

International Research Collaboration in Small and Big Science: Comparing global research output between biofuels and neutron scattering

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Abstract— We investigate patterns of international research collaboration in two different fields: biofuels, and neutron scattering. We use bibliometric analysis with data retrieved from the Science Citation Index, through Web of Science from 2003 through 2008. We find that international collaboration in relation to the number of publications in the field is more intense in neutron scattering than in biofuels. Moreover, international teams in neutron scattering include more countries than is the case in biofuels. We also find that publications in biofuels have increased faster among some of the BRIC (Brazil, India, China) countries than among the U.S. and European countries. In neutron scattering publications remain concentrated in more developed countries. The U.S. remains the leader in scientific production in both fields. The emergence of developing countries as producers of science in biofuels suggests opportunities for North-South collaboration in research.

I. INTRODUCTION

Society faces unprecedented challenges in issues related to global health, energy, environment, food, water security, and climate change. Many problems have become global and too complex for individual action. Issues not only transcend national borders, but also require knowledge and expertise from a number of scientific fields and technologies. For example, the emergence of nanotechnology illustrates the integration of knowledge and expertise from chemistry, physics, engineering, IT, and very often biology. The Human Genome Project is an example of the evolution in the field of biology. In the past, biologists limited themselves to describe and classify biological systems. With the proliferation of the study of systems biology, now scientists integrate biology, systems engineering, mathematical modeling, and computer science to understand the process by which atoms and molecules form the mechanisms that make up living organisms (Welsh et al., 2006).

Collaborative research has been directly linked to “big science”, a term first used by the physicist Alvin Weinberg to describe research in big research organizations set up in costly facilities, mainly in the field of high-physics. Examples include the recently inaugurated Large Hadron Collider (LHC), the largest European particle accelerator located in

Geneva, Switzerland. CERN, the European Center for Nuclear Research, has been an example of international cooperation across the Atlantic Ocean (Clery, 2009). Due to the scale of investments, those scientific organizations are frequently federally funded, and very often they harness funds from governments of different countries. In order to maximize the use of big instruments and balance financial returns, they attract external users that usually collaborate with “in-house” scientists.

Given the complex, global, and multidisciplinary nature of problems, collaborative research is no longer limited to “big science”. Collaborative research has been emerging as the new organizational mode of doing research, in big (large scale, costly laboratories), as well as in small (small scale, less costly laboratories) science. Scholars argue that collaboration at the international level expedite the process of learning, minimize risks of early stage research, and helps to increase the exchange of knowledge (Justus et al., 2005). There are expectations that the Obama administration will grant a more significant role for S&T within the U.S. R&D and foreign policy agendas (Hane, 2008).

The literature exploring patterns of international research collaboration shows that the U.S. is losing its dominant role, and that new hubs of research have been established in emerging economies, in special in Asia (Leydesdorff et al., 2008; NSB, 2008). We would like to test this premise, analyzing global research activity in two scientific and technological fields. Our goal is to compare the fields, evaluating the differences in patterns of international collaboration between them. We take biofuels as an emerging field in S&T, for which research is organized mostly according to the model of “small science”. We map research output in “neutron scattering”, a scientific field where research is performed in big and expensive laboratories, following the model of “big science”. We carried out a bibliometric analysis and build a dataset drawn from publications indexed by Thomson ISI Web of Knowledge Science Citation Index database, Web of Science, covering 2003 through 2008. We find that despite the emergence of China as a top player, the U.S. remains the world leader in scientific production in both fields. We verify stronger international collaborative activity in neutron scattering than in biofuels. While the pattern of international collaboration has slightly intensified over time in

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biofuels, the same has not happened in neutron scattering. We confirm expectations that more countries collaborate in a single publication in neutron scattering than in biofuels.

II. MAPPING THE FIELD

A. Biofuels

We developed a multi-stage search strategy based on literature and on consultation with specialists in the field. Publications in biofuels have grown more than threefold between 2003 and 2008, going from 500 to 1760 articles published in journals and conference proceedings. The total world publication indexed by ISI-SCI between 2003 and 2008 was almost 6,000 articles. International collaboration has followed the growing trend of publications, going from 13 percent to 15 percent of total publications in the field between 2004 and 2008. Fig. 1 shows the evolution in the number of publications and percentage of international collaboration between 2003 and 2008.

The science of biofuels comes mainly from OECD countries. Europe and North America account for two thirds of scientific publications between 2003 and 2008, while Asia accounts for one fourth (see fig. 2). The United States remains isolated as the leader in publications. Fig. 3 illustrates the boost in publications authored by scientists affiliated to American institutions since 2007. Three BRIC countries, China, Brazil, and India follow the US, revealing that their strategic focus is not only in manufacturing, but also in the production of science of biofuels.

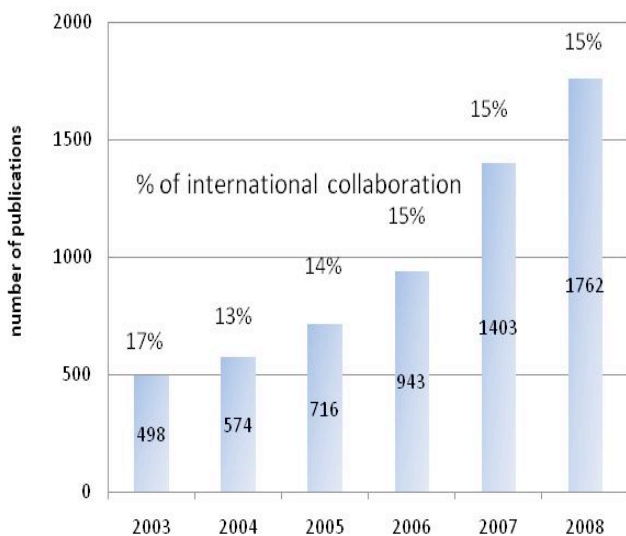


Fig.1 Biofuels: number of articles published in journals and conference proceedings. Elaborated by the authors from ISI-SCI 2003 - 2008

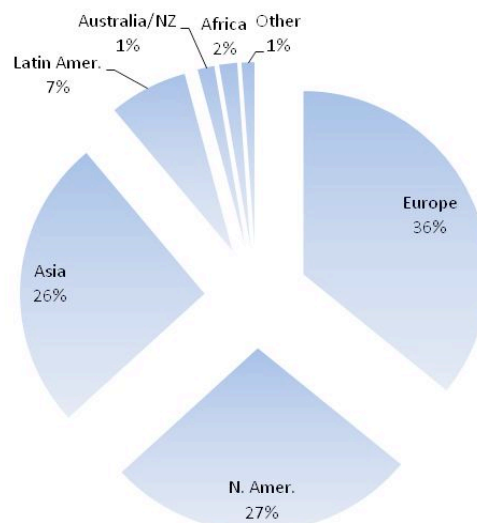


Fig.2 Biofuels: publication by regions. Elaborated by the authors from ISI-SCI 2003 – 2008. Europe includes Russia and former USSR countries.

Our analysis does not confirm the general finding that the U.S is losing grounds in the production of research publications, at least not in the case of biofuels. Publications by North American institutions increased at an annual rate of 38 percentage points between 2006 and 2008 (fig. 4), while those published by Europeans increased by 22 percentage points (fig. 5). However, one may not disregard the fast pace growth of publications authored by scientists affiliated to Chinese and Indians institutions. The annual growth rate of publications authored by scientists affiliated to Asian institutions was 56 percentage points between 2006 and 2008. Latin American growth has been led mainly by Brazil, which has become the third largest producer of scientific publications since 2007, after the U.S. and China. Table 1 shows the publications indexed by ISI-SCI in biofuels by the top countries since 2003.

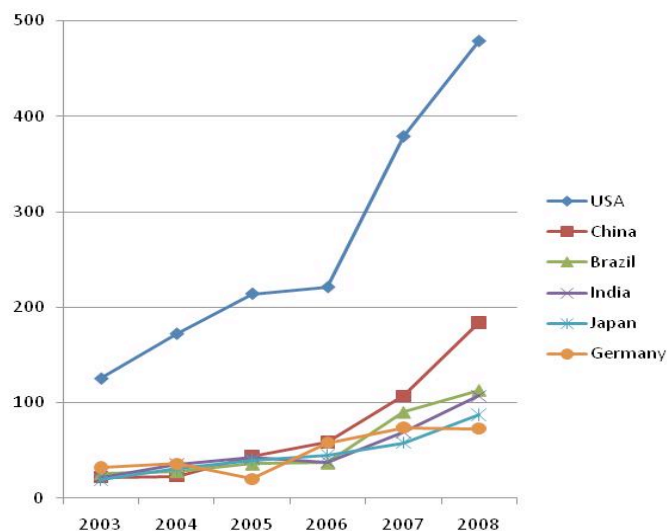


Fig.3 Biofuels: publication by top countries. Elaborated by the authors from ISI-SCI 2003 - 2008

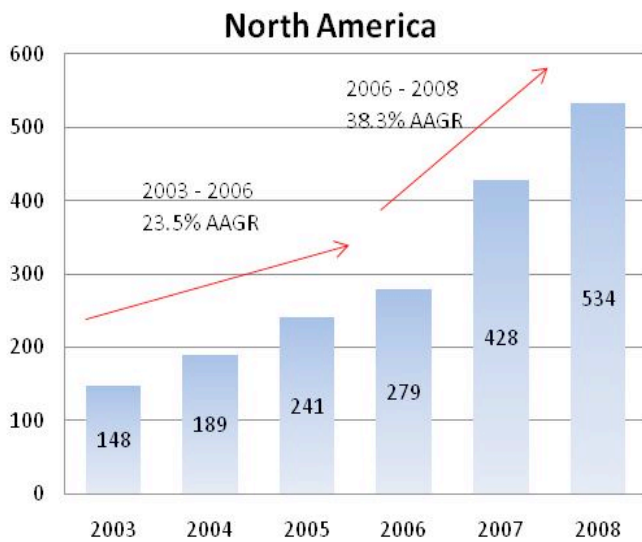


Fig.4 Publications authored by North American institutions. Elaborated by the authors from ISI-SCI 2003 - 2008

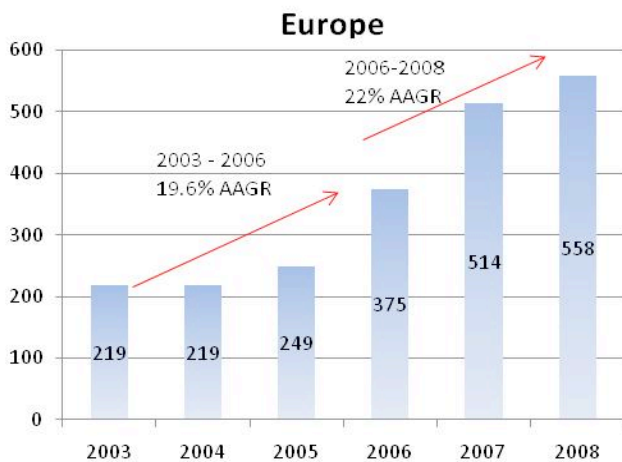


Fig.5 Publications authored by European institutions. Elaborated by the authors from ISI-SCI 2003 - 2008

TABLE I
BIOFUELS – ARTICLES PUBLISHED IN JOURNALS AND CONFERENCE PROCEEDINGS

	2003-2008	2003	2005	2007	2008
US	1590	125	214	379	479
China	439	22	44	107	184
Brazil	330	26	36	90	113
India	314	22	43	69	107
Japan	280	19	40	58	87
Turkey	253	19	31	57	87
Germany	293	32	20	74	73
Canada	239	25	32	56	64
Spain	211	19	19	58	59

Elaborated by the authors from ISI-SCI 2003 - 2008

The Agricultural Research Services from the U.S. Department of Agriculture is the leader producer of publications, with over 203 articles published in journals and conference proceedings between 2003 and 2008. Lund University comes second, but when taking into account only 2007 and 2008, the Swedish university goes down to 9th place behind some American, Chinese, Indian, and Brazilian institutions. Table 2 shows countries' statistics by rank and number of publications.

TABLE 2
BIOFUELS – HIGHEST PUBLISHING INSTITUTIONS

Institutions	Country	Rank 03- 06 (# of records)	Rank 07-08 (# of records)
US Dep. Of Agriculture (Agric. Research Services)	USA	1 (107)	1 (96)
Lund University	Sweden	2 (61)	9 (31)
Indian Inst.Technology(*)	India	3 (44)	5 (43)
Chalmers Univ.of Technology	Sweden	4 (38)	19 (22)
University of Sao Paulo	Brazil	5 (35)	6 (39)
University of Illinois	USA	6 (33)	3 (52)
Swedish Univ.of Agric.Sciences	Sweden	7 (30)	30 (16)
Iowa State University	USA	8 (28)	7 (36)
Technical Univ.of Denmark	Denmark	9 (28)	20 (21)
Tsing Hua Univ	China	14 (23)	4 (50)
Mississippi State Univ	USA	86 (7)	8 (32)
Chinese Academy of Sciences(*)	China	15 (22)	2 (71)

Source: ISI – Web of Science 2003 – 2008

(*) include different institutions that were indexed by Web of Science under a common name

B. Neutron Scattering

We found approximately 6,300 articles published in journals and indexed by SCI, Web of Science between 2003 and 2008, 44 percent of which were co-authored internationally by two or more countries. Fig. 6 illustrates the distribution of publications over the years, and shows that the percentage amount of articles co-authored internationally has remained around 43 and 45 points. As expected, neutron scattering is a more collaborative field than biofuels during the period analyzed.

In neutron scattering, the production of science is even more concentrated in North America and Europe than in biofuels. We found that between 2003 and 2008, 80 percent of articles were published by scientists affiliated to European and American institutions (fig.7). Asia, mainly led by Japan and China, has only 16% participation in world publications. The U.S. is the leader in publications with 1974 articles published between 2003 and 2008. It is followed by France (1322), Germany (1187), Japan (851), and England (773).

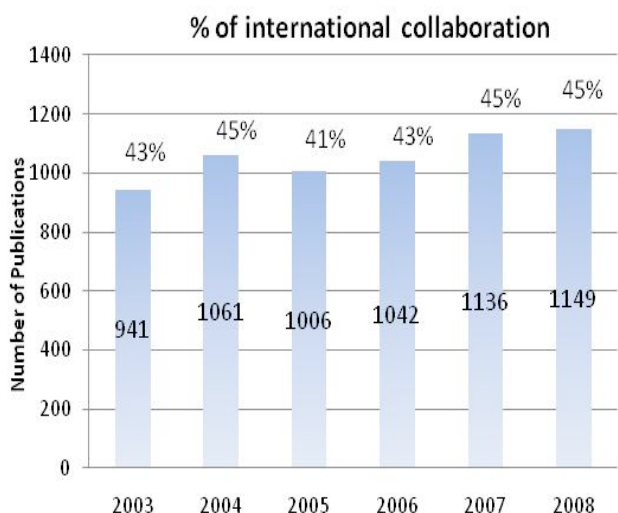


Fig.6 Neutron Scattering: number of articles published in journals
Elaborated by the authors from ISI-SCI 2003 - 2008

Fig.8 shows the evolution of publications by country during the period. The U.S. is the leader and growing faster than other countries, especially between 2006 and 2008. China has also shown steady growth since 2003. France is the second in publication and has gained ground when compared to Germany, England, and Japan. Russia is the sixth largest producer of articles with 456 published in the period.

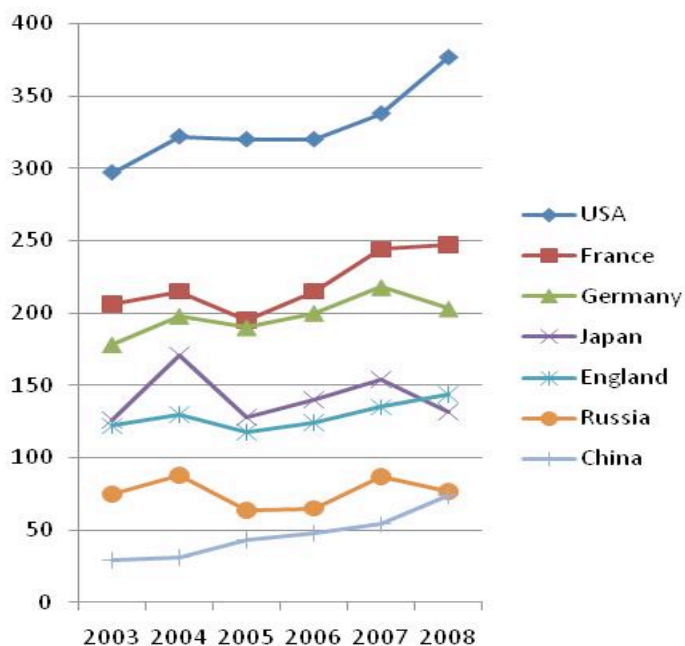


Fig.8 Neutron Scattering: number of articles published by countries.
Elaborated by the authors from ISI-SCI 2003 - 2008

Publications authored by scientists affiliated to North American institutions have increased faster than those affiliated to European ones. The average growth in publications increased from an annual rate of 2.8 percentage points between 2003 and 2006 to 9.2 percentage points between 2006 and 2008 in North America. Europe, on the other hand, declined from 2.2 percentage points between 2003 and 2006 to 1.3 percentage points between 2006 and 2008. Fig. 9 and 10 illustrate the contrast between the two regions during both periods.

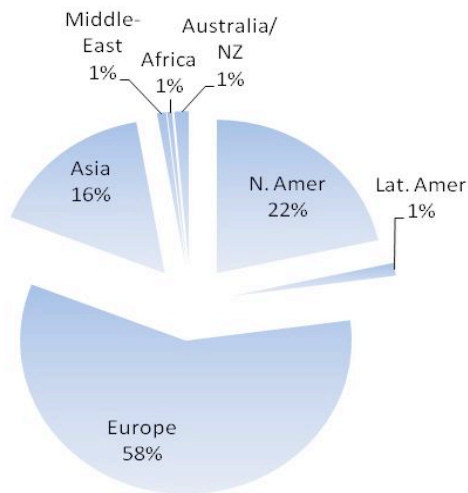


Fig.7 Neutron Scattering: publications by region. Elaborated by the authors from ISI-SCI 2003 - 2008

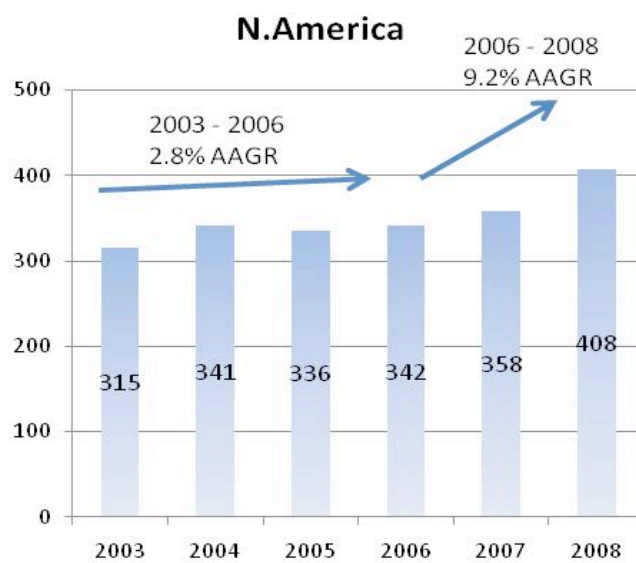


Fig.9 Neutron Scattering: publications authored by North American institutions. Elaborated by the authors from ISI-SCI 2003 - 2008

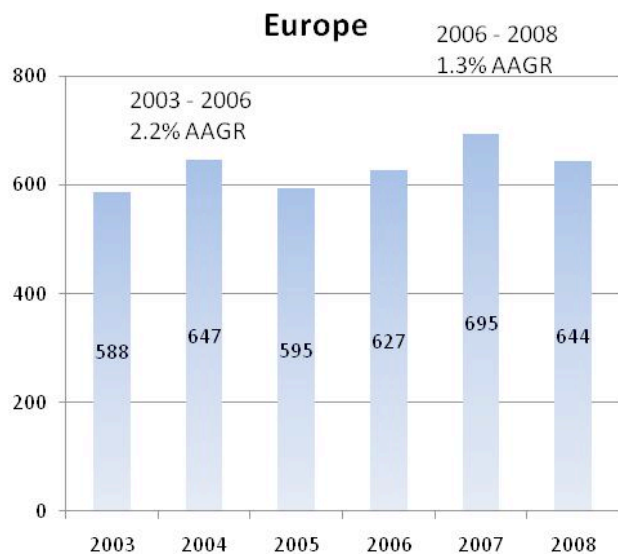


Fig.10 Neutron Scattering: publications authored by European institutions.. Elaborated by the authors from ISI-SCI 2003 - 2008

In contrast to biofuels, the main players in the science of neutron scattering remain the same, indicating some barriers of entry in the field such as beam time and high cost. The University of Maryland, and Los Alamos Laboratory have strengthened their position in the field. The Bhabha Atomic Research Center rose 8 positions, giving one sign of India's strategic interest in neutron scattering (table 3).

TABLE 3
NEUTRON SCATTERING: HIGHEST PUBLISHING INSTITUTIONS

Institutions	Country	Rank 03-06 (# of records)	Rank 07-08 (# of records)
Inst Max Von Laue Paul Langevin	France	1 (308)	1 (206)
Natl Inst of Standard & Technology	USA	2 (295)	2 (169)
Rutherford Appleton Lab, ISIS	England	3 (229)	3 (127)
Oak Ridge National Lab	USA	4 (117)	4 (87)
CEA Saclay, CNRS, Gif sur Yvette	France	5 (117)	5 (83)
University of Tokyo, Chiba	Japan	6 (121)	7 (75)
Russian Academy of Science	Russia	7 (111)	11 (57)
University of Maryland	USA	8 (99)	6 (78)
Hahn Meitner Inst Berlin GmbH	Germany	9 (97)	8 (58)
Argonne Natl Lab	USA	10 (97)	9 (57)
Kyoto University	Japan	11 (92)	20 (45)
Paul Scherrer Inst, Villigen	Switzerland	12 (87)	16 (49)
Los Alamos Natl Lab	USA	14 (82)	10 (57)
Bhabha Atom Res Center	India	20 (61)	12 (52)

Elaborated by the authors from ISI-SCI 2003 - 2008

A. Biofuels

We raised the question whether big producers of science tend to be collaborative or not. We map collaboration among the thirty countries that were the largest producers of scientific papers between 2003 and 2008. Fig.11 highlights the most collaborative interactions among countries. Each node represents a country, with larger nodes representing those having published the most between 2003 and 2008. The lines linking the nodes indicate the intensity in the collaboration. The spatial distribution of nodes also represents a measure of interaction. The distance between the nodes gives a sense of the scientific bond between two countries. The strength of the lines is calculated by a software algorithm, and only values beyond a certain threshold are taken into account by the map. For example, Brazil and France have no lines between them because the calculated linkage between them is not strong enough compared to other interactions represented in the map.

We found that European countries are more integrated in science than is the case for other countries. The big producers of science such as U.S., China, Brazil, and India, remained more isolated. The map also reveals linkages among South Africa, Australia, and Russia. Canada is more linked to Europe than the U.S. during the overall period.

B. Neutron Scattering

As expected, we found that the neutron scattering field is more collaborative than biofuels. The map in fig.12 reveals more linkages that go beyond European countries. The higher publication rate of the U.S., France, Germany, and Japan is represented by large nodes. Russia interacts with European countries, especially with former USSR (Ukraine) and Eastern European countries (Hungary, Poland, Czech Republic). Argentina has linkages with Europe through Spain. The U.S. has close ties with Canada, while France and Germany are main hubs of collaboration in Europe. Interaction between the U.S. and Europe is not strong enough compared to those among European countries. For this reason they don't appear in the map.

We also found that the number of publications with affiliations from more than two different countries is significantly higher in neutron scattering than in biofuels. Table 4 provides the proportion of publications co-authored internationally that have two, three, and more than three affiliations for each field. Overall, biofuels' international collaboration amounts to 15 percent. From those 15 percent, almost 90 percent of publications did not include more than two countries, and only 2 percent involve more than three countries, which confirms biofuels as a "small science".

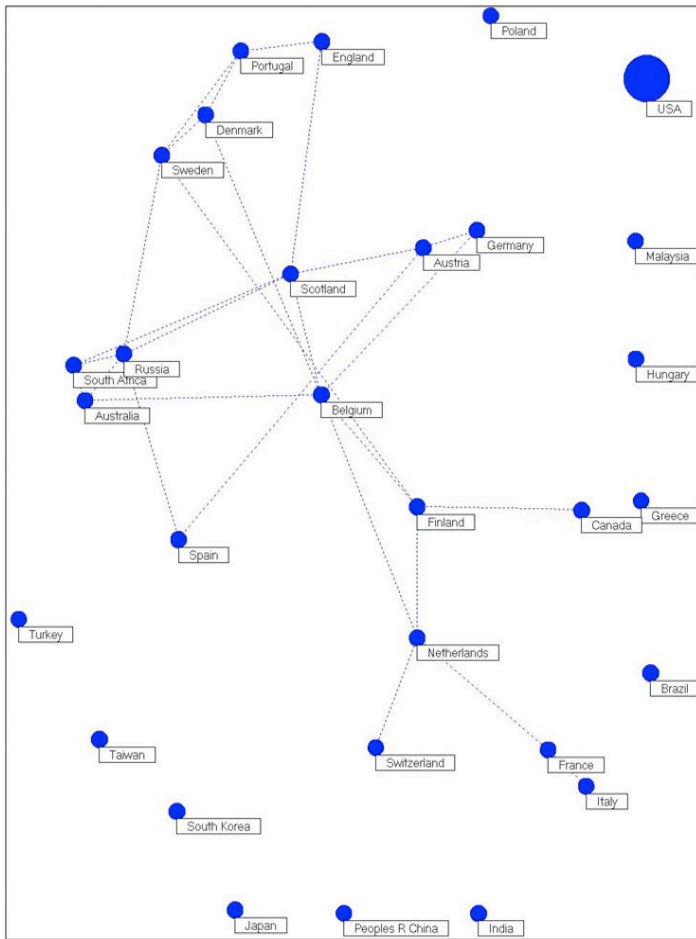


Fig.11 Biofuels: country auto-correlation map.. Elaborated by the authors from ISI-SCI 2003 - 2008

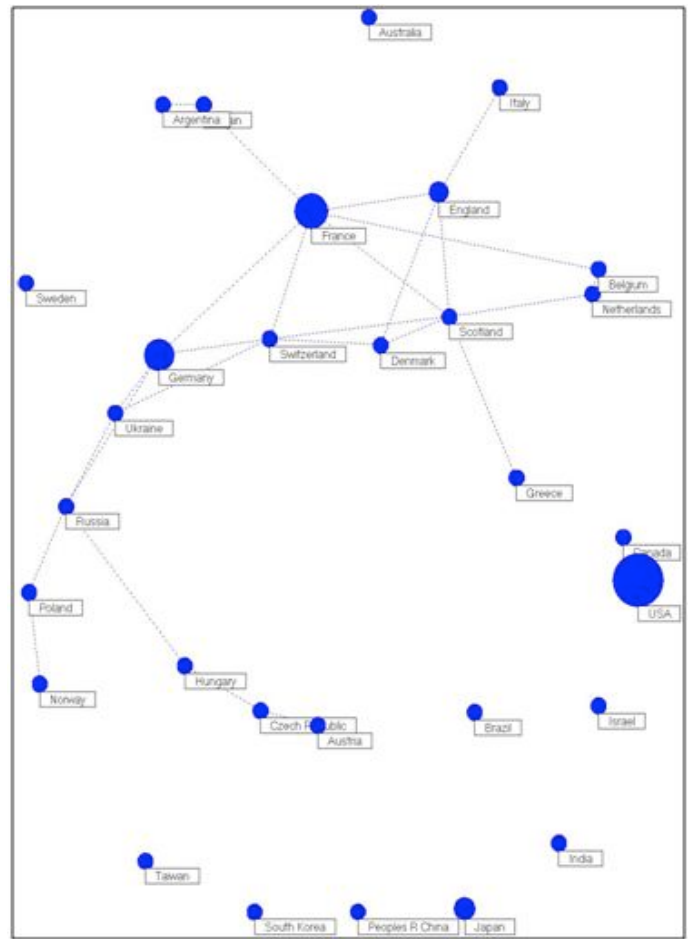


Fig.12 Neutron Scattering: country auto-correlation map.. Elaborated by the authors from ISI-SCI 2003 - 2008

Neutron scattering has a different profile. Almost 45 percent of publications involve international collaboration, from which two thirds are between two countries, one fourth is among three countries, and 9 percent involves more than three countries. Those numbers suggest that despite being more collaborative than biofuels, neutron scattering is still a “small science, but performed in big facilities”.

TABLE 4
BIOFUELS AND NEUTRON SCATTERING
PROFILE OF INTERNATIONAL COLLABORATION

Field	% Int. Collab.	2 countries	3 countries	More than 3 countries
Biofuels	15%	87%	11%	2%
Neutron Scattering	44%	67%	24%	9%

Elaborated by the authors from ISI-SCI 2003 - 2008

IV. CONCLUSION

As expected, we confirm that the field of neutron scattering is more collaborative than the field of biofuels. However, the number of publications involving more than three countries is very small, suggesting that neutron scattering is in fact a small science performed in big facilities. We find that the proportion of publications involving more than two countries was significantly higher in neutron scattering than in biofuels. The overall level of international collaboration as a proportion of total publication is higher in neutron scattering (44%) than in biofuels (15%).

The U.S. remains the leader in scientific production both in biofuels and in neutron scattering, but the American dominance is not reflected in its relative intensity of international collaboration. European countries are more collaborative than the U.S. in both fields in relative terms. Some of the BRIC countries – Brazil, India, and China – are becoming important players in the science of biofuels, and the U.S. cannot lose sight of opportunities for international collaboration with those emerging countries.

The top five institutions publishing in neutron scattering during 2007-2008 are the same top five publishing in 2003-

2006. In the case of biofuels, three new players joined the top five institutions in 2007-2008, when compared to 2003-2006 (tables 2 and 3). This may indicate that biofuels – being performed in small laboratories - offers fewer barriers of entrance than neutron scattering.

The analysis we developed in biofuels raise some potential topics for future research. With the emergence of new players in science from the South, developed countries should redefine international research collaboration between North and South, moving from “assistencialism” to become part of the core in the strategy of research policy. A better understanding of patterns of international collaboration between North and South in biofuels over time would help in guiding U.S. and European international research strategy in the future.

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