Journal of Analytical & Bioanalytical Techniques
ISSN: 2155-9872
Garrigues, J Anal Bioanal Tech 2022, 13:12
Research Article
Open Access

# Outline of Green Analytical Chemistry

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## Abstract

This introductory chapter examines the genesis and development of the idea of green analytical chemistry (GAC), from the introduction of clean analytical methods in 1995 to the current paradigm of democratic analytical chemistry (DAC). Today, GAC is widely acknowledged by scientists and technologists and combines a pragmatist's perspective on cost-cutting with an ethical compromise with environmental sustainability. The fundamental concept, in brief, is on preserving the analytical qualities of methods and averting harmful side effects for users and the environment. A summary of their development since the beginning of this philosophy is described, taking into account theoretical advancements in and the actual implementations of GAC.

**Keywords:** Green analytical chemistry; Clean; Reasons

## Introduction

### Green Analytical Chemistry Data

At the turn of the century, no one could have predicted the phenomenal success that green analytical chemistry (GAC) would have. Actually, early proposals in this area referred to "environmentally friendly conscientious analytical chemistry" or "an integrated approach of analytical methods," with the former being the subject of the editorial in the first special issue on clean analytical methods, which was published in 1995 in the Royal Society of Chemistry journal The Analyst. It may be argued that the negative impacts of analytical procedures would not be of major concern because analytical chemistry uses relatively small volumes of chemicals in comparison to synthesis and industrial chemical operations. However, Paul Anastas recognised the value of analytical measures in his works on green chemistry (GC), and the fact that analytical chemistry techniques are widely utilised in both academic and industrial laboratories gave this topic a unique significance to daily life. As a result, GAC has expanded significantly since the turn of the century. In reality, there were just 27 publications published on this subject between 1995 and 2000, and the majority of them focused solely on sustainable or clean approaches without explicitly utilising the term "green." The phrase "green analytical chemistry" was used for the first time in the title of Jacek Namienik's 2001 study, "Green analytical chemistry - some notes." This contribution was followed in 2002 by a paper by Joseph Wang titled "Real-time electrochemical monitoring: Toward green analytical chemistry"8 and "Some remarks on gas chromatographic challenges in the context of green analytical chemistry" (Wardencki and Namienik)7 in the electroanalytical field. Despite this, it's crucial to remember that, as of 2019, fewer than 60 papers had the full phrase "green analytical chemistry" in the title. The theoretical features of GAC have, however, been the subject of some research, and this will help the advancement of green technologies in the twenty-first century. using information from the Web of Science Core Collection database, this [1-5] graph illustrates the development of the literature on green analytical methods while taking into account the use of the terms "green analytical chemistry," "green analytical method," "clean analytical method," and "environmentally friendly method." It is clear from a comparison of these data with those found in the 2011 book Green Analytical Chemistry: Theory & Practice9 that this topic has had a significant influence on the analytical literature of this century, particularly since the release of the first book on GAC by Mihkel Koel and Mihkel Kaljurand, Green Analytical Chemistry, in 2010. From 1994 to the present, the countries with the most authors who published papers on GAC were Spain, Brazil, Poland, the United States, and China. The most popular journals for publication, accounting for more than 35% of the total contributions, were Talanta, Trends in Analytical Chemistry, Journal of Chromatography, Analytica Chimica Acta, Analytical and Bioanalytical Chemistry, Analytical Methods, and Microchemical Journal. This unequivocally corroborates Professor Kaljurand's assertion that GAC has a bright future: "Authors try to be ecologically friendly, editors and journals adore the term, and green is easily comprehended by the entire society" (M. Kaljurand, personal communication). In fact, the fact that green approaches are typically less expensive than traditional methods is one of the reasons that GAC is successful in applications laboratories as well as in academia. The scientific community is pleased with this extra benefit. It explains why so many journals have special issues devoted to GAC, which show the field's development and the ongoing attention of editors and authors.

## Materials and Methods

### The Reasons for the Success of GAC

With the exception of a few politicians, the general public's attitude towards the environment has changed during the past 20 years as a result of the issues brought on by the environmental effects of human activity on climate change. Many people now have serious concerns about environmental protection due to the mounting evidence of the limits of human and social development in our societies, the depletion of fossil fuel reserves, the new problems brought on by plastic and solid residues in general, gas [6-10] emissions into the atmosphere, and the pollution of sweet water reservoirs, including the impact of human activity on polar ice. Authors, referees, and editors have been prompted by worries about the safety of method operators and environmental harm to consider replacing toxic compounds with harmless materials or at least with less harmful ones due to the deleterious side effects

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**Received:** 03-Dec-2022, Manuscript No: jabt-22-83670, **Editor assigned:** 05-Dec-2022, Pre QC No: jabt-22-83670 (PQ), **Reviewed:** 19-Dec-2022, QC No: jabt-22-83670, **Revised:** 21-Dec-2022, Manuscript No: jabt-22-83670 (R), **Published:** 28-Dec-2022, DOI: 10.4172/2155-9872.1000491

**Citation:** Garrigues V (2022) Outline of Green Analytical Chemistry. J Anal Bioanal Tech 13: 491.

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of many reagents that have been widely used in our laboratories in the past. In order to increase the sensitivity and selectivity of sample preparation techniques, a lot of work is currently being done to find new sustainable feedstocks that may be utilised as reagents and solvents, such as agrosolvents. In summary, it can be said that GAC has introduced fresh concepts and goals for fundamental research, hence it is not related to environmental opposition to chemical use. Instead, GAC involves a thorough analysis of new alternatives, and as a result, the new mindset has demonstrated clever solutions to chemical issues and focused attention on problem-solving and fresh challenges rather than a fundamental ecologism that is unable to provide adequate solutions at the level of consumer needs. The so-called green analytical methods have gained prestige because they combine a pragmatic viewpoint with an ethical compromise with environmental sustainability and, in the end, provide the right solutions at the required levels of accuracy, sensitivity, selectivity, and precision without having any negative effects on users or the environment. On the other hand, the efforts made to switch from off-line batch calculations in the lab to point-of-care, in situ, or remote sensing of target analytes provide significant reductions in the consumption of reagents, waste generation, and energy demands. All of this reduces the method costs, thus offering less expensive options that are greatly appreciated by businesses and applications laboratories. The common use of vanguard methodologies in green analytical methods rather than expensive conventional rearguard analytical systems and the extended use of screening methods suitable to provide an appropriate level of information in a short time are close to this point of view, which again contributes to lowering methodology costs. Therefore, as Professor Farid Chemat said, "green analytical chemistry could also be called poor analytical (Figure1) chemistry." In conclusion, it is not at all surprising that GAC was created after flow methodologies became widely used in the 1970s because they helped to popularize method automation by utilizing flow injection analysis (FIA) and sequential injection analysis advancements to lessen sample and reagent consumption, as well as operator manipulation and waste generation. Fundamentally, automation is a very helpful technique to combine all the stages needed in analytical methods into a single manifold and to reduce human and environmental risks. Furthermore, the addition of a waste treatment phase following analyte detection demonstrated that chemical issues could be resolved with a little extra chemistry43, opening up new avenues for basic and applied research. An additional factor supporting the importance of GAC methods is the drive to transition from sophisticated methods based on the use of

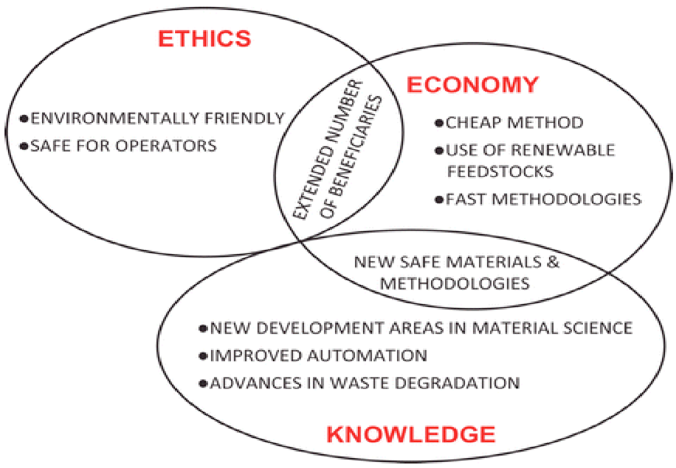


**Figure 1:** The causes of green analytical chemistry's success.

expensive instrumentation to the modelling of signals obtained with relatively affordable and easily accessible instruments. This drive is part of the effort to bring the benefits of analytical chemistry to isolated and less developed societies. It is possible to create quick and inexpensive procedures based on the use of chemometrics and direct measurements by using a number of samples that have been accurately described by reference approaches as calibration standards. 44 Therefore, the analytical tools and the accessibility of these approaches have been expanded to a large number of beneficiaries and users thanks to substantial data modelling, the use of less expensive equipment, and the use of free software accessible on the cloud.

## Discussion

### Theoretical Developments in GAC

Independent of the fact that GC places an emphasis on catalytic methods while GAC must try to be adapted to the needs of the user, the so-called SIGNIFICANCE mnemonic can actually be considered an excellent translation of the main principles of Anastas to the everyday work in analytical chemistry. It well crystallised the four priorities of GAC established by regarding (1) elimination or eduction of reagents and solvents, (2) reduction of emissions, and (3) elimination of toxic reagents.

### Practical Application of GAC

One of our goals when we began publishing books about GAC in 2011 was to share the concepts developed in our lab with as many research teams working on similar issues as possible throughout the world. For instance, the number of authors varied from two in the 2011 Elsevier book9 to 24 in the 2011 Royal Society of Chemistry book29 and to 50 in the 2012 Wiley book. 30 Contributors to the previously stated book came from countries like India, Poland, Estonia, Taiwan, Argentina, Italy, Japan, Iran, and Brazil, demonstrating the fact that the subject was popular not just in Spanish laboratories but also across the globe.

## The Future: A Democratic Analytical Chemistry Paradigm?

The conceptual development of GAC has advanced recently in tandem with initiatives to include new screening tools and affordable instruments to address analytical issues. The development of FIA47 and the use of microwave ovens for sample digestion48 in 1975 prepared the way for methodological advancements of the then-current techniques for analyte detection and sample preparation. They also demonstrated the potential for locating suitable low-cost solutions.

## Conclusion

On the other hand, the Internet and the phenomenal growth of social networks will offer new methods of data distribution without any time lag between data capture and distribution, generating both huge opportunities for quick decision-making and challenges to verify accurate information. The democratic analytical chemistry (DAC) concept has thus advanced from the extension of advantages to the primary facets of data creation, as already mentioned.

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