old chemical phosphatic fertilizer technology. We sent the results for favour of publication to *Current Science*. Initially, we were asked to name some experts in the area. We did propose a few names. Then we got a reply that the subject was highly specialized and hence cannot be published in *Current Science*. I wrote a letter to *Current Science*, drawing the attention of the editor, explaining the importance of the work. That paper eventually appeared[5] in *Current Science* as Scientific Correspondence. Today we have a PROM (phosphate rich organic manure) Society that is working for large scale implementation of this technique.

The majority of flotation researchers believe that flotation is a first order rate process, which is not true! My correspondence in minerals engineering with G. E. Agar, to resolve the dispute, is now history.

In my opinion, peer review is an unavoidable and painful process for young scientists till they publish ten articles in peer reviewed journals. After that, one will find that peers may be as ignorant.

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How much should a nation spend on academic research?

Gangan Prathap

How is India performing on the world stage in academic research? To put this in proper perspective, one needs an indicator that provides a rational estimate for R&D activity, and then normalize this for size. Recent studies[1–3] show that a single indicator with energy-like properties can effectively combine size and quality of scientific output. The proxy for the exergy (a more accurate thermodynamic definition of the energy-like term expressed by the formula that follows) of ideas turns out to be $E = iC = i^2P$, where P is measured in the unit in which ideas are conveyed (here, the number of papers) and i is a measure of the rate at which ideas are transmitted as citations C (here, $i = C/P$ is a proxy for quality, while C itself is a proxy for size or quantity of output). When this exergy audit is applied to the data on leading countries in research in all fields published by Essential Science Indicators of Thomson-Reuters for 1998–2008, Table 1 emerges. On a per capita basis, Switzerland produces 1108 times the academic research activity that India does. The average for the 28 countries listed in Table 1 is 82 times what India does. The exergy performance can also be displayed on a two-dimensional contour map as shown in Figure 1. The 'BRIC' countries cluster right at the bottom of the hill.

To understand Table 1 and Figure 1, one must go into the economics of R&D activity. Marburger III[4] asked, among other questions pertinent to the emerging discipline called 'science of science policy': 'How much should a nation spend on science?'. An attempt to answer some of these questions was made recently by Leydesdorff and Wagner[5]. The idea is to come up with relevant macro-level benchmarks which can be used to compare the efforts made by different nations in R&D. Many countries appear on the radar in Leydesdorff and Wagner[5], but not India! This article is devoted to see how India fares in the company of some of the leading players in global R&D, using the indicators and benchmarks that best serve to throw reasonable light on these activities[5].

Table 2 is a precursor to Figure 2. It computes the total R&D expenditure as a percentage of Gross Domestic Product (GDP), 2006 (selected nations)[6]. The data is sorted using the indicator (R&D Exp/GDP)/(FTER/population) as a

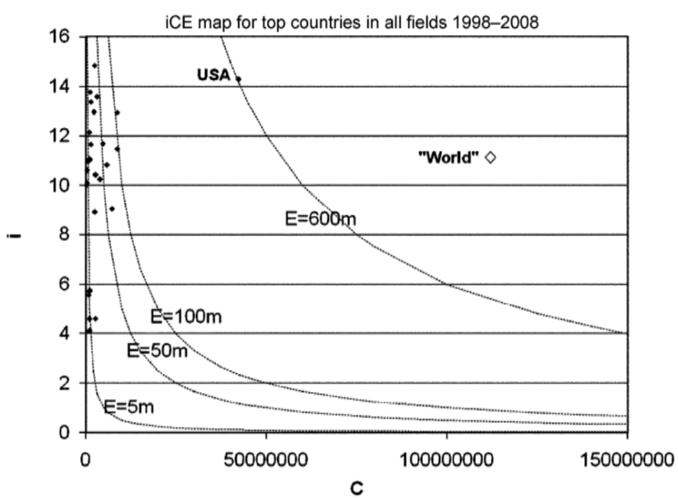

Figure 1. Exergy performance on a two-dimensional contour map.

Table 1. Exergy audit applied to the data on leading countries in research in all fields published by Essential Science Indicators of Thomson-Reuters for 1998–2008

Ranked by *E*/population								
Rank	Field	Papers	Citations	Citations per paper	Population	Exergy *E*	*E*/Pop	Normalized
1	Switzerland	168,527	2,502,210	14.85	7,637,300	37,151,642.67	4.864500	1108
2	Denmark	91,670	1,262,693	13.77	4,588,600	17,392,752.40	3.790427	863
3	Scotland	106,209	1,422,252	13.39	5,168,500	19,045,474.03	3.684913	839
4	Sweden	174,418	2,257,641	12.94	9,215,021	29,222,573.84	3.171189	722
5	Finland	85,567	1,038,721	12.14	4,588,600	12,609,315.69	2.747966	626
6	Netherlands	231,682	3,148,005	13.59	16,445,000	42,773,868.84	2.601026	593
7	USA	2,959,661	42,269,694	14.28	304,917,000	603,693,136.09	1.979861	451
8	England	678,686	8,768,475	12.92	60,587,300	113,286,783.32	1.869811	426
9	Israel	109,637	1,210,807	11.04	7,303,000	13,371,887.15	1.831013	417
10	Canada	414,248	4,837,825	11.68	33,351,800	56,498,886.49	1.694028	386
11	Norway	63,017	691,881	10.98	4,610,820	7,596,352.07	1.647506	375
12	Belgium	125,520	1,461,478	11.64	10,584,534	17,016,554.69	1.607681	366
13	Australia	267,134	2,784,738	10.42	21,394,309	29,029,497.29	1.356879	309
14	Wales	35,318	374,996	10.62	2,980,700	3,981,595.79	1.335792	304
15	Austria	87,953	974,554	11.08	8,192,880	10,798,443.47	1.318028	300
16	Germany	766,146	8,787,460	11.47	82,191,000	100,789,475.18	1.226284	279
17	North Ireland	17,376	174,069	10.02	1,750,000	1,743,785.49	0.996449	227
18	France	548,279	5,933,187	10.82	64,473,140	64,205,829.47	0.995854	227
19	Ireland	37,396	377,181	10.09	4,156,119	3,804,297.43	0.915349	209
20	Italy	394,428	4,044,512	10.25	59,619,290	41,472,910.94	0.695629	158
21	Japan	796,807	7,201,664	9.04	127,690,000	65,089,744.91	0.509748	116
22	Spain	292,146	2,602,330	8.91	46,063,000	23,180,606.37	0.503237	115
23	Taiwan	144,807	828,751	5.72	22,920,946	4,743,059.52	0.206931	47
24	South Korea	218,077	1,256,724	5.76	48,224,000	7,242,190.66	0.150178	34
25	Russia	276,801	1,135,496	4.1	1,418,889,00	4,658,043.74	0.032829	7
26	Brazil	157,860	880,821	5.58	187,522,000	4,914,770.27	0.026209	6
27	People's R China	573,486	2,646,085	4.61	1,325,637,000	12,209,131.22	0.009210	2
28	India	237,364	1,088,425	4.59	1,136,961,000	4,990,937.89	0.004390	1
	'World'	10,060,220	111,962,675	11.13	3,750,661,759	1,352,513,546.92	0.360607	82

Table 2. Total R&D expenditure as percentage of Gross Domestic Product (GDP), 2006 (selected nations) from http://www.aaas.org/spp/rd/intl206.pdf

Nation	R&D Exp/GDP	FTER/population	Leverage
Russia	0.0108	0.0033	3.2727
Finland	0.0345	0.0078	4.4231
Singapore	0.0231	0.0050	4.6200
Ireland	0.0132	0.0027	4.8889
Canada	0.0194	0.0036	5.3889
Spain	0.0120	0.0022	5.4545
United States	0.0262	0.0046	5.6957
Japan	0.0339	0.0053	6.3962
United Kingdom	0.0178	0.0027	6.5926
France	0.0211	0.0032	6.5938
Taiwan	0.0258	0.0039	6.6154
Sweden	0.0373	0.0054	6.8870
Germany	0.0253	0.0033	7.6667
Italy	0.0109	0.0012	9.0833
South Korea	0.0323	0.0032	10.0938
China	0.0142	0.0007	20.0000
India	0.0070	0.0001	58.8235
Averages	0.0215	0.0034	6.2632

Source: OECD, Main Science and Technology Indicators, 2008.

dimensionless leverage term, where FTER is the estimate of the active research population (Full Time Equivalent Researchers). Note the following equivalence:

(R&D Exp/GDP)/(FTER/population) = (R&D Exp/FTER)/(GDP/population).

In other words, the leverage term is a measure of the multiple of the per capita income of a nation that each nation is willing to invest in each of its R&D workers (total of salary and infrastructure costs). For the 17 nations in our list, the average is 6.2632, implying that for most nations (mostly in the developed group of nations), a country is prepared to invest 6–7 times the per capita income on each FTER. The leverage for India is the highest for this cohort because as a developing nation, it must pay developed world costs for its equipment and infrastructure even if its salary costs may be

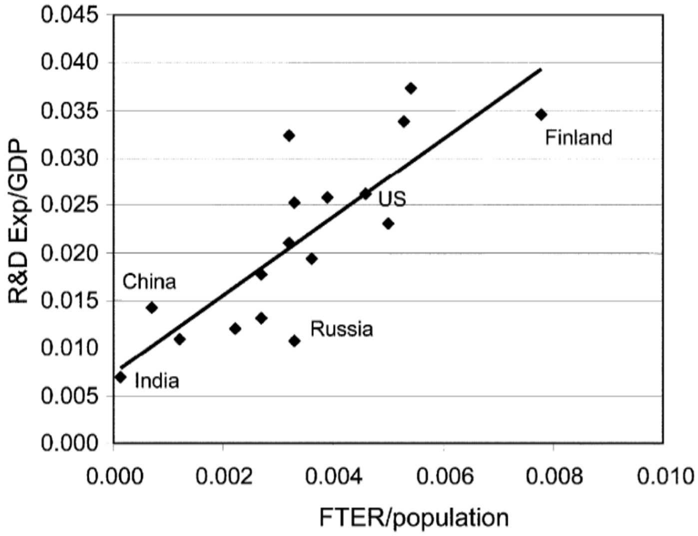

Figure 2. Re-working figure 5 of Leydesdorff and Wagner[5] to show the main input (or outlay) indicators: the percentage of GDP spent on R&D and the number of researchers as a proportion of total population.

more closely related to purchasing power parity figures. The United States has a nominal per capita income (http://en.wikipedia.org/wiki/List_of_countries_by_GDP_(nominal)_per_capita) of US$ 46,859 and it invests 5.6957 times this amount, i.e. nearly US$ 300,000 a year on each R&D worker. If we continue with nominal values of GDP and per capita income (US$ 1016), this formula will imply that India invests about US$ 60,000 a year on each FTER. Since the average salary cost of an Indian FTER may be less than US$ 10,000 a year, a proportionately huge share goes for equipment and infrastructure costs. However, the cost of doing research in India is considerably lower than in the US, giving theoretically a competitive advantage for those who propose to outsource contract research to India.

Figure 2 now re-works figure 5 of Leydesdorff and Wagner[5] to show the main input (or outlay) indicators: the percentage of GDP spent on R&D and the number of researchers as a proportion of total population (in figure 5 of Leydesdorff and Wagner[5], the latter is shown as permillage of total employment). From Table 2, we see that four countries (Finland, Japan, Sweden and South Korea) already spend more than 3% of their GDP on R&D. For India to reach this league, not only must it increase its investment by 30–50 times but its number of R&D workers by 30–80 times.

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