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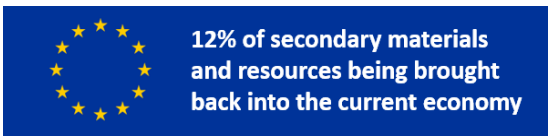
Chemistry and circular economy: a need for a multi-actors and pluridisciplinary approach

Gregory Chatel



The European Commission estimated that in Europe only 12% of secondary materials and resources are returned to the current economy. This means that this economy is still largely linear. [1] A Circular Economy Action Plan has been adopted in March 2020 and should boost circular economy projects at the level of research, development, marketing and consumers. This plan is part of the European Green Deal.

There is a great number of definitions for the term "circular economy".[2] Recently, Prof. Anke Weidenkaff defined in Chemistry Views that the aim of a circular economy is to make closed product cycle by re-use, recycling, refurbishment, or regeneration of all used materials.[3] More globally, we often opposed it to the linear economy ("make, use, dispose"), emphasizing the need to set up closed loops to use the material while reducing the consumption of virgin resources and its negative effects on the environment. The circular economy should not be restrictive and should allow the emergence of new opportunities and innovations. The circular economy leads to increase the value of resources by increasing their conversion into higher value products while eliminating low value waste. Moreover, in this case, the lifetime of products is increased. In terms of waste valorization, we all have waste from the manufacturing industry in mind, but waste from nature can also be affected by these new circular economy loops, as some examples in this article will show.

5 levels of contribution of chemistry to circular economy:

In a concept article recently published in *Chemistry – An European Journal*, I discussed how chemistry can contribute to the circular economy approach to improve our environmental, economic and societal system.[4] Through five proposed levels of contribution (Figure 1), chemists can take their part in this adventure:

1 - innovation through the consideration of green chemistry principles,
2 - the simplification of syntheses,
3 - development of new technological systems and novel ways of valorization,
4 - systematic and generalized environmental and economic assessment,
5 - global approach in link with other actors and disciplines.

This last level encourages chemists to work even more together across all fields of chemistry to find complementary solutions, but also to contribute more broadly by adopting territorial, multi-partners and multidisciplinary approaches within circular economy projects to ensure positive overall impacts.

Figure 1: The five levels of contribution of chemistry to circular economy[4].

LEVEL 1	Green chemistry and eco-compatible synthesis/processes to limit the negative environmental impact of chemistry.
LEVEL 2	Simplification of syntheses and limitation the complexity of the products with closed loops of production chains and optimized resource efficiency.
LEVEL 3	Innovations, new technologies, new ways of valorization and new concepts.
LEVEL 4	Systematic and more generalized environmental/economic assessments, in particular using lab-scale Life Cycle Assessment.
LEVEL 5	Consideration of issues/opportunities with a territorial and global vision, and a multi-partner and multidisciplinary approach.

In conclusion, circular economy is a huge opportunity to innovate and work differently, but it is also a great need for our planet, and especially for the planet that we will leave to our children and their descendants. Indeed, we cannot over-consume resources which no longer have time to renew themselves or which become missing. Earth Overshoot Day, the calculated illustrative calendar date on which humanity's resource consumption for the year exceeds Earth's capacity to regenerate those resources that year, occurs each year earlier (August 22nd in 2020). In addition, as David Cole-Hamilton rightly pointed out recently, if we fail to build a sustainable world economy, poverty, inequality, economic stagnation and conflict will all grow towards the destruction of the world as we know it.[5]

How start this circular economy on a territory?

The interesting point is how start this circular economy on a territory. For example, if the collect of a waste type does not exist, it is not possible to valorize it, but if it does not exist a valorization, a collect has no reason to exist.
The starting point of these new projects of circular economy are often an opportunity, a meeting of actors, people who want to work together, etc. However, these opportunities have to be provoked. Below are three examples where we created new projects of circular economy thanks to these particular encountered conditions.

First example: opportunities from a chance encounter
In 2016, a colleague told me, over a coffee, how she was fighting against the invasion of Japanese Knotweed (*Fallopia japonica*) on her personal land. Indeed, this invasive alien plant is a large clump-forming plant, which grows up to 3 m tall, with light green shield-shaped leaves and bamboo-like hollowed stems. It spreads very quickly and can invade an entire surface thanks to its thick and extensive roots called rhizomes, which can reach several meters deep (Figure 1). The main problem is its strong spread since a few millimeters of rhizomes can allow Japanese Knotweed to grow preventing any other plant species from developing. In addition to the problem of biodiversity loss it poses, Japanese Knotweed leads to economic losses in land values as well as roadside safety problems. Because of its very efficient mode of propagation, the waste resulting from the mowing or uprooting of this invasive plant is no longer accepted in municipal waste disposal centers.

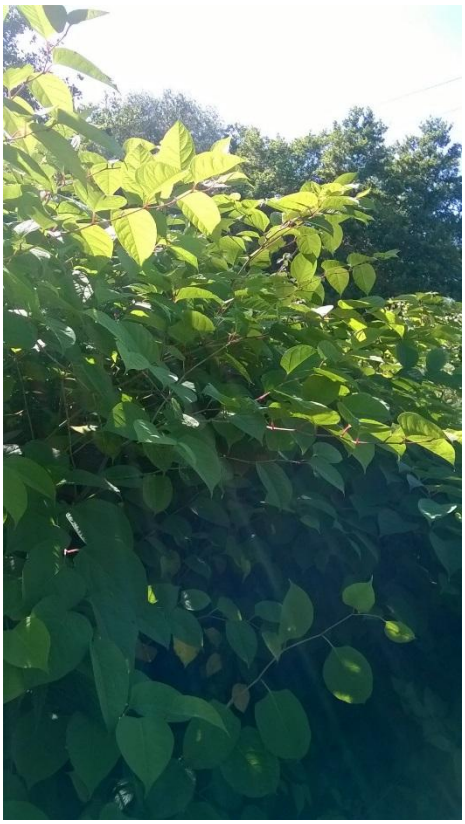


Figure 1: Japanese Knotweed.

We started to work on the valorization of the rhizomes at lab, through the extraction of molecules with a great potential for cosmetic and nutraceutical applications. A bit by chance, we met an executive employee from a chemical industry company who wanted at this moment to create a start-up to find an environmental sense in his professional action. Some years after, after obtaining various funding and the work of several internships students and postdoctoral fellows, a patent has been filed and the start-up Rhizomex has been created.[6] Indeed, our eco-friendly process allows the grinding, extraction, *in-situ* transformation and purification of some selected polyphenols of interest from the rhizomes (Figure 3). Then, the start-up has been developed to create a rhizomes recovery channel while offering a new valorization outlet, with a territorial approach. The proposed solution is a double valorization through a first extraction of molecules of interests and an agronomic valorization of the solid extraction residue leading to a zero waste circular economy strategy.

Figure 3: The exciting approach of this research was to start from the grubbing-up site to the lab, working on large amount of rhizomes.

Second example: opportunities from the network

I am involved in a network of eco-industries in the Savoie territory (French department), where research laboratories and companies regularly meet to bring about new projects on waste and more generally on the circular economy. We started in 2017 a project with a local company of this network, Trialp, that collected used frying oils and coffee grounds from the restaurants of the territory. In our lab, we started to valorize coffee grounds, in particular using supercritical fluids.

Figure 4: Our first visit to the Trialp facilities in 2017.

Another avenue of innovation that circular economy can bring is the functional economy where customers pay for the use of products and not for their possession. In this case, the paradigm shift lies in the fact that the product is no longer sold (and then do not become a waste produced by the custumer) but it remains the property of the company that operates it. The customer uses it and then the company ensures its recovery, recyclability and traceability much more easily. By collecting ground coffee, Trialp has noticed that the majority of the restaurants are supplied with coffee by the same company. We could imagine an original system where this company will not sell coffee but rather propose a “coffee service”, recovering the coffee grounds after its use in the restaurant. Thus, the recovery of the coffee grounds will be facilitated, as well as its recycling, while maintaining the traceability and tracking of the products. In conclusion, it could be interesting to explore this way in the framework of circular economy...

Third example: a new regulation leading to the need to change practices

In December 2017, a prefectural order was taken to prohibit the burning in the open air of agricultural waste in the Savoie Mont Blanc territory (France). In this context, we started to work with the winegrowers, the state and environmental services, the city representatives, the political decision-makers, the associations, the citizens and several other researchers to develop alternatives to the burning of viticultural waste (Figure 4), produced annually across the territory. We formed the consortium for nearly a year in order to convince all the actors to join us and participate to this territorial project. We also had to quickly find funding solutions to start and launch the research project, which we called VITIVALO with my colleague Dr. Piot, with whom I coordinate this project).[7] The development of a cascade of valorization ways rather than a single valorization path, proved necessary to set up a viable economic sector on the territory and achieve acceptable environmental standards.

Figure 4: The viticultural waste studied in the VITIVALO project.

Indeed, we demonstrated the interest to first extract molecules of interest from grapecanes and grapevine stocks.[8] In particular, the most widespread grapevine varieties in the Savoie Mont Blanc territory, Jacquère and Mondeuse varieties, present important amounts of two stilbenes, *trans*-resveratrol (Rsv) and *trans*-ε-viniferin (Vf), in comparison with the well-known high stilbenes levels in Gewurztraminer and Pinot Noir varieties. [9] In these studies, we also highlighted the great variability of the extracts composition as a function of applied pre-extraction parameters at lab.

The VITIVALO project also involve several laboratories and companies on the impact on air quality, the valorization of extraction residues as insulating bio-based materials or for industrial compost. This strategy of cascade of valorization ways aims to propose a "zero waste" approach. The establishment of comparative Life Cycle Analyses (LCA) is also planned to assess the set-up of this new sector on the territory. At last, we communicate with inhabitants, citizens and especially with several primary schools to sensitize them and their families to the developed approach.

Figure 5: Through the “One year with VITIVALO” program, several school worked on these problematics and inform the families of the territory.

In summary, the chemists learned a lot from the understanding of the practices and issues of viticulture professionals thanks to this broader approaches engaged in the VITIVALO project. Indeed, they had been able to bring additional innovations compared to those which would have resulted from a more traditional “chemist's approach”. For example, we focused our study on the period of cutting of grape canes (November-March) and not on the overall year to focus on real conditions. The grape canes from different vine varieties are often mixed in vineyards that is why we studied the effects of the varieties leading to interesting differences.

The meteorological conditions (exposure to the sun, amount of rain, etc.) or the cultivated land (type of soil, slopes, etc.) can also lead to interesting discoveries on the content of molecules of interest.
In addition to the waste valorization, other positive effects may result from the implementation of circular economy projects, responding to much more global issues such as, in our case, the creation of a new local and economic sector on the territory the reduction, the impact on air quality, the help to change in the practices of the viticulture professions or the support to the decision-making.

This type of project, where waste transport distances have to remain limited to keep a sense in terms of circular economy and environmental impact, is generally linked to a defined territory. However, the added value may be to serve as a demonstrator whose system can be then reproduced in other territories (for example in other wine regions) and finally leads to global impacts on a larger scale.

New opportunities and collaborative approaches:

In numerous cases, the solutions have to be brought by a combination of expertise and a cascade of approaches, involving all fields of chemistry (organic, engineering, analytical, polymer and/or inorganic chemistries). But chemists have also to work more closely with other disciplines (political scientists, economists, ecologists, sociologists, computer scientists, etc.). through multidisciplinarity approaches that can lead to exciting synergistic effects and innovations! In the case of the VITIVALO project for example, the imagined cascade of valorization was possible only by working between organic chemists, analytical chemists, materials and polymers engineers. Atmospheric chemists were also involved to demonstrate the impact the current practices of open air burning. Specialists in economy and sociology were also inevitable to demonstrate the economic and societal advantages of developing a new circular economy sector in the territory.

In addition, I really believe that the circular economy projects require the participation researchers, but not only. They have to involve all the actors of the studied value chain, including the companies, the consumers and the decision makers. All the actors have to be associated in a consortium for each project, often on a delimitated territory, and work all together. Based on these latest thoughts, chemists are encouraged to integrate projects of circular economy with a territorial and global vision, and a multi-partners and multidisciplinary approach.

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Dr. Gregory Chatel received his PhD degree from the *Université de Grenoble* (2012, France). Then, he joined Prof. Robin D. Rogers' group at *The University of Alabama* (USA) as a postdoctoral research fellow. Then, he joined the *IC2MP Institute* of the *Université de Poitiers* (2013, France) as an Assistant Professor. After three years, he joined the *LCME Laboratory* of the *Université Savoie Mont Blanc* (2016, France) to develop an research in green chemistry and sonochemistry for biomass and waste valorization as well as processes of fine chemistry. He obtained his *Habilitation* and become Associate Professor (2018, France). He is now the co-leader of the *Matter team* of the new interdisciplinary *EDYTEM Institute* (Univ. Savoie Mont Blanc/CNRS) with the merger of the two

laboratories, LCME and EDYTEM (January 1st, 2021). In 2020, Dr. Chatel received the silver medal of the European Young Chemists' Award from the European Chemical Society (EuChemS).

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