commentary

# Brazilian science towards a phase transition

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**The historical trajectory of materials science in Brazil shows the fast establishment of a high-quality, sizeable and productive scientific community. It is now time for a change in attitude towards real innovation and excellence.**

The Amazon forest covers about 40% of the Brazilian territory, an area about 6.5 times larger than France. There, a very rich ecosystem exists in a metastable equilibrium on a generally poor soil base, which makes deforestation a very serious problem. However, a rather frequent and interesting phenomenon can be found in the region, the so-called *Terra Preta de Índio*, or Indian Black Earth (Fig. 1). This soil can be distinguished from other types by its black colour and by its unusually high productivity[1,2]. It has produced much more vigorous and nutritious crops and fruits than any other soil in the region over a much longer usage time[3,4], and its formation is generally attributed to ancient agricultural activity by former Amazonian civilizations[5]. Among the unusual aspects of the black soil is a high amount of carbon, up to 70 times more than is present in other soils. Understanding the structure of these carbon materials, the way they have been formed and their role in keeping the soil productive over a long period of time are necessary questions to be answered so that such soil can eventually be reproduced in a laboratory.

It would be natural for Brazilian researchers to have a highly visible role in this subject area. Brazilian institutes such as the Instituto Nacional de Pesquisas da Amazônia and the Empresa Brasileira de Pesquisa Agropecuária are well financed and ideally structured to deal with the scientific and technological issues related to the Amazon region and agriculture, respectively, having held many research programmes and organized national and international meetings on Indian Black Earth. It is also important to mention the considerable impact made by publications written by Brazilian researhers on related subjects, for example on carbon materials. A simple crosslinked search using the ISI Web of Science database between the words 'carbon' and 'Brazil' yields around 9,000 publications with over 100,000 citations. However, despite all this investment and effort, no Brazilian paper in the field

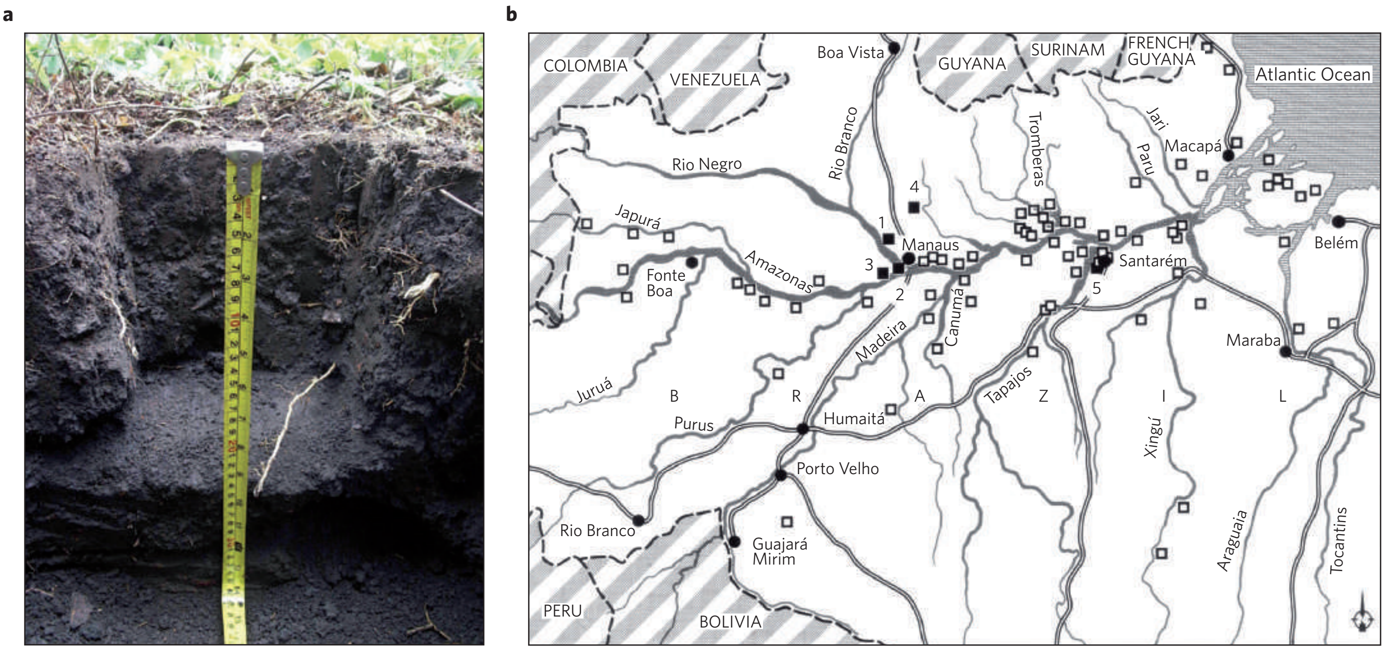


**Figure 1 |** Materials science in the jungle. **a**,**b**, The *Terra Preta do Índio* (**a**) can be found in different locations in Amazonia (**b**), with marked regions shown on the map[6]. Open squares represent principal known *Terra Preta* sites, and filled squares show the locations of *Terra Preta* sites. Part **a** is reproduced courtesy of Newton Falcão, from the Instituto Nacional de Pesquisas da Amazonia; part **b** is reproduced with permission from ref. 6.

has appeared in a high-impact journal such as *Nature* or *Science*. The case of the *Terra Preta de Índio* is a typical example of science in Brazil, characterized by solid and important work and that only needs a change in attitude to reach the top level of excellence in results.

## Building science from scratch

Brazilian history in science and innovation with worldwide impact started only in the early twentieth century with Alberto Santos Dumont and Carlos J. R. Chagas. Santos Dumont, the son of a wealthy family of coffee producers, lived most of his life in Paris, where he developed the first practical dirigible balloons, flying around the Eiffel Tower in 1901. He also performed the first ever public flight of an aeroplane in 1906, with his 'No. 14-bis' aircraft. Chagas, also the son of coffee farmers, worked at the Oswaldo Cruz Institute in Rio de Janeiro. There, and in the Brazilian hinterlands, he discovered in 1909 the Chagas disease. His work is almost unique in the history of medicine: he described the whole infectious disease cycle — the parasite, the vector, the clinical manifestations and the epidemiology. The achievements of Chagas and Santos Dumont are still being felt today: Chagas's results are closely related to the strong Brazilian research community in epidemiology, while Santos Dumont's pioneering efforts helped to launch the highly successful Brazilian aerospace industry — Brazil's Embraer is at present the third-largest aircraft producer in the world.

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It was only in 1951 that the Brazilian government created the first two public agencies charged with the task of developing scientific research: the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) had the aim of promoting and stimulating scientific and technological investigations. On the other hand, the Comissão de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) was set up to develop and improve human resources for teaching and research. As a result of these initiatives, the number of Brazilian publications (as registered in the ISI Web of Science) grew exponentially from 19 between 1960–1970 to more than 200,000 in this past decade (Fig. 2a).

Brazilian research in condensed-matter physics and materials science effectively started in the late 1960s. A large supply of international credit resulted in huge investments in infrastructure: federal freeways, hydroelectric and nuclear power plants, oil extraction and refineries. At the same time, infrastructure for university research, focused mainly on natural sciences and engineering, also started to be built up. Also worth mentioning is the creation in 1966 of Universidade de Campinas and the establishment of research infrastructure in several federal universities, as well as state universities in São Paulo state. In the case of experimental condensed-matter research, the early 1970s saw the setting up of research departments in Universidade Federal de Minas Gerais; Universidade Federal de Pernambuco; Universidade de São Paulo; Universidade Federal do Rio Grande do Sul, as well as others. In the 1970s and 1980s, the physics and chemistry departments at those universities received large amounts of federal grants — mainly through the Financiadora de Estudos e Projetos federal agency — to develop research in the growth and characterization of semiconductors and for the establishment of optical, magnetic and other materials characterization techniques. This move was essentially the origin of materials research in Brazil as a whole. From the 1990s to the present time, this federal research financing system has been replaced by local state agencies and by federal financing of large specific projects and research networks.

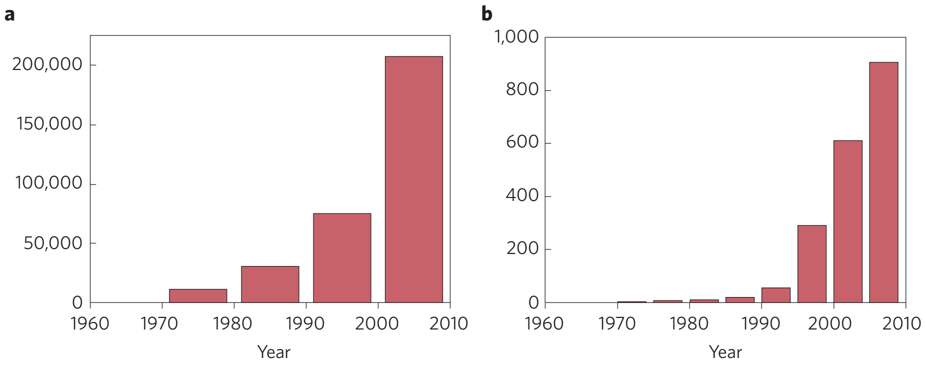


**Figure 2 |** Brazilian science in the literature. **a**, Total number of Brazilian publications per decade. **b**, Number of Brazilian publications in journals with the word 'materials' in the journal's name. Each bar represents the number of papers published over a five-year period. The data are taken from the ISI Web of Science database.

## Economic growth and investments

According to the International Monetary Fund, in 2009 Brazil was among the ten richest countries in the world (Fig. 3a). However, when the gross domestic product (GDP) is analysed per capita, the difference between developed and developing nations is clearly shown (Fig. 3a, solid line). Developed countries also show a higher percentage of GDP investment in research and development (Fig. 3b). This is the picture we hold today, after the turbulent twentieth century, a period when Brazil oscillated between democracy and dictatorship; from so-called economic miracles with average economic growth at 10% each year for many years in a row to explosive inflations, reaching values as high as 365% each year. It can be argued that Brazil achieved a healthy economic and political structure only in the early 1990s, and it has been maintaining it ever since. Nowadays, Brazil is a member of several economic organizations such as Mercosul, the União de Nações Sul-Americanas, the G8+5 and the G20, and has hundreds of international commercial partners (25.9% coming from Latin America, 23.4% from the EU, 18.9% from Asia, 14.0% from the United States and 17.8% from elsewhere). In the 2009 meeting of the World Economic Forum in Davos, Brazil was considered the country with the largest increase in economic competitiveness. Brazil has a sophisticated technology sector, with projects in aviation, submarines, space research (Brazil is a member of the International Space Station), biofuels (with an emphasis given to ethanol) and petroleum (73% of the petroleum used in the country is produced in Brazil itself). However, Brazilian companies, with a few exceptions, still do not have their own research and development laboratories and are scarcely supporting university research. As a partial solution to this problem, the federal government has established the 'Fundos Setoriais' — or sectoral funds — system, which is based on the taxation of companies to finance research in their areas of production.

Research funding has therefore increased substantially in the past decade, even though it has been mostly financed by the government. Recently, National Institutes in Science and Technology have been established by the federal government through a nationwide competition, following the successful steps of previous programmes such as the Millenium Institutes (2001) and the National Research Networks (2006). These large thematic projects have allowed the establishment of networks of researchers selected by excellence, who can nowadays work in strong collaboration in long-term financed projects. Strategic research centres have also been created and financed, such as the Centro de Tecnologias Estratégicas do Nordeste (CETENE); the Materials Metrology Division (Dimat) at the Brazilian Metrology Institute (Inmetro; Fig. 4); and the Biofuels Laboratory in São Paulo (Laboratório Nacional de Ciência e Tecnologia do Bioetanol; CTBE). The first (CETENE) is part of a big project to induce stronger development in the poorest regions of Brazil (the north and northeast). The second (Dimat) represents a push to develop state-of-the-art scientific metrology in the country: today, Dimat operates the southern hemisphere's first aberration-corrected electron microscope. The last — CTBE — represents the investment of the Brazilian government to maintain Brazil's leading position as one of the world's most important sources of renewable energy. Moving now to the personal level, research funding per researcher in Brazil is at the same level compared to the most wealthy nations (Fig. 3c), although when the same value is plotted per capita (Fig. 3d), a large discrepancy is still seen. This shows that despite recent increases in numbers, Brazil's research community is still relatively small.

## Does Brazil have critical mass?

The present stable economy in Brazil is allowing the country to attack its most serious societal problem, the very low education level of the population, which is associated with the large income disparity. Although in 2003 Brazil spent R$18 billion (R$ is the Brazilian unit of currency, the real), in basic education, in 2010 the Brazilian Department of Education invested R$59 billion (1 US$ ≈ 2 R$). In the past five years, 13 new federal universities were built, as well as over a hundred new campuses for existing universities. The number of students at federal universities doubled in the last eight years. The programme to combat illiteracy is today held in nearly 2,000 cities with indices higher than 25%. The average number of years in basic school in 1992 was below five, whereas in 2008 it surpassed an average of seven years. The present state of undergraduate and graduate education is discussed below.

Brazil's population is close to 193 million, with 28.5% aged between 15–29 years old. According to the Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira, in 2008 more than 2,000 education institutions offered almost 25,000 undergraduate courses. More than 3 million seats are offered by selective processes in undergraduate programmes that have more than 300,000 professors. Most colleges are linked to the private sector (over 90%), while universities are evenly distributed between the public and the private sectors.

In 2009 there were over 4,000 graduate courses in Brazil, including 1,500 PhD programmes (34.4%) and more than 52,000 professors. At the end of 2009 there were 160,000 graduate students, 58,000 in PhD programmes; this number was below 1,000 in the early 1980s. Interestingly, there is a clear correlation between the number of PhDs and the number of articles published in journals with international circulation. Also remarkable is the change in scholarship modalities given by CNPq and CAPES to Brazilian students and researchers in the past six years: first, the number of inland fellowships had a 50% increase, while the number of fellowships for studying abroad has stopped growing. Second, within these fellowships for studying abroad, the number of fellowships for developing a PhD programme in another country reduced by about 50%, while the number of short-term interchange periods (visiting projects, post-docs and sabbaticals) increased. These changes indicate the maturity of Brazilian graduate programmes. Fortunately, the number of students and researchers going abroad and not returning to Brazil is very low, as Brazilians are generally attached to their culture and the country is able to guarantee a good working structure for new researchers.

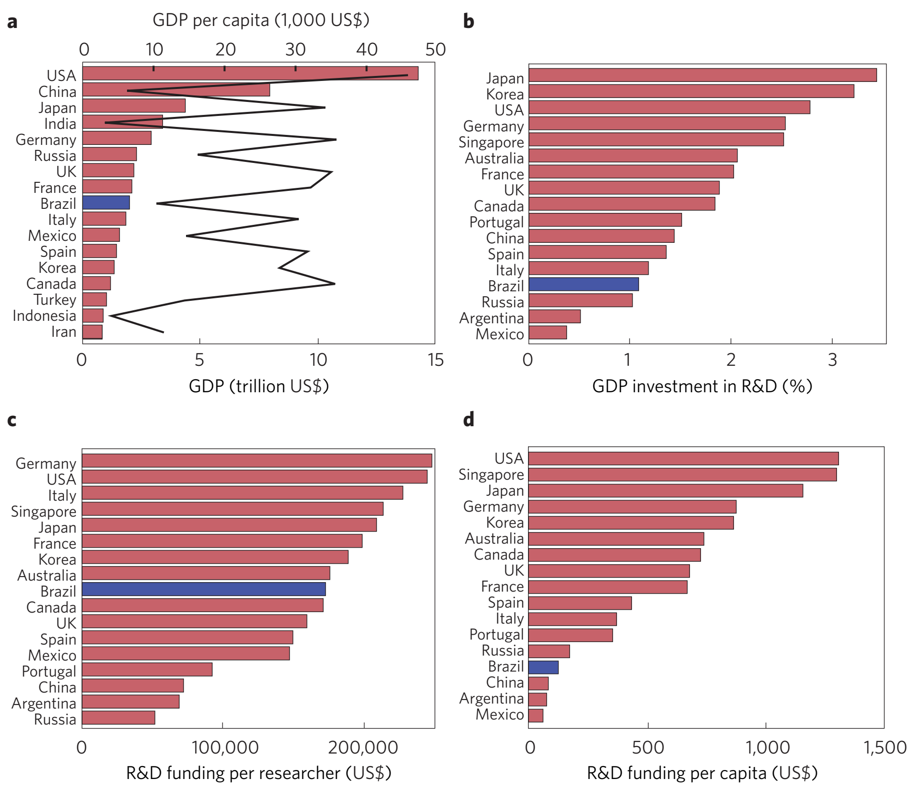


**Figure 3 |** Science funding. **a**, The coloured bars show the GDP of the world's 17 richest countries, according to the International Monetary Fund. The solid line shows the GDP per capita. **b**, Percentage of the GDP applied to research and development (R&D) so far in 2010. **c**, Research funding per researcher. **d**, Research funding per capita. The data are obtained from the Brazilian Department for Science and Technology and are updated frequently[7].

## The status of materials research in Brazil

With appropriate infrastructure, investment and levels of educational, nowadays there is in Brazil a relatively large community of physicists, chemists and engineers performing high-level research in materials science. For instance, the Encontro National de Física da Matéria Condensada (National Condensed Matter Physics Meeting) of the Brazilian Physical Society began with 80 participants in 1978 and is held annually, with about 1,300 participants in 2010. The Brazilian Materials Research Society, founded in 2001, also holds annual meetings with about the same number of participants. The international visibility of this community has also increased, as indicated by the organization of several international conferences such as the Eighth International Conference on the Science and Application of Nanotubes (NT07); the International Conference on the Physics of Semiconductor (ICPS 2008); and the International Conference on Advanced Materials (ICAM 2009), all held in Brazil. International prizes have also been awarded. For instance, the 2009 Sômiya Award from the International Union of Materials Research Societies recognized the importance of seven researchers in the field of carbon, and three of them were from Brazil. The number of articles and citations has also been strongly increased, as demonstrated above by those in the theme 'carbon'.

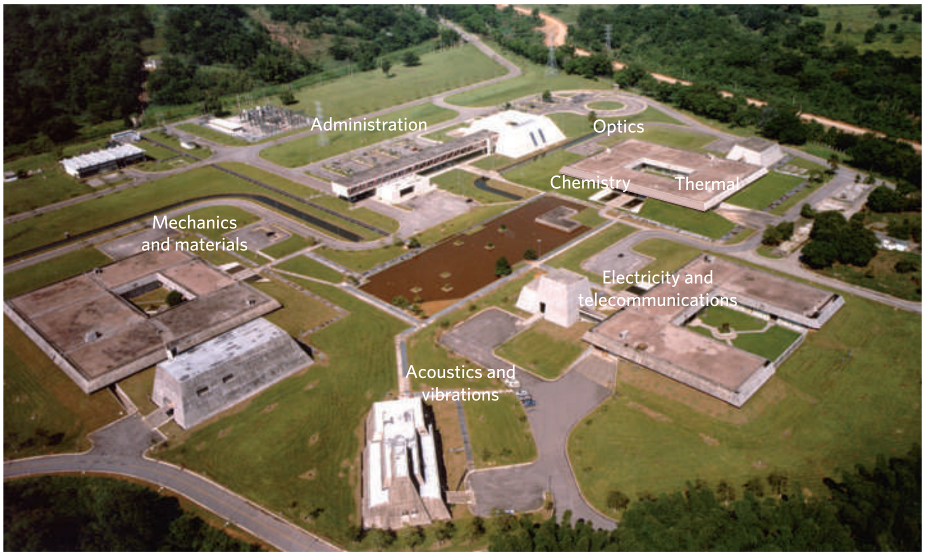


**Figure 4 |** Part of the scientific campus of the Brazilian Metrology Institute (Inmetro). The campus is based on a special geological area and far from any urban centre. Most laboratories are built on top of concrete, rubber and sand, without physical connections with neighbouring laboratories and corridors. Picture courtesy of Inmetro.

> Researchers need to focus on frontier aspects of more risky but potentially more relevant problems.

This rise in the size of the materials science community is also evident from the number of publications. So far in 2010 there have been about 1,000 Brazilian papers in journals specializing in materials science. But although this number is almost an order of magnitude smaller than in countries such as Germany, England, France and the United States, it has grown exponentially in the past decades, as illustrated in Fig. 2b. The scenario is very similar for condensed-matter physics, with about 3,000 papers and more than 40,000 citations; again, not yet at the level of other countries, but dramatically higher than not too long ago.

A more problematic picture emerges if we look at publications that reflect clear conceptual advances. As an example, we can just consider the publications in a journal such as *Nature Materials*: in these past eight years the journal has published more than 800 papers by authors from the United States, over 200 from the United Kingdom, more than 100 from Japan, and merely four from Brazil. Another example is the number of patents: of the 499 Brazilian patents requested to the United States Patent and Trademark Office in 2008, only 131 were granted, a very low number for a country that wants to transfer its scientific outcomes to society.

## Approaching the critical point

Brilliant flares in science and innovation, like the work of Santos Dumont and Chagas, seem not to have inspired in Brazil a 'mass production' of innovative minds. A very respectable infrastructure is in place: over 800,000 Brazilian students graduated in 2008; the size of the research community and the available funding for research will probably continue to increasing at a higher rate. With sustainable economic growth and the considerable increase in the level of education in Brazil, the time has come for a transition from solid but incremental science towards real innovative research. What is needed is a phase transition that should be based on two strongly correlated aspects. On the one hand, the country needs a closer connection between the economy and science, with the involvement of the national industrial sector — it should be noted that less than one fifth of graduate courses in Brazil are technology oriented. On the other hand, however, researchers themselves need to focus on frontier aspects of more risky but potentially more relevant problems, submitting their work to the most visible journals whenever they find exciting results, rather than focusing on publishing partial results to increase the total number of papers. Only in this way can researchers build the scientific basis for economic and social development with strong participation of the national industrial sector. Once such a shift in attitude has occurred, we will not have to wait long for Brazilian science to exploit its full potential and reach the level of excellence enjoyed by other countries. ❐

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