The Changing Trends in Research on Slags

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ABSTRACT

Since the first Metallurgical Slags Conference was held in 1980 in Halifax, Nova Scotia, Canada, there have been many changes in the field of research on slags and fluxes. A review of research activities involving slags over this sixteen years has been carried out to establish these changes. Surveys have been made of (i) the papers contained in the Proceedings of the Slags Conferences held in 1980, 1984, 1988 and 1992 and (ii) abstracts of references cited in metadex searches of 1979, 1987 and 1995. The information derived from these surveys has been classified according to (a) country of origin, (b) the nature of the measurements and (c) the type of slag studied.

It was concluded that (i) the centre of gravity for slag research had moved significantly eastwards with an apparent decline in EEC and American activity, (ii) rapidly increasing research effort in China, Korea and Australia, (iii) Japan has become the largest contributor to slag research and (iv) Russia remains an active centre for slag research despite the decline in research which has accompanied the disintegration of the USSR. Increased slag research was observed in (a) Foaming and Smelting Reduction, (b) Recycling and (c) Mould Fluxes.

1. INTRODUCTION

The first Metallurgical Slags Conference was held in Halifax in 1980 and subsequent conferences were held in Lake Tahoe, Glasgow and Sendai at four year intervals. The continuous drive for ever-increasing efficiencies and the introduction of environmental constraints have resulted in significant changes in metallurgical practice. In this period, there have also been huge changes in political and economic situations (such as the break-up of the USSR and the emergence of Korea and China as major producers of steel). Consequently, we have carried out a review to identify the changes in slag research resulting from the political, economic and technological changes which have occurred between 1980 and 1996.

2. METHOD OF INVESTIGATION

As a base for the investigation the programmes and the proceedings of the four slag conferences on metallurgical slags and fluxes have been used.[1234]

From the first conference in Halifax, no proceedings were published but at the symposium copies of the presentations were made and distributed. These were no longer available to the authors but the majority of the papers were published, subsequently, in the Canadian Metallurgical Quarterly. The survey is therefore based on slag-related papers published in Canadian Metallurgical Quarterly, vols 21 to 23 for the 1980 Conference and in the papers published in the Proceedings for the other Conferences. The papers have been classified according to geographical origin, nature of the slags studied and the type of research activity. To maintain consistency (a) the EEC refers to countries comprising the EEC in 1996 and (b) Russia refers to all states originally constituting the USSR.

Since presentations at the Conference are influenced by both geographical and financial considerations, they tend to give a distorted picture of research on slags. Consequently, it was decided to also review the published papers in the literature. Therefore, the available literature on slags, published in the year preceding a slag conference, was used as a reference. This year was selected to avoid distortion resulting from publications reported in the year of the Slags Conference. A literature survey through the Metadex CD-ROM system produced a listing of annual publications selected on "slags" as descriptor or as part of the publication title. The abstracts of these papers were used to identify the nature of the research investigations and the slag studied and, as far as possible, the geographical origin of the authors.

However the Metadex citations for translated journals can take up to two years to appear; this could produce a bias in the values of the geographical origin in the case of 1995. Consequently, a further search was carried out on the geographical origin of citations for 1993.

3. REVIEW OF METADEX CITATIONS

3.1 Annual citations

The total number of citations of slag-related papers between 1980 and 1995 are shown in Table 1 and Figure 1.

Table 1
The total number of citations of slag-related papers

1980	'81	'82	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	'93	'94	'95
357	321	335	376	393	389	433	382	388	405	327	329	359	339	269*	225*

*These totals may be incomplete since translated papers are not cited for 2 or 3 years after the year of publication.

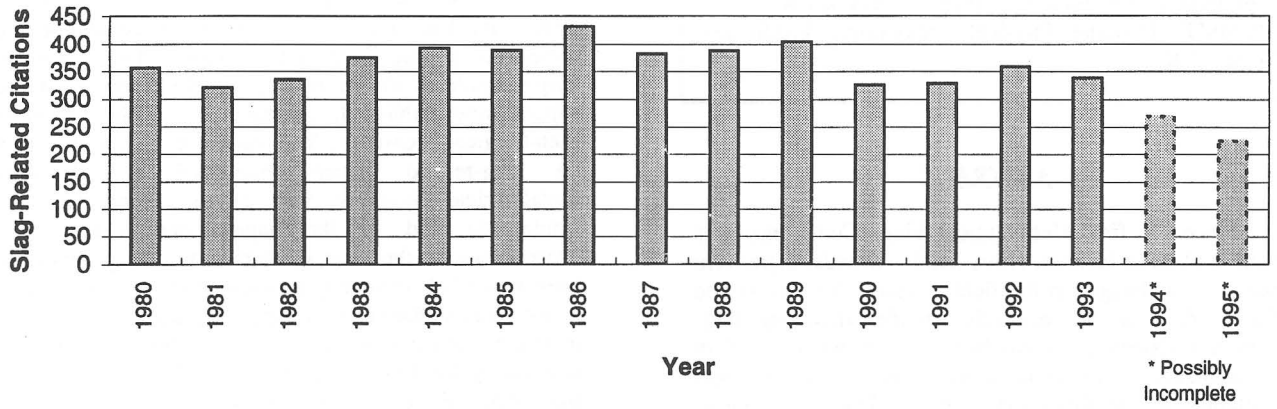

Fig 1 Annual number of publications of slag-related papers 1980 to 1995.

The totals for 1994 and 1995 may be incomplete since some translated papers are not cited until 2 or 3 years after the year of publication.

Inspection of Table 1 reveals the surprising result that the number of slag-related publications has remained reasonably constant at 350 p.a. However, a closer-inspection of the data, reveals that there was a gradual increase in publications per annum up to 1989 (where it exceeded 400) but publications fell to approximately 330 p.a in the years 1990 to 1993. These trends mirror those for the annual sales of steel. Possible reasons for the drop of about 20% in the number of slag-related publications are (a) the adverse economic conditions in the principal steelmaking nations and (b) the decline in interest in both the study and teaching of metallurgy in Europe and North America resulting in lower academic output.

3.2 Geographical origin of research

The results of the survey of publications in the years 1979, 1987 and 1993/1995 are summarised in Table 2 and Figure 2.

Table 2
Geographical origin of research on slags (%)

Country	1979	1987	1995 (1993)
USA	15.3	8.4	15.4 (9.5)
Canada	4.7	3.2	10.6 (6.5)
Japan	12.2	17.1	13.2 (22.5)
EEC	23.7	21.8	10.1 (13.4)
Russia	29.8	25.3	16,3 (15.4)
E Europe	5.4	8.4	3.1 (4.0)
China	2	8.7	15 (13.9)
Korea	0	0.5	5.7 (4.0)
India	1	1.7	2.6 (2.0)
Australia	1.4	1.0	4 (3)
S America	2	1.5	0.5 (1.5)
S Africa	1.7	0.5	1.3 (6.7)
Others	0.8	1.9	2.2 (3.5)
Total Publications	295	403	227 (402)

( ) indicates values for 1993, values for 1995 may be affected by time lag for translations.

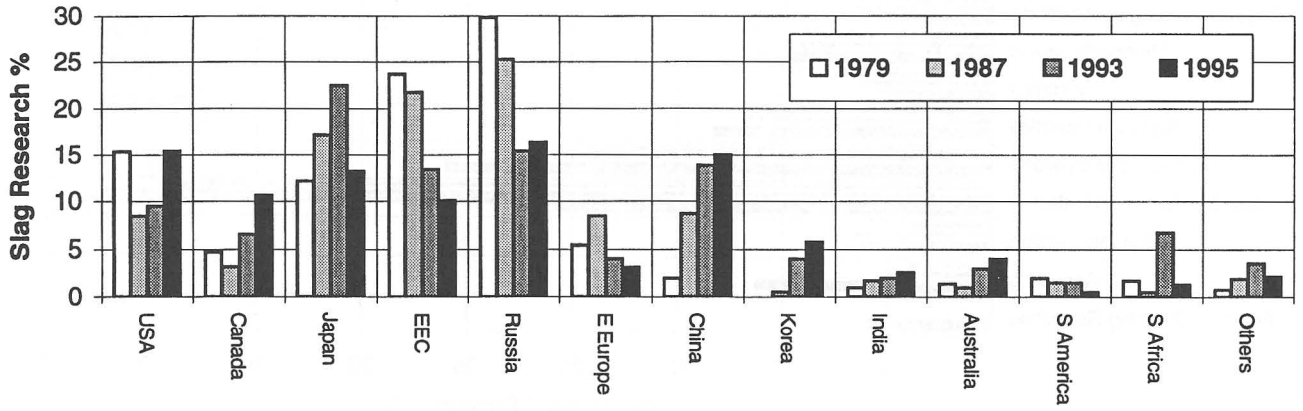

Fig 2 Geographical origin of slag-related publications in 1979, 1987, 1993 and 1995 (as %).

It can be seen from Table 2 that:

(i) Russia was the most active country in slag research with ca 30% in 1979 but the proportion of publications fell to about 15% in 1993/1995, presumably due to the upheavals following the collapse of the USSR. Nevertheless, Russia remains an active centre for slag research;

(ii) the research activity rose in Japan between 1979 and 1987 but apparently dropped in 1995; this was thought to be due to the incompleteness of the 1995 search due to the time lag required for translation and this was confirmed by the 1993 data which showed a continuous increase in activity and indicated that Japan is now the major contributor to slag research*;

(iii) the research effort in China and Korea has continued to increase and China is now a major contributor to slag research;

(iv) the research effort in the USA is apparently variable and decreasing and that in the EEC appears to have decreased significantly from 24% to 10-13%. The latter is a most surprising result.

3.3 Nature of research activity

The results of the surveys covering research activities for slags for 1979, 1987 and 1995 are given in Table 3 and in Figure 3.

Table 3
Distribution of slag-related research activities (%)

Activity	Year		
	1979	1987	1995
Phase/mineralogical equilibria	6.7	2.1	3.4
Thermodynamics	9.8	9.0	11.3
Kinetics	6.3	5.6	4.4
Physical properties	11.6	8.2	13.3
Slag/metal equilibria	19.2	19.0	26
Plant data/process modelling	38.4	43.1	20.7
Refractory erosion	4	7.9	3.4
Recycling	4	5	11.3
Foaming/Smelting Reduction	0	0	6.0
Total No	224	378	213

The research activities have remained remarkably constant although it was noted that there were increases in Foaming/Smelting-Reduction and in the Recycling of slags. The increase in the latter occurred presumably as a response to recent tighter legislation on waste disposal. It was also noted that the ratio of (S partition/P partition activities) was around 2 in 1979 but close to 1 in 1987 and 1995. This reflects the interest in hot metal treatment (including dephosphorisation) and the rapid increase in continuous casting in the steel industry, with the resultant demand for good phosphorus control

*However the 1993 figures may have slightly over estimated Japanese effort since they covered papers from the 1992 Slag Conference held in Sendai which had a large number of Japanese contributions.

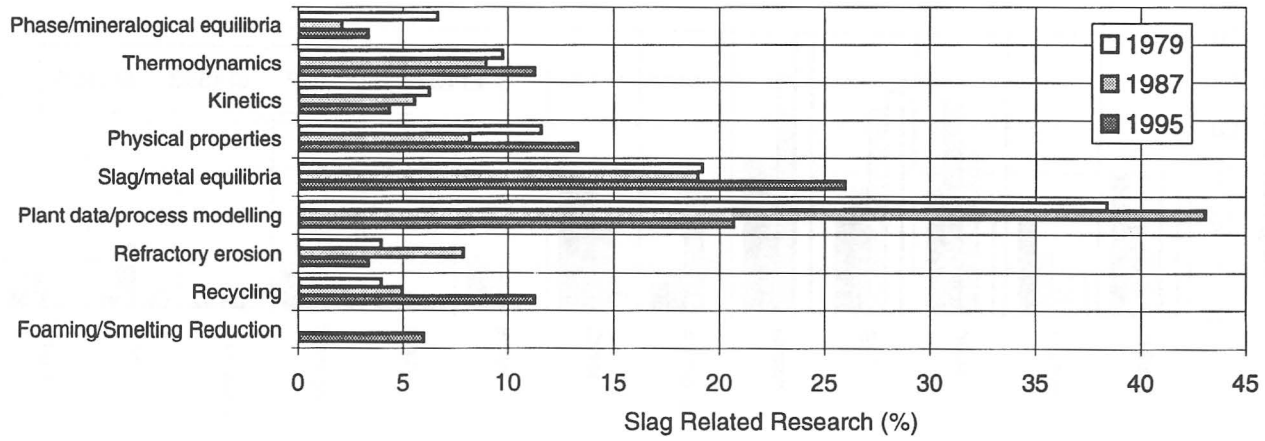

Fig 3 Research activities of slags investigations in 1979, 1987 and 1995 (as %).

through treatment in the ladle.

3.4 Type of slag studied

The results of the surveys for 1979, 1987 and 1995 are summarised in Table 4 and Figure 4.

Inspection of the results suggests that:

(i) in general, there has not been any substantial changes in the type of slag studied;

(ii) there has been a gradual increase in research on mould fluxes;

(iii) there may have been small decreases in research on Ironmaking and Steelmaking slags;

Table 4
Type of slags investigated

Slag Type	Year		
	1979	1987	1995
Ironmaking	17.3	10.1	9.2
Steelmaking	20.3	23.7	14.6
Ladle/Refining	8.2	15.4	8.4
Mould flux	4.8	5.9	13.6
Ferroalloys	3.9		1.5
Coal	0.4	0.3	0.5
Welding flux	0.9	1.2	1.5
Non-ferrous	10.4	15.6	9.7
Maltes	14.7	10.1	10.7
Synthetic	19	16.6	30.6
Total No	231	337	206

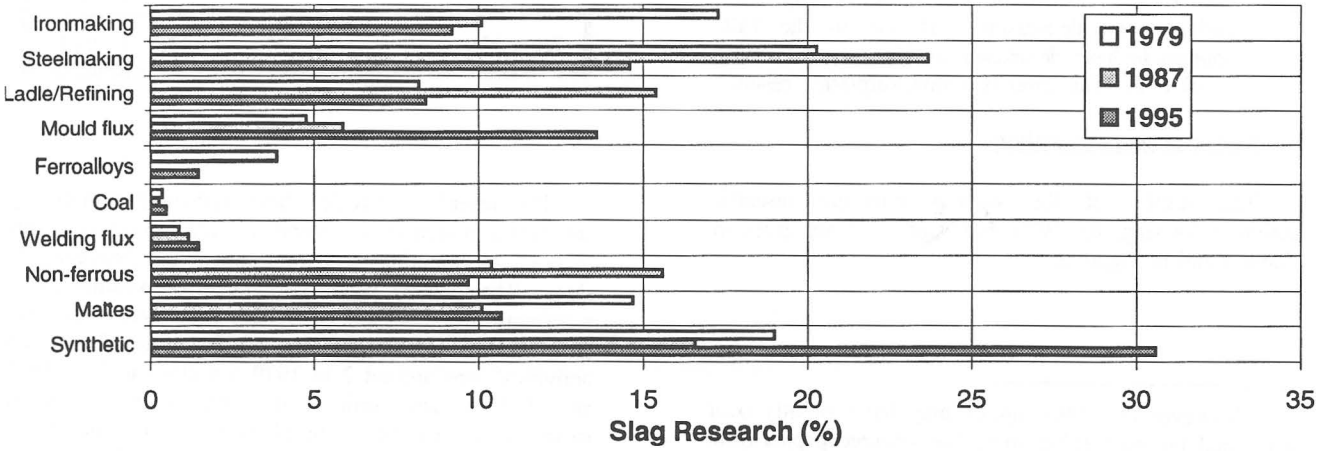

Fig 4 Type of slags studied in 1979, 1987, 1995 (as %).

(iv) there was an increase in research using synthetic slags (which would suggest an increase in fundamental studies) but this may not be real since it could be due to (a) the incompleteness of the 1995 search and (b) attribution by the present authors to the various classes of slag which is particularly difficult since a synthetic slag composition may be selected to represent, for example, a blast furnace slag or an ESR slag etc.

4. REVIEW OF CONFERENCE PROCEEDINGS

4.1 Geographical origin

The results of the review are summarised in Table 5 and Figure 5.

The results show that the Conference Proceedings publications are not a true reflection of research activity since they are affected by geographical and economic factors. For instance Russian activity in 1979 constituted 30% (Table 2) of publications compared with 5.6% in the Conference proceedings. In contrast, Japanese contributions are at a high level wherever the Conference is held. It is difficult to deduce from these data whether the large decrease in EEC research activity recorded in the Metadex Search is a real effect.

Table 5
Geographical origin of papers published in Conference Proceedings (%)

Country	Year			
	1980[(a)]	1984	1988	1992
USA	13	28.6	12.1	4.8
Canada	24	14.3	7.6	3.2
Japan	20.4	26	36.4	50.8
EEC	29.6	15.6	37.9	17.7
Russia	5.6	0	0	7.3
E Europe	0	1.3	0	1.6
China	1.9	2.6	0	6.5
Korea	0	0	0	4.0
India	1.9	1.3	1.5	0
Australia	1.9	5.2	3.0	3.2
S America	0	5.2	0	0
S Africa	1.9	0	1.5	0.8
Total No	54[(a)]	77	66	124

[(a)] Based on papers subsequently published in Can. Met Q. vols 21-23.

4.2 Nature of research activity

The results are summarised in Table 6 and Figure 6.

The distribution of research activity does not seem to have varied much after the Halifax meeting (1980) which contained above-average effort in thermodynamics, kinetics and below-average effort in slag-metal reactions and equilibria. It can also be seen that:

(i) there has been an increase in effort on Foaming and Smelting Reduction reflecting international activities in both smelting processes such as DIOS, Hismelt, AISI Direct Reduction etc projects;

(ii) the increased research effort in Recycling noted in the published literature is not reflected in the papers presented at the Conferences;

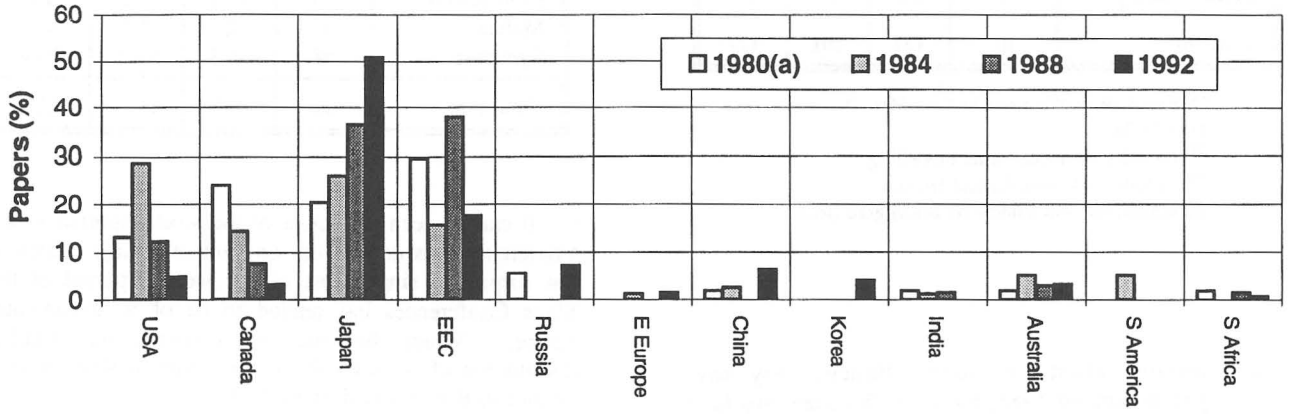

Fig 5 Geographical origin of papers published in Slags Conferences Proceedings held in 1980, 1984, 1988, 1992 (a) see footnote to Table 5.

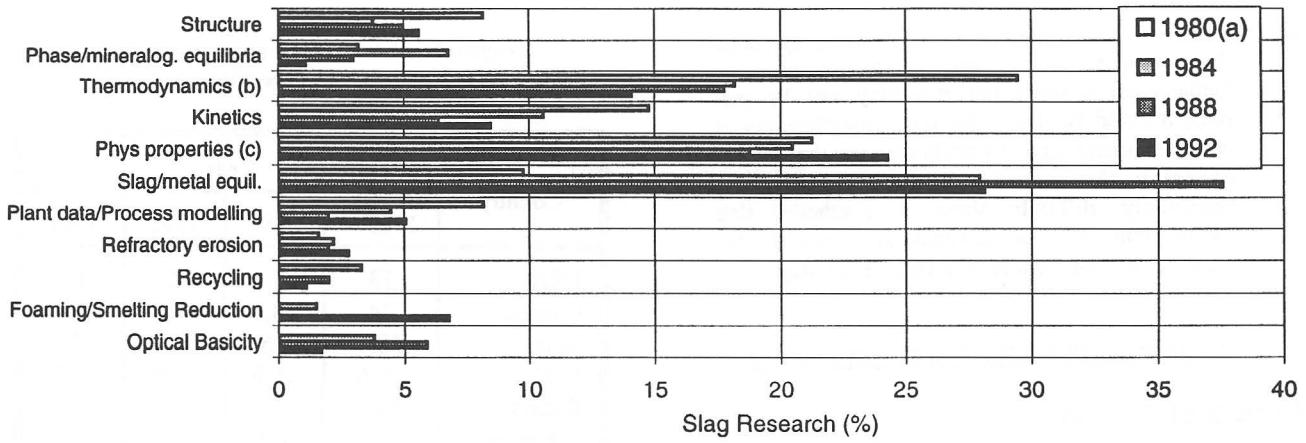

Fig 6 Nature of research activity in papers published in Slag Conference Proceedings (a) see footnote to Table 6.

Table 6
Nature of research on slags published in Conference Proceedings (%)

Research Study	Year			
	1980[a]	1984	1988	1992
Structure	8.2	3.8	5	5.6
Phase/mineralog. equilibria	3.2	6.8	3	1.1
Thermodynamics[b]	29.5	18.2	17.8	14.1
Kinetics	14.8	10.6	6.4	8.5
Phys properties[c]	21.3	20.5	18.8	24.3
Slag/metal equil	9.8	28	37.6	28.2
Plant data/Process modelling	8.2	4.5	2	5.1
Refractory erosion	1.6	2.2	2	2.8
Recycling	3.3	0	2	1.1
Foaming/Smelting Reduction	0	1.5	0	6.8
Optical Basicity	0	3.8	5.9	1.7
Total No	61	132	101	177

[a] Based on publications in Can. Met. Q. vols 21-23
[b] Includes thermodynamic modelling
[c] Includes heat transfer and friction measurements and studies on Marangoni flow

(iii) research effort on Optical Basicity may have peaked around 1988; however, this may also have been influenced by the fact that most of the principal investigators of optical basicity were present at the Glasgow Conference in 1988.

4.3 Type of slags studied

The results are summarised in Table 7.

Table 7
Type of slags studied for publication in Conference Proceedings (%)

Slag Type	Year			
	1980	1984	1988	1992
Ironmaking	0	3	3.3	4.3
Steelmaking	10	3	5.5	4.3
Ferralloy	2	0	1.1	0.8
Ladle/Refining	8	1	2.2	4.3
Mould flux	2	3	5.5	6.0
Coal	0	1	1.1	0
Welding flux	0	3	1.1	0
Non-ferrous	14	10.9	2.2	5.1
Maltes	6	2	2.2	4.3
Synthetic	58	74.3	76.7	70.9
Total No	50	101	90	117

It can be seen that most of the work reported at the Conference was carried out on synthetic slags, which is not surprising since most of the work reported at the Slags Conferences has tended to be of a fundamental nature. When this bias is removed, the relative distribution of work on the various type of slags is very similar to that reported in Table 4.

5. CONCLUSIONS

i) The annual output of slag-related research publications has remained constant at about 350 per annum but it was noted that after 1989 there has been a decrease of about 20% which may be a consequence of economic hardships experienced by steelmaking companies.

ii) Russia remains a major contributor to research on slags but their effort has decreased in recent years, presumably, as a result of the upheaval which has accompanied the disintegration of the USSR.

iii) There appears to have been a sharp drop in the research on slags within the nations of the EEC and, to a lesser extent, in the USA; it is suggested that this may be associated with the decrease in teaching of Metallurgy as a university course.

iv) Japan has shown an increasing commitment and has become the largest contributor to slag research and Chinese, Korean and, to a less extent, Australian research effort has increased steadily in recent years; thus the centre of gravity of slag research has moved significantly towards Asia and the Pacific countries.

v) The nature of the experimental research and of the slags studied have remained remarkably constant, although there has been increased interest in (a) Foaming and Smelting Reduction, (b) Recycling of slags, (c) Mould fluxes.

vi) Slags Conference Proceedings do not provide an accurate picture of slag research since (a) they tend to cover the more fundamental aspects of the field and (b) national participation tends to be severely distorted by geographical and financial considerations.

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