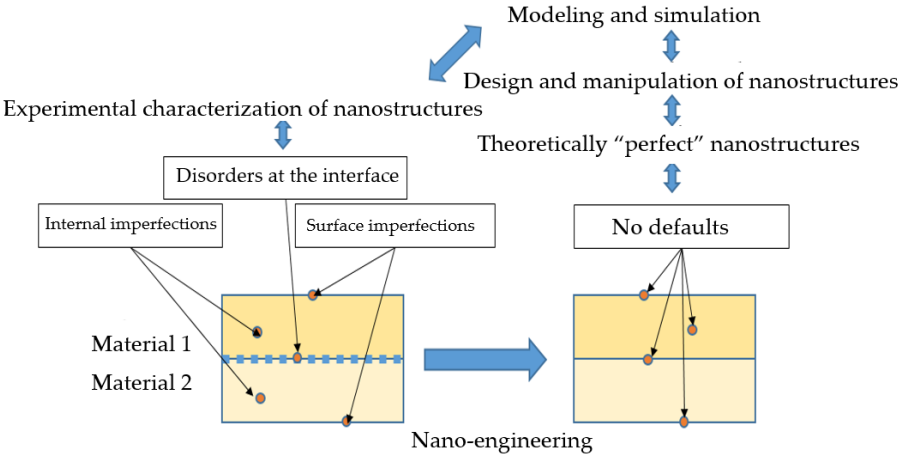


Figure 2.11. *An example of the place of PE between basic sciences and application.*

Automotive sector	Electronics	Food	Textile and clothing
Short-term recycling	"Green" electronic equipment	Precision agriculture	Precision agriculture
Materials of biological origin	Automatic disassembly	High-tech bio-farms	Biofabricated leather (bio-printing)
Robotic assembly and disassembly	Manufacturing 4.0 of the equipment	Use of the genome	New natural fibers
Cobotics	"Green" packaging	Agriculture 5.0	Cultivation of genetically modified fibers
3D metal printing	Traceability of the minerals used	Bio-printing and other cellular engineering methods	Advanced organic waste treatment
Blockchain	Automated design	Automated agriculture	High-tech bio-farm
Augmented workers	3D electronics	Advanced wastewater treatment	Bio-polyester
Connected systems	Towards fully robotized factories	Distribution chain: traceability and control	Recycled textiles
Connected storage		"Vertical" closing	Blockchain adapted to fashion
		Food printed in 3D	Clothing manufacturing 4.0
		New packaging	Automated seam assemblies
Interest in/by PE			Use of nanotechnologies

Table 3.1. *Opportunities in terms of processes offered by digital technology (in brick red: interest for PE in the form of a disruption; in light blue: incremental innovation; in light green: possible openings).*

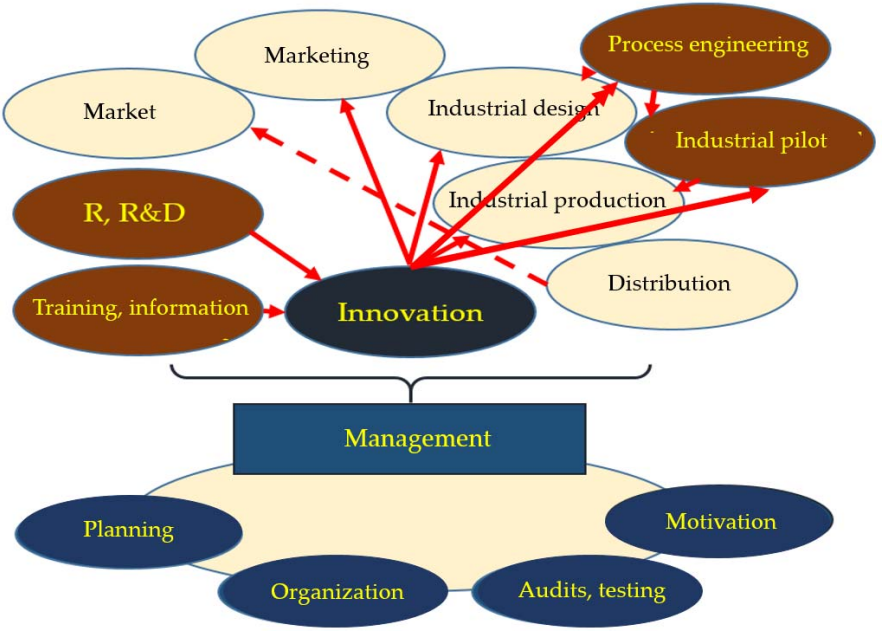


Figure 3.12. *Relationships between different skills before reaching the market (in yellow on a brown background, the areas where PE is involved). For a color version of this table, see www.iste.co.uk/schaer/process2.zip*

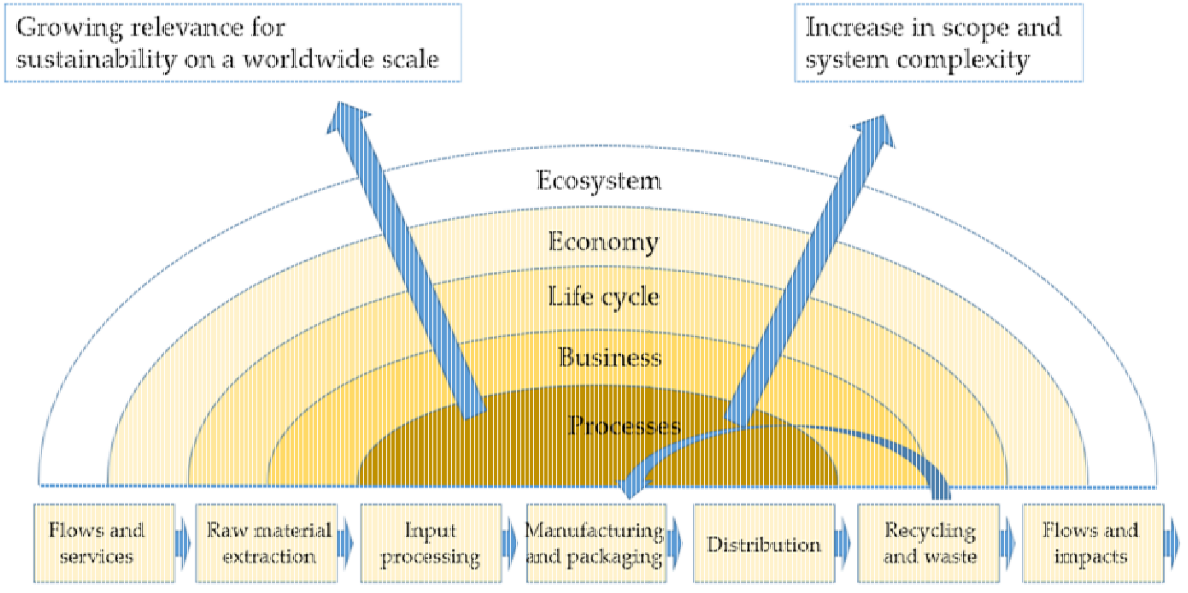


Figure 4.7. Sustainable development and process engineering.

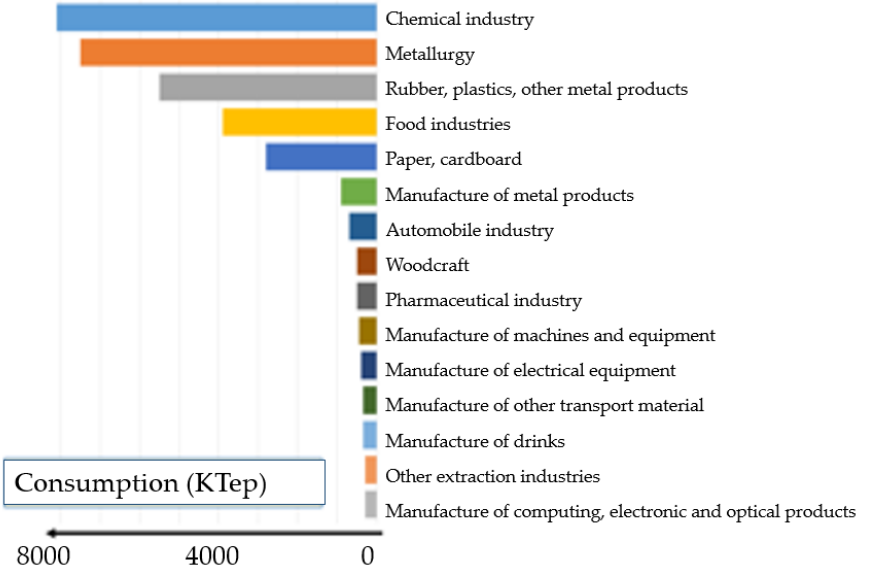
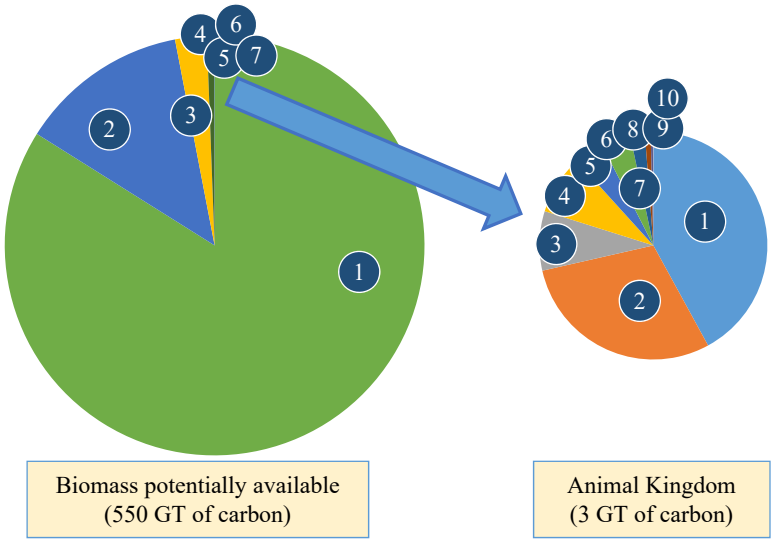


Figure 4.10. *Annual energy consumption of the process industries (KTep).*

a)



b)

Additions:	Animal kingdom
Plants (450)	Arthropods (1)
Bacteria (70)	Fishes (0.7)
Fungi (13)	Molluscs (0.2)
Archeobacteria	Aneides (0.2)
Protists	Livestock (0.1)
Animals (3)	Cnidaires (0.1)
Viruses (0.2)	Humans (0.05)
	Nematodes (0.02)
	Wild mammals (0.007)
	Wild birds (0.002)

Figure 4.13. *Potentially available biomass (in gigatons of carbon equivalent).*

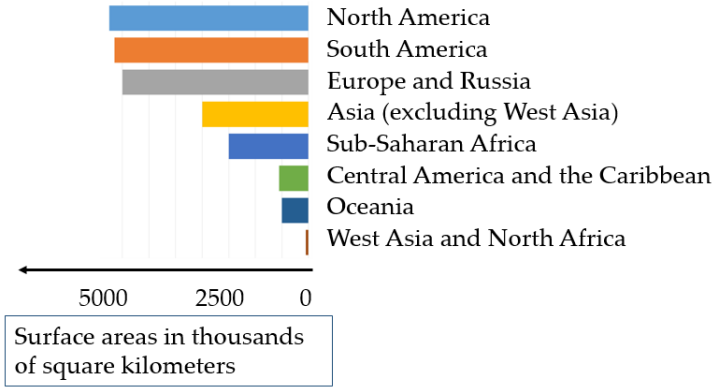


Figure 4.14. *Global forest deposit.*

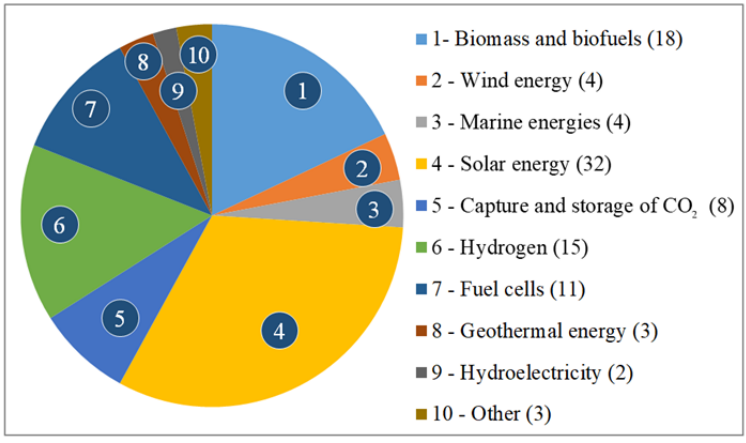


Figure 4.19. *Involvement of the CNRS in energy research (% out of 1,676 full-time equivalents).*

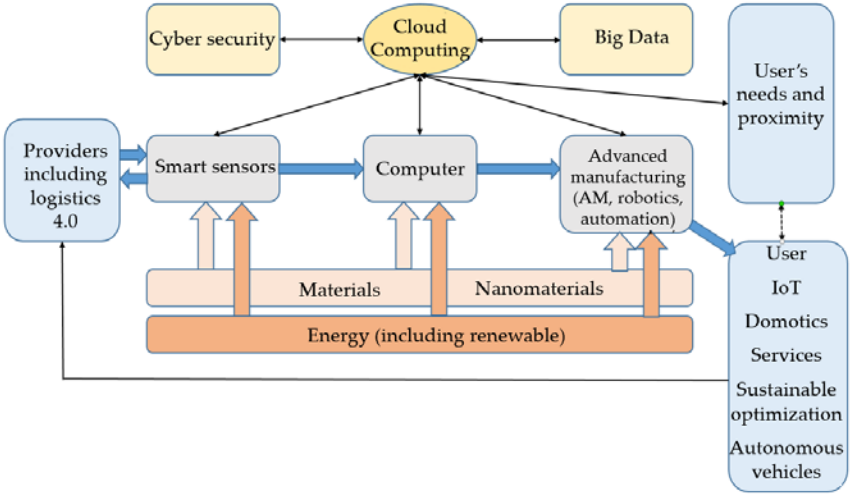
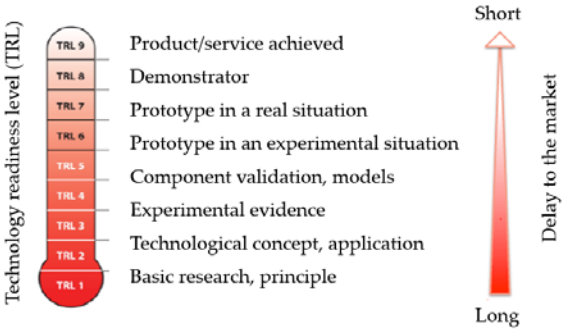
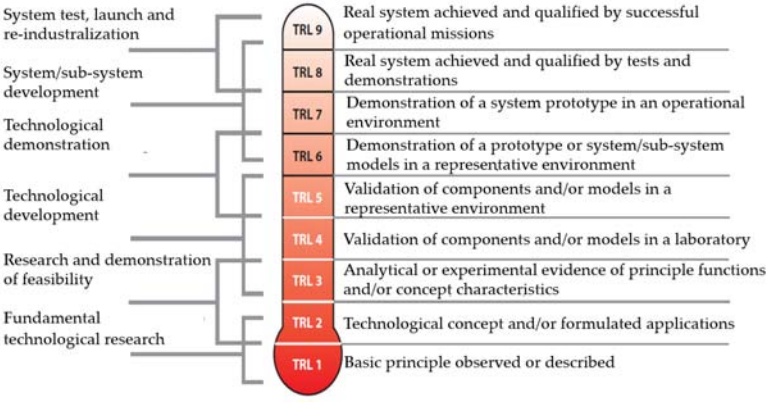


Figure 5.3. *Industry 4.0 (AM for additive manufacturing; IoT for Internet of Things).*



a)



b)

Figure A1.1. *TRL (technological maturity level).*

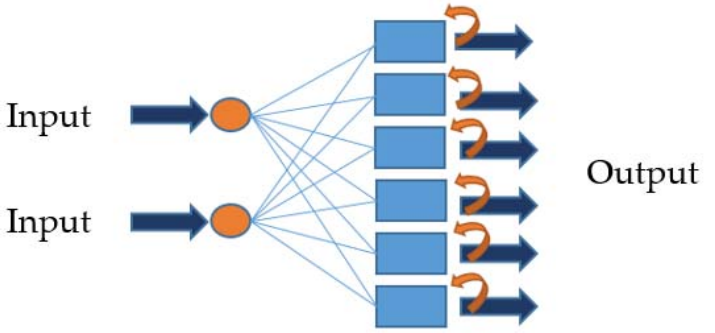


Figure A2.4. *Network with feedback (red arrows).*

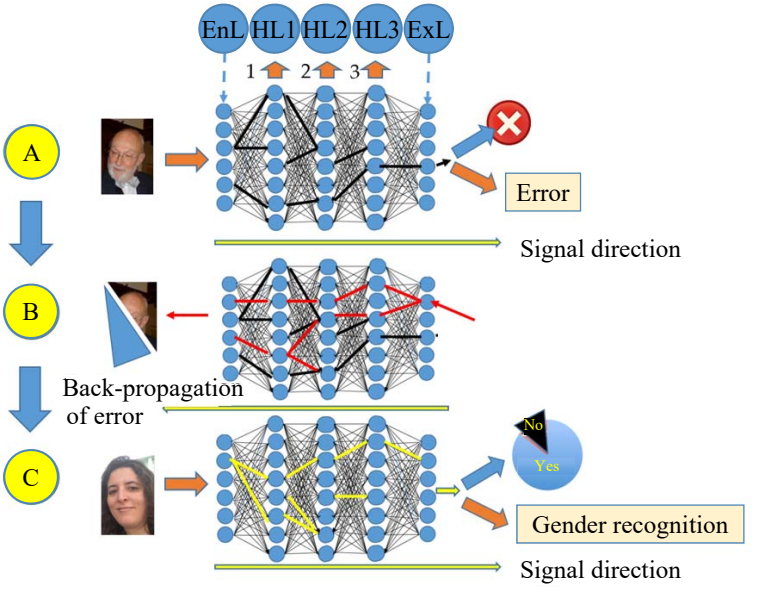


Figure A2.6. *Pattern recognition.*

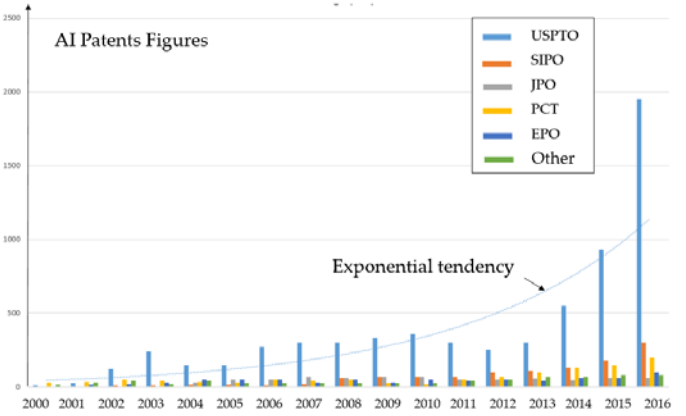


Figure A2.9. *Patents in Artificial Intelligence.*

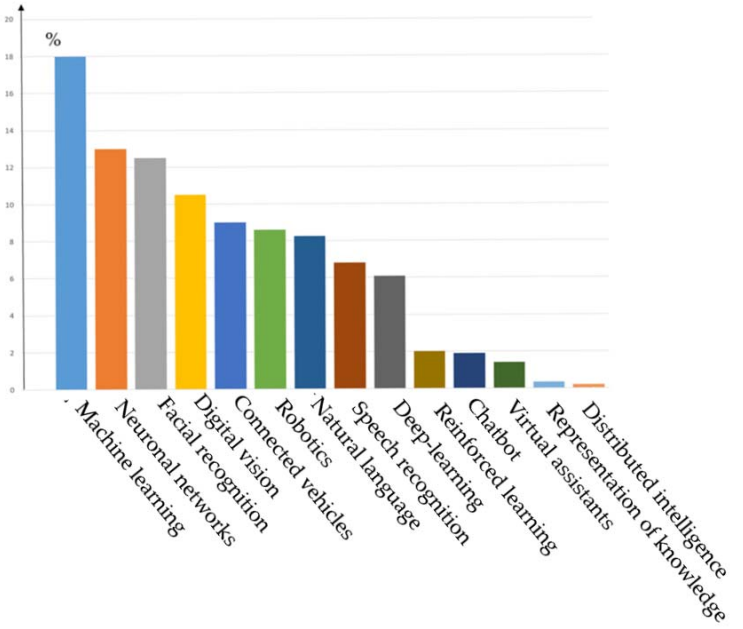


Figure A2.10. *Distribution of percentages of activities by AI sub-domain.*

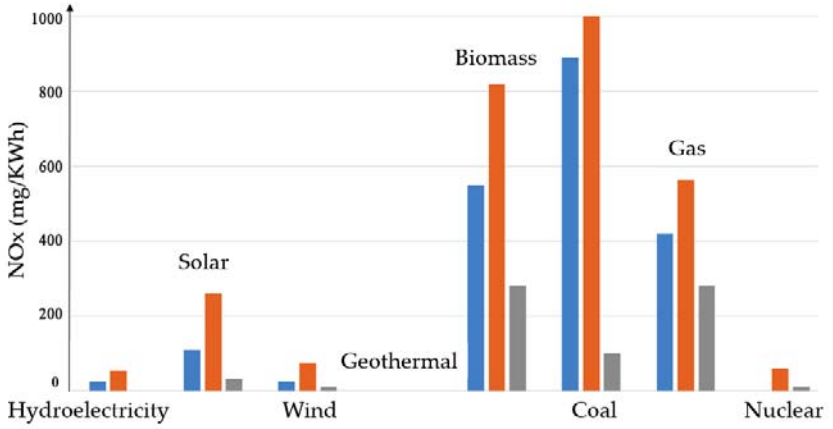


Figure A3.1. *Production of nitrogen oxides (NOx) according to electricity generation technology (blue: medium; red: maximum; gray: minimum).*

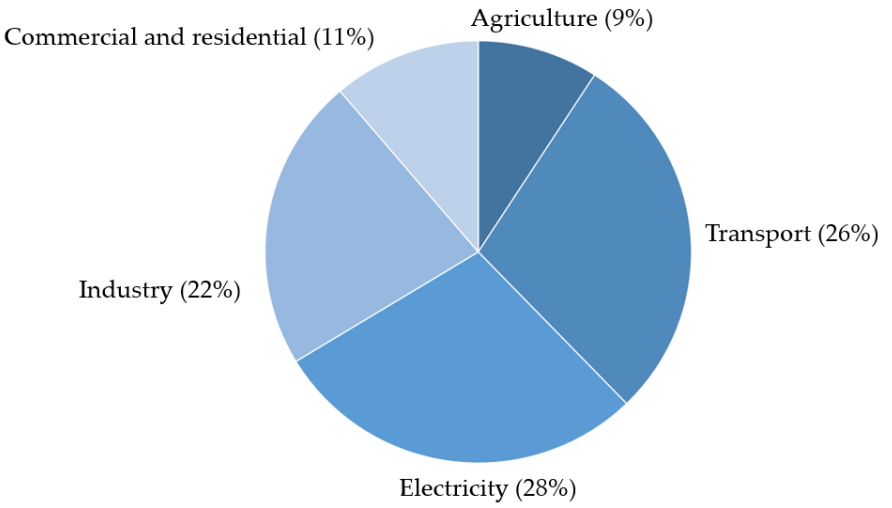


Figure A3.2. *Carbon dioxide emissions by major domain in the United States (USGCRP 2017).*

Figure A3.3. *Sustainable development goals.*