This is a repository copy of *From waste to wealth using green chemistry:The way to long term stability*.

White Rose Research Online URL for this paper:
https://eprints.whiterose.ac.uk/133769/

Version: Accepted Version

Article:

Clark, James H. orcid.org/0000-0002-5860-2480 (2017) From waste to wealth using green chemistry:The way to long term stability. Current Opinion in Green and Sustainable Chemistry. pp. 10-13. ISSN 2452-2236

https://doi.org/10.1016/j.cogsc.2017.07.008

Reuse
This article is distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs (CC BY-NC-ND) licence. This licence only allows you to download this work and share it with others as long as you credit the authors, but you can't change the article in any way or use it commercially. More information and the full terms of the licence here: https://creativecommons.org/licenses/

Takedown
If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.

eprints@whiterose.ac.uk
https://eprints.whiterose.ac.uk/

Manuscript Details

Manuscript number	COGSC_2017_21
Title	From waste to wealth using green chemistry: The way to long term stability
Article type	Review article

Abstract

Waste is an extremely valuable resource that we have been accumulating over a long period. Interesting and viable organic “waste-to-resource” opportunities include plastics and food supply chain wastes. Their use as chemical feedstocks will fit well with a circular economy model. Plastics is a major waste opportunity: worldwide we only recycle a few % of the plastic we use, yet plastic manufacturing consumes some 10% of all the oil we consume, and much of it causes serious environmental damage through negligent release. The chemical content of food supply chain wastes are much more complex and varied than in plastic waste but offers a wide range of valuable chemical products. Bio-refineries can be defined as integrated complexes in which a number of renewable-derived feedstocks (bio-waste, biomass) can be converted in a range of useful products including chemicals, materials and fuels similar and sometimes identical to those obtained from petroleum.

Keywords	waste; plastic waste; food waste; biorefineries

Corresponding Author	James Clark
Corresponding Author's Institution	University of York
Order of Authors	James Clark

Submission Files Included in this PDF

File Name [File Type]

Highlights.docx [Highlights]

From waste to wealth using green chemistry.docx [Manuscript File]

Figure 1.jpg [Figure]

Figure 2.jpg [Figure]

Figure 3.jpg [Figure]

To view all the submission files, including those not included in the PDF, click on the manuscript title on your EVISE Homepage, then click 'Download zip file'.

Highlights

- What is now called Waste should be treated as a resource
- End-of-life plastics are a rich source of small organic chemical compounds
- Food waste contains many interesting organic chemical compounds but is complex
- Bio-refineries should convert biomass to chemicals, materials and energy

From waste to wealth using green chemistry: The way to long term stability

James H Clark, Green Chemistry Centre of Excellence, University of York, York YO105DD, UK

Abstract

Waste is an extremely valuable resource that we have been accumulating over a long period. Interesting and viable organic "waste-to-resource" opportunities include plastics and food supply chain wastes. Their use as chemical feedstocks will fit well with a circular economy model. Plastics is a major waste opportunity: worldwide we only recycle a few % of the plastic we use, yet plastic manufacturing consumes some 10% of all the oil we consume, and much of it causes serious environmental damage through negligent release. The chemical content of food supply chain wastes are much more complex and varied than in plastic waste but offers a wide range of valuable chemical products. Bio-refineries can be defined as integrated complexes in which a number of renewable-derived feedstocks (bio-waste, biomass) can be converted in a range of useful products including chemicals, materials and fuels similar and sometimes identical to those obtained from petroleum.

Key words: waste, plastic waste, food waste, biorefineries

Highlights

- What is now called Waste should be treated as a resource
- End-of-life plastics are a rich source of small organic chemical compounds
- Food waste contains many interesting organic chemical compounds but is complex
- Bio-refineries should convert biomass to chemicals, materials and energy

From Linear to Circular – the basis of a sustainable society

We have created a society based on the linear economic model of extract-process-consume-dispose and whether its organic carbon to synthesis a plastic or indium to manufacture a mobile phone, the same unsustainable model applies. And not only do we convert a precious and limited resource to a waste (and often after a very short lifetime such as for a plastic bag) we also often treat that "waste" in a way that it damages the environment [1]. How can the Circular Economy [2] improve things? We need to ensure the resources embedded in every article we manufacture and use are returned for continued use – be that in the same type of article or something completely different. Most circular economy models do this either via the natural bio-sphere for organic articles or substances or via the man-made techno-sphere. If every resource was ready-for-reuse within 100 years of its original use, and assuming we can build everything the world's population could want from existing and readily available resources, we would achieve sustainability. This is based on gross assumptions – that we don't consume more resources or have any materials losses in the recovery phase, as well as assuming we capture all items for reuse. Even if we are only 80% correct, we would then need to continuously improve our resource efficiency by 20% or we increase our resource pool by using existing wastes, of which we have accumulated a lot! Waste is an extremely valuable resource that we have been accumulating over a long period and while much of it is dispersed, we do have concentrations of waste, most notably in landfills. Landfill mining needs to be on the agenda in every region of the planet and it should make a significant contribution to the resource deficit while simultaneously easing our waste problems. Targets should be set not only to minimize or totally stop land-filling but also to reduce existing land-fills.

Interesting and viable organic “waste-to-resource” opportunities include plastics and food supply chain wastes. Both of these are available across the planet in very large volume, present a serious problem to society, and have some degree of waste management already in place. Plastics is a major waste opportunity: worldwide we only recycle a few % of the plastic we use, yet plastic manufacturing consumes some 10% of all the oil we consume, and much of it causes serious environmental damage through negligent release (e.g. in the oceans [1]). Plastics tend to be chemically quite simple (the largest volume plastics are poly-olefins mostly made up of only one very simple chemical monomer) and ideal as feedstocks for the existing petrochemical industry as long as we can crack the polymers with some selectivity and reasonable energy efficiency. The logistics are not helpful however, with plastics widely distributed into numerous applications ranging form short-lived packaging to long lifetime construction and transport. It might however, be interesting to see where large volumes of waste plastic are already concentrated and if these could translate into large enough quantities of small molecule chemicals (alkenes, etc.) to be useful in an integrated chemical manufacturing unit.

Food supply chain wastes are already concentrated in certain regions including major growing areas and major food processing centres. Harvesting fruits, vegetables, beverages and cereals can lead to substantial volumes of low value by-products while downstream, the processing of foods such as fruit juicing, the extraction of actives, and food freezing leads to major quantities of unwanted residues. Much of the (UN estimated) 1+ billion MT of edible food waste is dispersed in household and shops as well as further upstream and are best used as food on a food waste avoidance strategy. However, much of the even larger quantities of inedible parts of foods (peels, stones, shells etc.) and rejected food supply chain wastes are concentrated and therefore, easier to valorize. The fruit juicing industry for example, is a source of very large quantities of inedible by-products that are rarely exploited to their maximum chemical potential. The chemical content of food supply chain wastes are much more complex and varied than in plastic waste but that should be seen as a good thing offering a wide range of valuable chemical products [3]. These include extracts (waxes, terpenes, etc.) as well as important classes of compounds with high market demand (flavonoids, sugars, phenolics, etc.) and valuable bulk components including starches, nano-cellulose and pectin. A good example of this is the extraction from citrus waste notably orange peel, of valuable pectin, terpenes (especially limonene) and potentially other valuable chemicals notably flavonoids (healthcare supplements) and cellulose (which could be fermented to bio-ethanol for example) [4]. Currently the peel is used at best as a animal food supplement (often not at all) though its low protein content and bitter taste makes it of poor quality and marginal value. This would lend itself to a future, zero-waste, multi-product bio-refineries that make chemicals, materials and fuels consistent with a zero waste biorefinery concept [5].

We cannot achieve sustainability and ignore our waste legacy. In reality the best we can expect to achieve is to move slowly (but hopefully surely) towards a circular economy model while simultaneously learning how to valorize our accumulated wastes. For both of these, we need a full and determined three-way partnership between industry, government and the public – industry needs to embrace the concept of new feedstocks and the new technologies needed to valorize them, governments need to ensure that legislation isn't interfering with its utilization (e.g. on waste labeling and movement) and that policy is generally supportive, and we all need to understand and support a change in attitude about what we currently see as something that has no significant value and is best disposed of - “waste”. This attitude and the consequential societal behavior (the “throw away society”) is not sustainable. Rather we need an education program that helps everyone see the value in waste – be it through direct reuse by someone else, refurbishment into another article, or resource recovery (ultimately down to the constituent molecules that could then be used in a multitude of applications) (Figure 1).

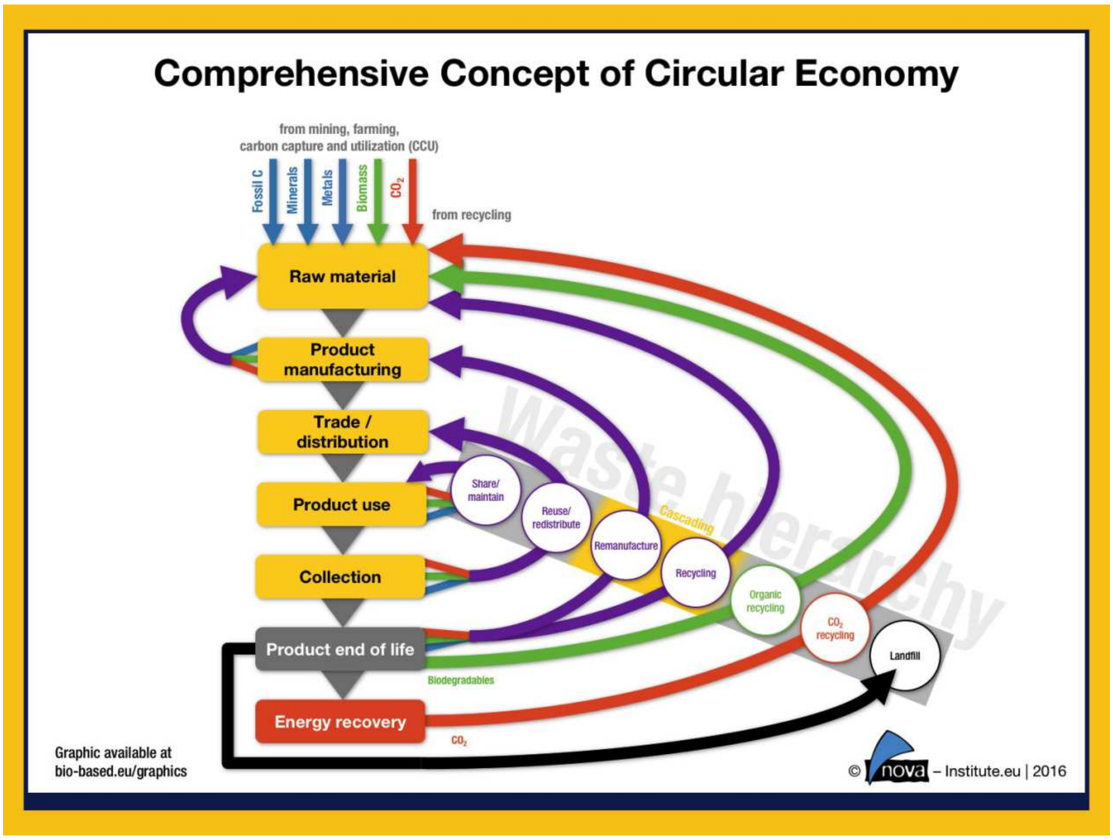


Figure 1. Routes for getting value from waste

<u>The biorefinery – moving away from fossil resources</u>

Society has benefited from a manufacturing industry closely associated with petroleum refining since the early 20th century. However, the manufacturing industries, which provide us with abundant products, is now challenged for its long term development: limited reserves of feedstock heavily based on un-renewable crude oil, reducing discoveries of “new oil” and an associated substantial fall in investment, the rise of public awareness about human and environmental safety of existing products and processes, and the growth of legislation and policy affecting industry. Scientists are now seeking for renewable, more environmental friendly and safer ways to substitute products currently based on the petrochemical industry. Bio-refineries are promising as replacement for supplements to petroleum-based refineries [6]. Bio-refineries can de defined as integrated complexes in which a number of renewable-derived feedstocks (bio-waste, biomass) can be converted in a range of useful products including chemicals, materials and fuels similar and sometimes identical to those obtained from petroleum. These must make use of environmentally friendly technologies (e.g. microwaves, continuous flow processes, heterogeneous catalysis, etc.) or we would be failing to take this opportunity to move towards a green and sustainable manufacturing industry.

Biorefinery feedstocks should be carefully selected taking into account their complexity and potential in terms of composition, volumes and possibilities to be converted into high value products (Figure 2). Accordingly, wastes including food waste [3], agriculture [7] and forestry residues [8,9] and biomass residues from industry can be suitable raw materials for biorefineries. Valorisation of these wastes can provide not only a solution to the disposal of waste, but also alternatives for the products based on the petrochemical industry.

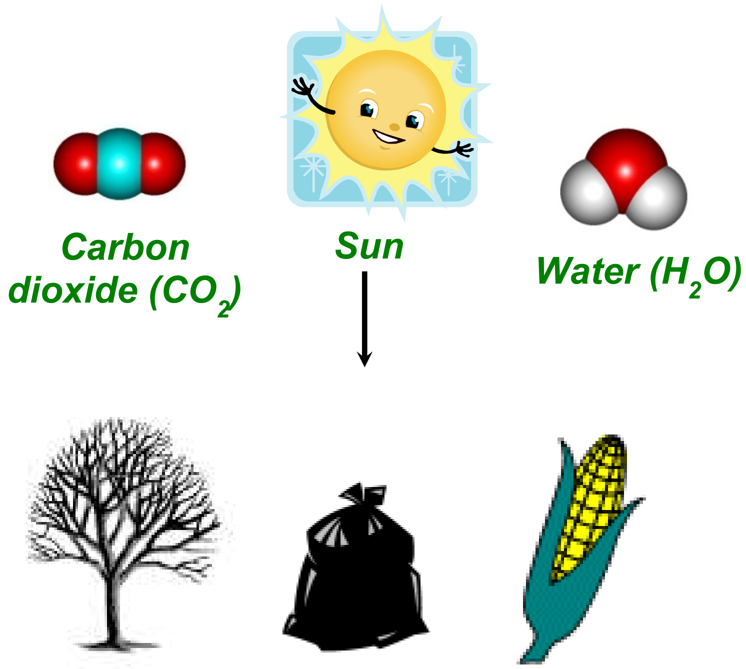


Figure 2. Sustainable sources of biomass

Biomass has gained lot of interest in the last 10-20 years because of the utilization of biomass-derived wastes into fuel, solid, liquid and gas. Biomass resources are classified into three categories based on their origin. Primary biomass resources are produced directly by photosynthesis including numerous crops, residues from harvesting of agricultural crops, forest trees and residues from their collection (branches etc.). Secondary biomass resources are obtained from the processing of primary biomass resources (physical, chemical and biological) while post consumer residue stream are considered as tertiary biomass resources including animal fats, used vegetable oils and packaging waste. For chemical purposes, waste is classified into four source independent categories i.e. polysaccharides, lignin, triglycerides and proteins. One definition of a biorefinery is, “the sustainable processing of biomass into a spectrum of marketable products (food, feed, materials, chemicals) and energy (fuels, power, heat)” [10].

The biomass feedstocks for biorefineries are renewable carbon-based raw materials which broadly fall into two categories: dedicated feedstocks, such as crops (sugar crops, starch crops, lignocellulosic crops, oil-based crops), grasses and forestry, and aquaculture; the other one is wastes, including food waste, agricultural and agro-industrial waste, forestry residues and other organic residues (manure, wild fruits and crops, and etc.). Biorefinery systems are essentially units with different technologies that can transform biomass into useful value added products, such as chemicals, fuels and other sources of energy, and materials (Figure 3). Promising technologies include supercritical carbon dioxide extraction, fermentation, microwave processing, and catalytic upgrading of biomass-derived mixtures.

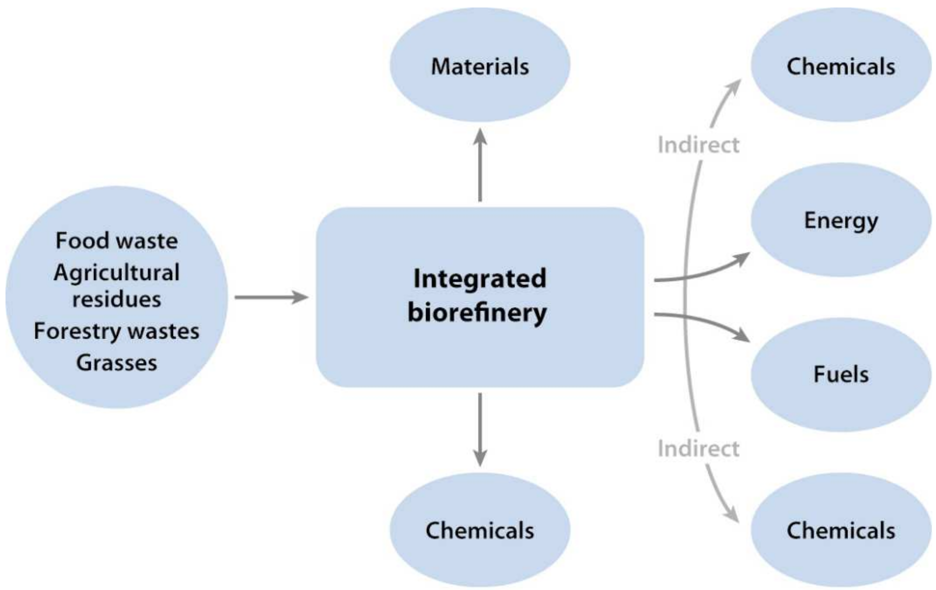
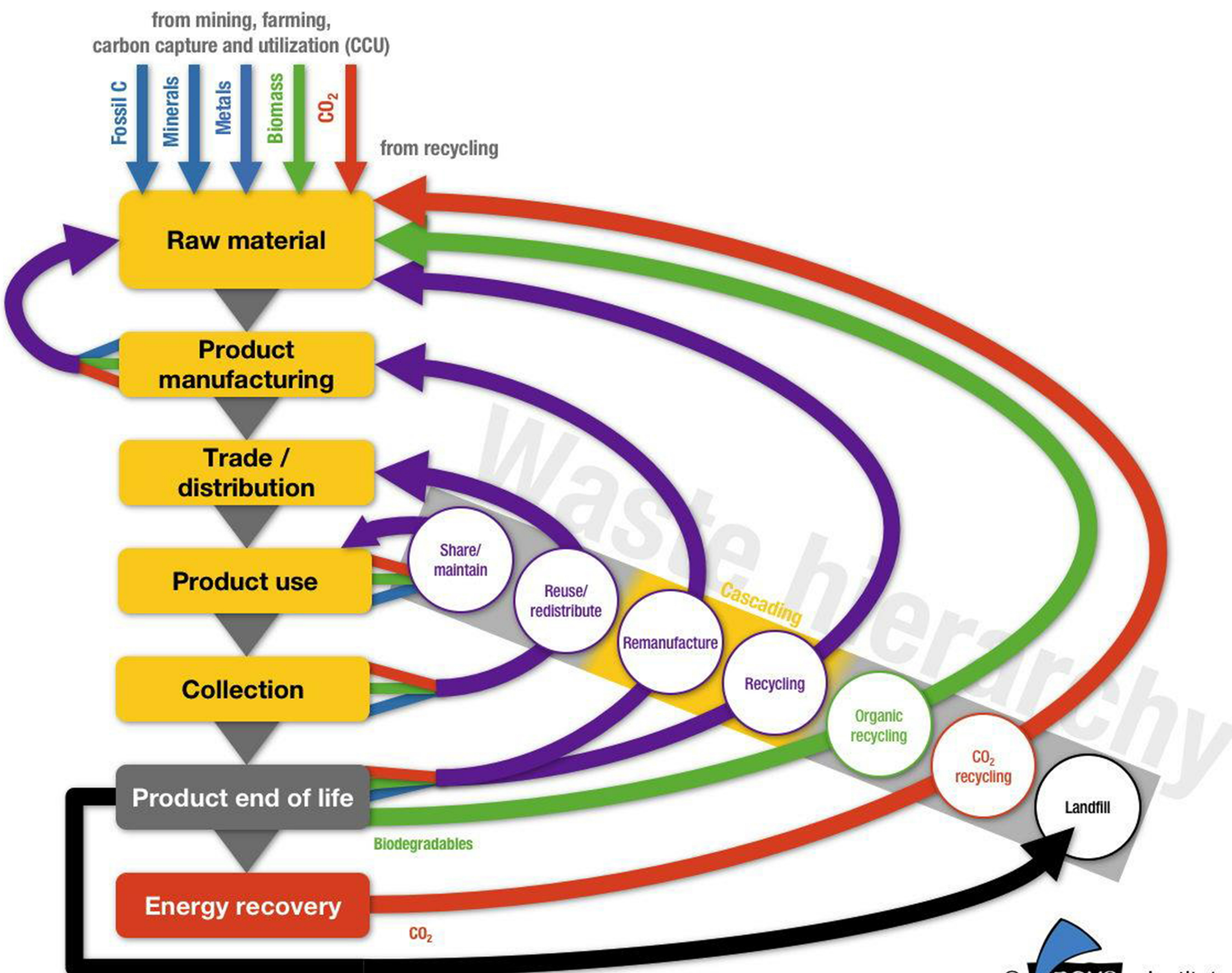


Figure 3. Waste-based biorefineries for making a wide range of products

References

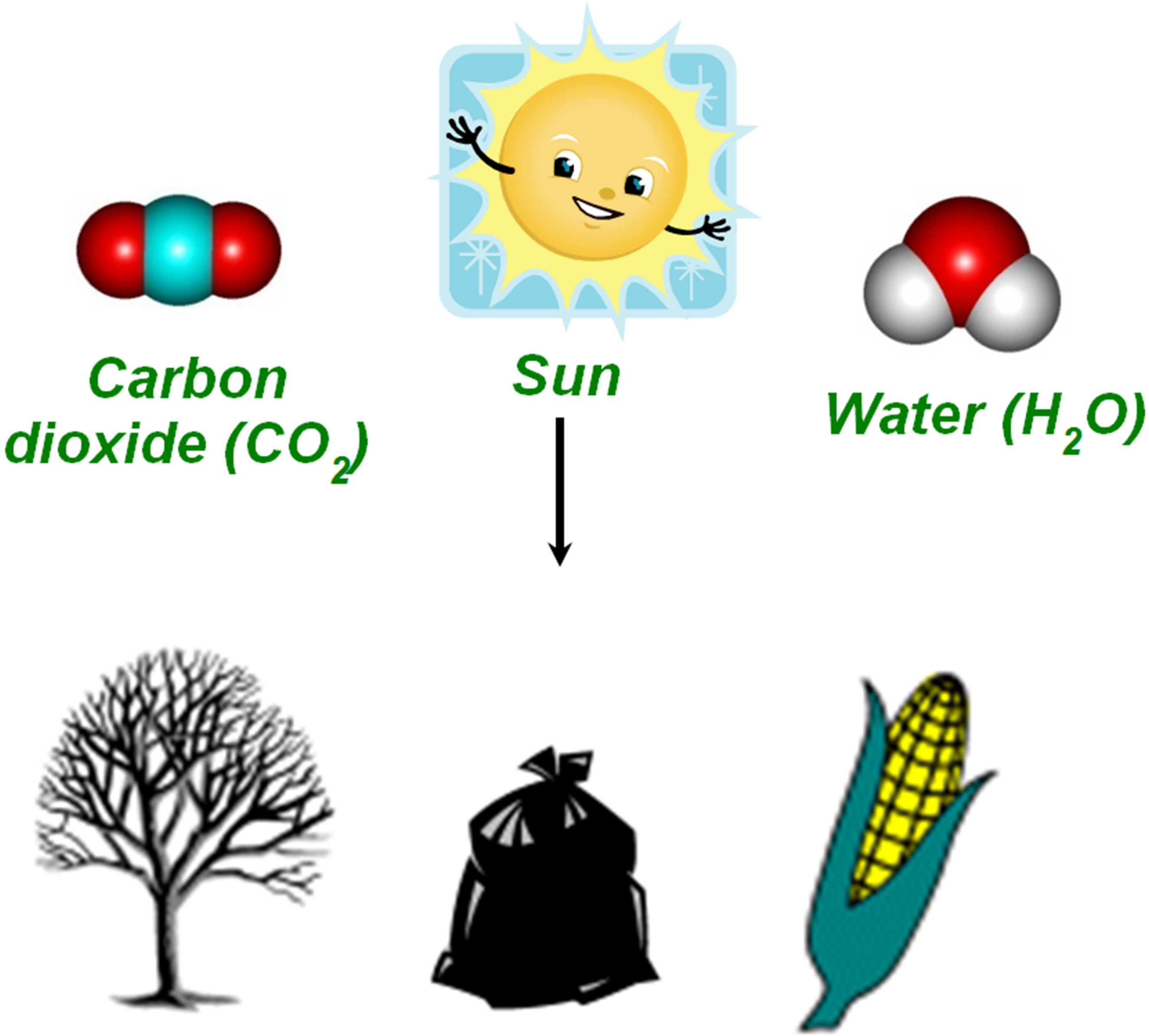
[1] See for example, the plastic islands in the Pacific Ocean http://www.greenpeace.org/international/en/campaigns/oceans/fit-for-the-future/pollution/trash-vortex).
[2] http://www.ellenmacarthurfoundation.org/circular-economy
[3] C.S.K. Lin, L.A. Pfaltzgraff, L. Herrero-Davila, E.B. Mubofu, S. Abderrahim, J.H. Clark, A. Koutinas, N. Kopsahelis, K. Stamatelatou, F. Dickson, S. Thankappan, Z. Mohamed, R. Brocklesby, R. Luque, Food waste as a valuable resource for the production of chemicals, materials and fuels. Current situation and global perspective, Energy Environ. Sci. 6 (2013) 426-464.
[4] A.M. Balu, V. Budarin, P.S. Shuttleworth, L.A. Pfaltzgraff, K. Waldron, R. Luque, J.H. Clark, Valorisation of orange peel residues: waste to biochemicals and nanoporous materials, ChemSusChem. 5 (2012) 1694-1697.
[5] J.H. Clark, T.J. Farmer, L. Herrero-Davila, J. Sherwood, Circular economy design considerations for research and process development in the chemical sciences, Green Chemistry. 18 (2016) 3914-3934.
[6] M.A. Oke, K. Annuar, K. Simarani, Mixed feedstock approach to lignocellulosic ethanol production—prospects and limitations, Bioenerg. Res. 9,4 (2016) 1189–1203.
[7] S. Kim, B.E. Dale, Global potential bioethanol production from wasted crops and crop residues, Biomass and Bioenergy, 26 (2004) 361-375.
[8] R.D. Perlack, L.L. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, D.C. Erbach, Agriculture. April, 78 (2005) DOE/GO-102.
[9] E.M.W. Smeets, A.P.C Faaij, Bioenergy potentials from forestry in 2050, Clim. Change. 81 (2007) 353-390.
[10] A. Sonnenburg, J. Baars, P. Hendrick, IEA Bioenergy Task 42 Biorefinery, 3 (2012) 183.

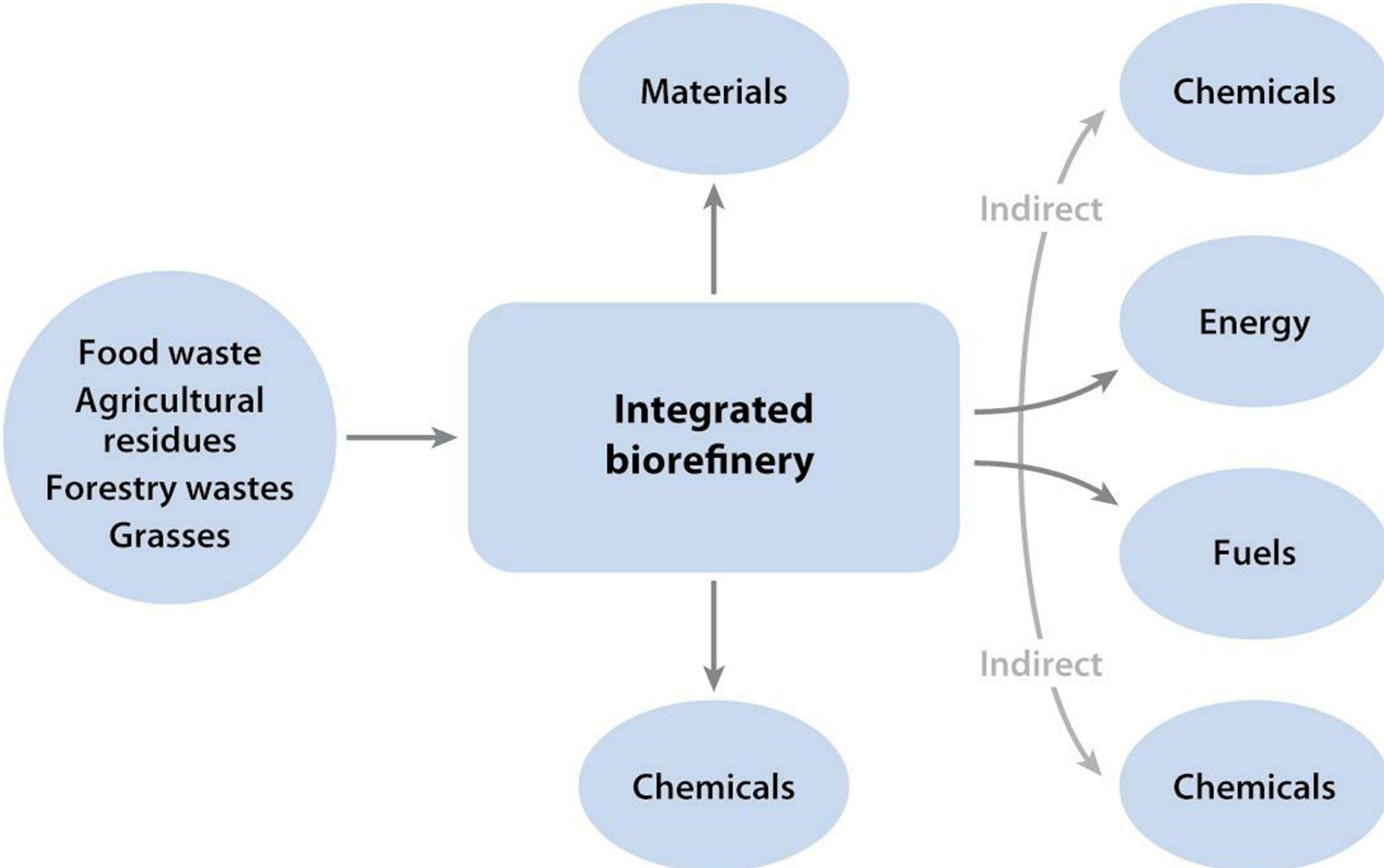
Comprehensive Concept of Circular Economy



Graphic available at
bio-based.eu/graphics

© nova – Institute.eu | 2016


Carbon dioxide (CO_2)
Sun
Water (H_2O)


Materials
Chemicals
Indirect
Energy
Food waste
Agricultural residues
Forestry wastes
Grasses
Integrated biorefinery
Fuels
Indirect
Chemicals
Chemicals