2. The innovation trajectory of *Spirulina* algal technology

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Abstract

Research in agricultural and post-harvest science in India has conventionally been seen as a preserve of State scientific establishments with private enterprise only playing an active role in recent times. Using the case of Spirulina *algal technology, this paper illustrates the 'hidden histories of science' in civil society initiatives, arguing that they need to be seen as part of the 'legitimate' narrative if science has to have a pro-poor human face. Civil society initiatives have an important role in scientific initiatives in developing countries and often follow an alternate paradigm of learning and innovation that holds many lessons for research project design, management, and practice. This case study describes the innovation trajectory of* Spirulina *and the central role of a civil society organization – the Murugappa Chettiar Research Centre (MCRC) in it. The discussion explores features of the research culture or scientific practice of MCRC that enabled successful innovation, reflecting in a way contemporary ideas about innovation as systemic phenomena. This contrasts sharply with prevailing research conventions in much of the Indian scientific establishment and thereby suggests important institutional lessons for research policy.*

Introduction

This paper explores a civil society initiative in agro-processing from the perspective of attempting to understand innovation processes and their institutional contexts. Civil society initiatives are unusual in that often they have not been driven by the formal science establishment and its outputs, but instead have been led by an alternative paradigm of learning and innovation. However, these initiatives have not been studied and their contribution to informing research project design, research management, and practice remain largely unexplored. This paper thus explores and highlights potentially underutilized sources of innovations from which research policy can draw inspiration and lessons.

The reported case study looks at the work of a non-governmental research organization, the Shri AMM Murugappa Chettiar Research Centre (MCRC), based at Chennai, India, and its work in developing *Spirulina* algal technology in India. The work, spanning a period of two decades, is an unusual case of the active involvement of a non-governmental organization (NGO) in all aspects of the innovation chain, ie, development of the scientific idea (invention), translating that idea into a commercial proposition (innovation), and extension of the technology both into the market and rural communities (diffusion). Through this case study, this paper also seeks to understand the institutional context of innovation in civil society initiatives in the agro-processing

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sector and its difference between State and market initiatives with respect to partnerships, a pro-poor focus in research, and the understanding of technology transfer.

The paper begins by briefly exploring the institutional setting of post-harvest innovation in India. This highlights the potential importance of civil society initiatives in this area, and also illustrates the fact that these tend to be overlooked. It is argued that, in part, the reason for this relates to the conventional sequential or linear view of innovation that continues to inform research policy, and locates civil society organizations conceptually at the end of the technology delivery pipeline. Contemporary innovation systems perspectives, it is suggested, may help to locate the activities of different organizations in a more holistic view of the innovation process and thus reveal the role and value of civil society organizations.

The second part of the paper presents a history of the *Spirulina* algal technology trajectory, detailing the different phases of activity and the evolution of actors, roles, and objectives associated with what was, in effect, an Indian *Spirulina* innovation system. It seeks to situate the work of MCRC within existing national research on algal technology, and highlights points of departure both in the nature of research and the way it has been practiced. It also explores the nature of partnerships in the various phases and the changing role of the main actors in the system.

The third part of the paper looks more closely at the research culture of MCRC in order to explore the way civil society conceptualizes research and development. Features of this research culture include the manner of problem definition, the continued emphasis on innovation, enabling of organizational learning, forming of partnerships, creation of multidisciplinary teams, and emphasizing multifunctional tasks. The technical and non-technical writings of research staff are critically examined for the analysis of the research culture.

The final section explores the implications of the case for agricultural science and comments on the way many of the findings substantiate the holistic perspectives embodied in the innovation system concept. The paper thereby seeks to demonstrate that the case is not just about *Spirulina* or MCRC, but also about a new framework for closer interaction between formal and not-so-formal science, ie, science by the State, and science by civil society.

Agro-processing innovations in different institutional settings

The post-harvest or agro-processing sector needs to be seen as part of the larger non-farm sector and decentralized rural industries. Moulik and Purushottam (1986) in one of the few studies on technology transfer in this sector have argued that the decentralized rural industrial sector in India is conceptually and operationally different from the agricultural sector and that therefore it is not enough to transplant successful experience of the technology transfer process in agriculture. Pointing to the complex dimensions of technology transfer in this sector, the Planning Commission of India in a review of village industries remarked that that most technical research centers in India were uni-disciplinary bodies and were ill-equipped to handle multidisciplinary problems of village industries (GoI 1981). The National Research and Development Corporation (NRDC) that provides a mechanism for commercializing laboratory ideas in industrial research and development (R&D) feels that the agro- or food-processing area is one of the most difficult in which to achieve successful commercialization. Some of the problems identified include: the requirement of multiple partners with diverse backgrounds, long gestation periods, non-availability of raw materials throughout the year, and many risk factors (NRDC 2003).

Hall et al. (2003) have recently argued that post-harvest R&D seems to sit uncomfortably in the conventional arrangements for agricultural research. Unlike crop improvement research that has clearly identified central scientific personnel (plant breeders, molecular biologists), well-defined products (new varieties), and a clear main client (farmer); post-harvest R&D has no neat categorization. It covers engineering, food science, pathology, and marketing economics, has a large number of players both public and private, and diverse stakeholder interests and agendas with different skills responding to different incentives. Post-harvest innovation (PHI) is thus frequently embedded in a wider set of relationships and contexts than is implied by the conventional research–extension–farmers' model of R&D. Managing PHI and doing so with a pro-poor policy goal is therefore challenging as it involves complexity of an order of magnitude greater than that associated with crop improvement-based innovations.

Dealing with this complexity has proved difficult and many of the constraints to post-harvest innovation have been identified as institutional in nature and relating to conventional approaches of R&D planning (Hall et al. 2001). The conventional (and widely criticized) model to which much of Indian R&D still conforms is premised on the desirability of linear relationships linking research and economic production. In this model, investments made in basic research are assumed to produce knowledge whose value increases through further 'downstream' incremental investments in adaptive research. The knowledge is finally given to a dedicated organization (extension) charged with passing it to a technology user who finally applies the new knowledge to economic production. In this model there is institutional separation, with activities associated with knowledge search and generation (research) organized separately from those involved with knowledge transfer and application. There is thus a division of labor whereby public scientific bodies – seen as the primary source of new knowledge – are organized in a hierarchical structure with a linear flow of resources and information from the top to the bottom. One of the problems that this mindset encourages is the view that civil society should be located at the last stage of the innovation chain (extension activities) and not as contributing to invention. After all, civil society organizations are not research organization and thus their activities should be restricted to disseminating the innovations of others. This case seeks to challenge this assumption.

There is now wide recognition that assumptions of the conventional or linear model of innovation do not reflect the complex reality of technology development and innovation in the agriculture sector. Instead this is now understood as a process that: involves linkages and feedback between the main actors (Clark et al. 2003); multiple sources of innovation (Biggs 1990); iterative processes of learning and reframing of approaches and research questions (Hall et al. 2003) that at times lead to new roles for actors (Hall 2004). Of particular relevance to the focus of this paper on innovation in civil society is the recognition that the actual practice of science depends to a large extent on the different settings in which it takes place. For this reason understanding the role of organizational cultures in research planning and performance evaluation has assumed importance (Pickering 1992; Feller 2002; Watts et al. 2003).

The concept of an innovation system by Freeman (1989) and others draws together many of these ideas. Innovations in this view emerge from the interactions of a number of players from both the research and non-research sectors; the production of knowledge and innovations is not linear, but iterative and contextual; it involves dead-ends and new directions, with experience from application throwing new research questions and opportunities. Institutional contexts are of fundamental importance in shaping innovation processes and outcomes; and these systems of actors and institutions are evolutionary in nature, relying on incremental learning to deal with emerging constraints and opportunities. The introductory comment of a review of these concepts by Edquist (1997) provides a useful overview of the main elements of recent thinking:

> 'Innovations are new creations of economic significance. They may be brand new, but are more often new combinations of existing elements. Innovations may be of various kinds, eg, technological as well as organizational. The process through which technical innovations emerge are extremely complex; they have to do with the emergence and diffusion of different knowledge elements, ie, with scientific and technological possibilities, as well the 'translation' of these into new products and production processes. This translation by no means follows a 'linear' path from basic research to applied research and further to the development and implementation of new processes and new products. Instead, it is characterized by complicated feedback mechanisms and interactive relations involving science, technology, learning, production, policy, and demand.' (Edquist 1977, p. 3).

An analysis of the capacity of post-harvest innovation in India reflects the linear understanding of innovation and the tension it creates concerning the appropriate role of scientific and civil society organizations. During the last two decades, there have been several compendia on rural technologies in India. These compilations were, in fact, responses to criticisms from within and outside the scientific establishment on the contribution and relevance of the formal science and technology establishment to the problems of rural India. Two key scientific institutions – the Council for Scientific and Industrial Research (CSIR) and the Department of Science and Technology (DST) – produced compilations highlighting their contribution to rural development. Simultaneously there were efforts from civil society to broaden the debates on expertise in science and technology by seeking to legitimize through these compilations the large numbers of scientific practices in rural areas outside formal science, and to address issues such as science and technology (S&T) and rural women. Table 1 lists these compendia and provides details of post-harvest technologies.

Of the compilations in Table 1, the 1993 database, though dated, has an interesting compilation of resource persons with their institutional affiliations and subject interest. This compilation has been classified into categories that indicate the concentration of various types of institutions in agro-processing, food processing, and post-harvest technologies. Table 2 below shows the distribution of resource persons from this compilation.

Broadly speaking, most of the resource persons who were part of the national agricultural research system (NARS) saw themselves more as specialists in post-harvest technologies, while resource persons from institutions in civil society saw themselves more in the areas of food and agro-processing.

Table 1. Compendia on rural technologies in India.

Year	Compilation	Publisher[1]	Postharvest technologies details
1980	Rural Development and Technology: A Status Report cum Bibliography	CSIR	
1982	Science and Technology for Women: A Compendium of Technologies	DST and CSV	Over 1000 voluntary organizations contacted for the compilation
1984	Technologies for Human Welfare and Community Services. Vol. 2. Technologies for Rural Development	CSIR	26 food technologies. All but 3 from CFTRI, Mysore
1986–92	CAPART Directory of Rural Technologies (7 volumes)	CAPART, TTTI and CRDAT	Vol. 1 'Farm and Postharvest Technologies' and Vol. 5 'Village Industries and Artisans'
1993	Directory of Resource Persons for S&T Based Societal Programmes	DST and CTD	904 entries including 236 on postharvest
1995	CSIR Rural Technologies: A Compendium	CSIR	109 of the 350 entries are on food and agro-processing
1996	Compendium of Replicable Technologies and Models	DST and CTD	31 technologies vetted only field-level experience only included
2001	Technology Models for Rural Application	DST and CTD	39 replicable technologies described

1. CSV = Centre of Science for Villages, Wardha
CTD = Centre for Technology and Development, New Delhi
CFTRI = Central Food Technology and Research Institute, Mysore
CAPART = Council for Advancement of Peoples Action for Rural Technologies
CRDAT = Centre for Rural Development and Appropriate Technology, New Delhi
DST = Department of Science and Technology
CSIR = Council for Scientific and Industrial Research
TTTI = Technical Teachers Training Institute, Bhopal.

This institutional analysis shows that the mandate of post-harvest technologies has gone well beyond the formal science establishment as represented by the Indian Council for Agricultural Research (ICAR) or CSIR systems. While the sources of post-harvest innovation in India are diverse, planning and thus formal R&D has been concentrated in a very limited number of establishments such as the Central Food Technology Research Institute (CFTRI) in the CSIR systems as well as the Central Institute for Post Harvest Engineering and Technology in the ICAR system. In recent years organizations such as the Council for Advancement of Peoples Action for Rural Technologies (CAPART) and the Science and Society section of the DST have emerged as important players. Further, the presence and expertise of NGOs representing civil society is by no means small. This is yet another reason why civil society initiatives need to be given serious consideration.

Table 2. Institutional distribution of resource persons in postharvest technologies.

Category	Agro-processing	Food processing	Post-harvest	Resource persons
Indian Council of Agricultural Research (ICAR) and agricultural universities	9	12	23	28
NGOs	10	16	13	25
Other universities and educational institutions	5	10	10	14
Other research institutes	3	6	6	10
CSIR laboratories	5	4	7	8
Private consultants	3	8	2	8

Source: Collated from CTD 1993. Many resource persons indicated more than one area of interest hence overlaps.

For the purposes of this paper the question is: what does the emergence of NGOs in the post-harvest sector imply for innovation processes and attendant polices?

Institutional context of civil society initiatives

There have been several initiatives from organizations outside the formal scientific establishment and the private sector in agro-processing. Although these initiatives have entailed significant institutional learning and potential insights for others, they have not been documented sufficiently and have escaped most narratives in the history of agro-processing in India. Efforts by civil society have often been presumed to be sporadic, small in scale, or trivial in scope and have bypassed academic analysis. Documentation of these efforts has, at best, been restricted to internal histories of these organizations and not as part of science or research policy debates. This case study of a civil society initiative in agro-processing argues that there are 'hidden histories of science' in agro-processing and that civil society initiatives need to be seen as part of the 'legitimate' narrative of institutional development if science is to have a pro-poor focus.

Since the early part of the 20th century, there have been critiques on the practice of public research in Indian agriculture. Some of these critiques have been translated into alternate scientific practice. The Allahabad Agricultural Institute started by Sam Higginbottom in 1910 was one of the earliest such experiments that had to its credit the first-ever degree course in agricultural engineering in India, one of the earliest schemes of extension projects, and a women's program in home science. Its emphasis on practical training set it apart from other agricultural schools in India that were then almost exclusively teaching centers meant to fill posts for the agricultural service with little or no direct contact with farmers (Hess 1967).

Though Higginbottom's work did not receive State attention, it caught the imagination of Indian nationalists such as Gandhi who had a long correspondence with him and wanted him to head the agriculture wing of the Congress. Years later, as part of a dissenting tradition of scientific intervention with a pro-poor focus, Gandhi constituted the All India Village Industries Association (AIVIA) in 1934. This can be seen as the first organized large-scale effort to intervene on behalf of the poor in the agro-processing sector.

Though AIVIA was a pioneer in civil society initiatives and rural innovations in agro-processing, it does not figure in standard readings on agro-processing in India. Articulating the need for a different science for the rural poor, a voice neglected by the formal scientific establishment, Gandhi remarked that "the intervention would need business talent, expert knowledge, and scientific training." Citing the example of nutrition he pointed out how his questionnaire to several well-known doctors and chemists on the chemical analysis and different food values of polished and unpolished rice, *jaggery* (unrefined sugar), and sugar, remained unanswered (Gandhi 1934). A notable part of the institutional structure that followed was the attempt to broad-base AIVIA by having a number of stakeholders. These stakeholders were to include laypersons who could be members with no qualifications other than the desire and interest to participate, together with agents who were to market the produce. Such a system necessarily ensured a better information flow between the various actors. In the writings of the outspoken Gandhian economist, JC Kumarappa, the secretary of AIVIA, one finds details of the kind of questions that should engage this new research and its scientists. These were linked to contemporary issues of food shortage and famine but were addressed within a much broader context that sought to include such non-productive and qualitative concerns as the requirement of a balanced diet for everyone as opposed to a mere increase in food supplies (Kumarappa 1971).

The conception of research that sought to look at integrated systems and not just at the productivity of their parts in AIVIA is noticeable. Thus, there was an emphasis on the whole plant as food for humans and fodder for cattle; in oil processing the research was conscious of the oil content of the cake as cattle feed and not just the productivity of the seed for oil. This emphasis on nutrition for the masses as an important consideration for research is noteworthy, and AIVIA collaborated with several scientific institutions of the time. Past attempts to look at science in civil society have overemphasized the critique of formal science. In the present institutional context the positive contribution of civil society is in the setting of research directions and parameters for detailed enquiry. Given their proximity to the field, the starting points of research in civil society often have critical field-level and user insights that cannot be achieved through any critical research and policy management exercise in formal science. This is sufficient reason for formal science to take research by civil society seriously and to engage in dialog with it.

There have been several innovations from civil society since AIVIA. The responses have been diverse, based on their respective institutional contexts. AIVIA has changed in character since the establishment of the Khadi and Village Industries Commission in 1957 that took over the mandate of AIVIA, making it a State-led and sponsored activity. This has led to serious erosion of AIVIA's original charter. However, there have been several organizations that have sprung up, especially in the late 1970s, to address a pro-poor mandate in the rural non-farm sector. One of these is the Centre of Science for Villages (CSV) at Wardha, that was set up in 1978.

The 1990s have seen major changes in the agro-processing sectors, with civil society initiatives seeking to establish new relations with the market through diverse products and institutional means. This is in the context of the large-scale failure of State-led efforts in enabling poor farmers to cope with the changing nature of local and global markets in the wake of liberalization. Some like the Nimbkar Agricultural Research Institute (NARI) in Phaltan, Maharashtra, have suggested diverse uses of such crops as sorghum. The Centre for Technology and Development (CTD) based in New Delhi with years of experience in rural industrialization is another such initiative. Conceived as a multidisciplinary group with engineering, natural, and social sciences backgrounds, this center has been involved in technology transfer for small-scale farmers in fruit, vegetable, and agro-processing in recent years. The experience of CTD shows an understanding of the contemporary market that is different from that of the State and corporate interests. A more recent institutional innovation, still in process, is the Rural Innovations Network (RIN) that has sought to approach the problem from a different perspective. It has been inspired by the Society for Research and Initiatives for Sustainable Technologies and Institutions (SRISTI) initiative of the National Innovation Foundation, and the Honey Bee Network of farmer-led innovations. RIN sees itself as providing critical managerial inputs to facilitate the honing of entrepreneurial skills using business models of venture capital in the corporate sector, thereby ensuring both monetary and social returns to rural innovators, donors, investors, research institutions, voluntary organizations, entrepreneurs, and rural consumers.[2]

The institutional context of these diverse approaches to innovations in agro-processing from civil society is increasingly being realized. Scholars such as Vaidyanathan (2000) have argued the need to see the public space in agricultural research as much wider than government departments. Giving greater autonomy from governmental control to research organizations, and giving non-governmental public institutions the space and resources to play a larger, more effective role in research, have been seen as issues of direct relevance in restructuring the public research system. The case study of *Spirulina* algal technology at the MCRC below is but an explication of the tradition of constructive dissent and innovation of science in civil society.

Spirulina algal technology in India

As a food system innovation *Spirulina* has been seen as a ‘wonder food’. It is a high quality food supplement containing vitamins B_1, B_{12}, B_{16}, C, and E in addition to protein, etc. It has tremendous potential for use in food, cosmetics, and health care. The only single, natural source providing the highest amount of protein ever known to man, *Spirulina* contains 71% protein, three times that of soybean, and five times that of meat. *Spirulina* protein quality is among the best. The annual protein yield per unit area is the highest among other protein-yielding crops. Like all other microbial cells, *Spirulina* contains all the natural vitamins, including the B-complex range, minerals, and growth factors such as gram-linoleic acid. It contains large amounts of beta-carotene, a precursor of vitamin A. Its concentration of nucleic acids is among the lowest recorded for microbial cells considered as food or feed. Other microorganisms, including those pathogenic to humans and other animals, are eliminated in the *Spirulina* production process due to its requirement of a very highly alkaline growth medium. *Spirulina*’s preference for tropical and sub-tropical climatic conditions offers a good use for land in arid areas.

Spirulina has wide-ranging applications as a food supplement (to combat stress by executives and by athletes for quick energy synthesis); health and medicine (non-insulin dependent diabetes; cholesterol control; vitamin A deficiency and malnutrition; as an adjunct to cancer patients undergoing chemotherapy; a lactating agent for mothers, etc.); as a feed in pisiculture, sericulture, and entomology; as a coloring agent in food and chemical assays, and in cosmetics.[3]

While the benefits of *Spirulina* as a wonder food have been shared within the international scientific community for quite some time now, the developments of this technology in India was not a local adaptation of an internationally developed technology. On the contrary, Indian research on *Spirulina* applications had many firsts to its credit. India was at one time the only country in the world conducting a joint effort by many government agencies covering all aspects of *Spirulina*, from simple cultivation basins to large-scale commercial farms. The Government of India (GoI) sponsored large-scale nutrition studies with animals and humans and investigated therapeutic uses. The world's largest feeding trial with *Spirulina*, involving 5,000 pre-school children who were fed a special formulation of *Spirulina* alga for one year, was conducted by MCRC. Medical reports confirmed that it was a useful supplementary vitamin A diet, putting to rest motivated attempts by corporate science that was keen to push synthetic vitamin A, and that raised doubts on the toxicity of *Spirulina*. India was one of the first countries to have a standard for the alga. India also has the first decentralized production facility for *Spirulina* in the world, which came about because of the earthquake-relief operation in Latur.

Spearheading much of the work in India was the MCRC a civil society organization led by CV Seshadri. Within the Indian research and development context, the work on *Spirulina* represents a rare case of an organization being involved in all stages of the development of an innovation – conception, commercialization, and extension to social sectors. In the following account the efforts made by MCRC are reviewed within the larger context of *Spirulina* algal research in India.

Indian work on *Spirulina* algal technology can broadly be grouped into seven phases or stages. Table 3 provides a timeline of *Spirulina* algal research in India together with some global developments.

MCRC and the innovation trajectory of *Spirulina* in India

The story of *Spirulina* and its transition from a research idea in the laboratory to an applied technology in the form of a commercially produced food supplement is typical of many stories of innovation. It is complicated. It is characterized by key players entering (and departing) the stage at different times, with champions emerging at critical points, only to fade and let others emerge. It involves basic research and applied and adaptive tasks, but not always in that sequence. And it is highly nuanced and not easily understood without an investigation of the players, institutional and other contexts, and process that relate to this particular innovation. It might be useful to think of this story as one about the evolving architecture of the *Spirulina* innovation systems. Over the last 30 years or so this has involved different grouping of partners, different relationships, and process. The main phases of this evolving architecture are discussed below. What is

Table 3. Timeline of *Spirulina* chronology in India and the world.

Year	Important event
1940[1]	*Giant evaporator used to dry Lake Texcoco at Mexico leaves algae (*Spirulina*) on external parts clogging extraction of soda brines*
1961	Singh's work on blue green algae for nitrogen fixation published by IARI
1967	*French director of Sosa Texcoco and other scientists decide to grow* Spirulina
1969	GS Venkatraman's book *Cultivation of algae* published by ICAR
1973	Indo-German algal project initiated at CFTRI. Focus on protein supplement *Scenedesmus obliquus* used, later found too expensive and elaborate
1974	India's first algal production unit established at Navsari, Gujarat
1976	All India Coordinated Programme on Algae (AICPA). Multi-institutional, as bio-fertilizer, protein source, fuel and component in recycling system. Institutions involved were CFTRI (food and feed), National Environmental Engineering Research Institute (NEERI) (sewage water algae), CSMCRI (food, feed, biogas), Auroville (food and feed), IARI (bio-fertilizer), NIN and IVRI (evaluating feed and food)
1976	*Sosa Texcoco first* Spirulina *producer in the world with daily production of 2 tonnes*
1977	Center for Algal Studies set up at MCRC later combined with Energy Division
1978	Spirulina *discovered as staple food in use in Chad and also by the ancient Aztecs. Dainippon Ink Corporation's (DIC's) first plant in Bangkok*
1979	Spirulina *exported to US for human health use. Earthrise markets* Spirulina *in tablets in natural food stores in USA*
1980	MCRC identifies and cultures local strain of *Spirulina fusiformis*
1981	*Earthrise Farms started in California for production by Proteus and DIC. Production begins in 1983*
1982	Ripley Fox starts work on integrated systems of *Spirulina* cultivation in Centre of Science for Villages (CSV), Karla. Mud pot cultures experiment initiated at MCRC
1984-91	MCRC work on *Spirulina* is commercialized and India's first production facility established
1991	Second AICP on algae initiated with four objectives including large-scale nutritional studies. MCRC receives National Research and Development Corporation (NRDC) Innovation award for *Spirulina* work
1992	Nutritional program completed. Bitot's spot deficiency decreases from 80 to 10%. Alternative to imported pure vitamin A demonstrated
1993	Ballarpur industries set up *Spirulina* production unit at Mysore. 200 t $year^{-1}$ plant
1995	MCRC asked by DBT to take up *Spirulina* as income generation in earthquake-affected Latur

1. Italics indicate developments outside India.

noteworthy about this story is how MCRC emerged as an important player at a critical time and, for reasons discussed later was able to drive the innovation process in ways that may not have been possible in an institutional setting of the formal scientific establishment.

Early work by IARI

Algal research in India dates back to 1953 when the Indian Agricultural Research Institute (IARI) began research on the use of algae for nitrogen fixation and later to treat sewage and industrial waste. Much work in this period was in the form of research on the taxonomy of algae and their use as bio-fertilizers. The organizations involved were CFTRI (in 1973 CFTRI entered into collaboration with Germany to produce a pilot plant), the National Botanical Research Institute (NBRI), Lucknow; the National Environmental Engineering Research Institute (NEERI), Nagpur; the Indian Veterinary Research Institute (IVRI), Izzatnagar; and Auroville, Pondicherry. An All India Co-ordinated Programme on Algae (AICPA) started in 1976 to cover various aspects of algal production for food, feed, and fertilizers (Becker 1993). The work on algal bio-fertilizers was ahead of its time, and did not fit into the push given to synthetic fertilizers as part of the Green Revolution in India. The first *Spirulina* farm in India was established at Navsari, Gujarat, in 1974. Although there were no major breakthroughs in *Spirulina* cultivation, this early work is important because it created a base for the later active involvement of MCRC. It also usefully illustrates the time lag involved in the commercialization of an idea.

MCRC's initial work

The MCRC set up in 1973 as a private R&D center of the Murugappa Group of companies was transformed by C V Seshadri who, as its director from 1976, made it into a leading autonomous R&D center with a range of activities showing strong social concerns. Seshadri brought to MCRC the skills of a researcher and academic with considerable industrial experience (he had just established India's largest yeast factory in Mysore). In 1977 the Algal Division was set up. An important conceptual leap at MCRC on algal research was the linking of energy and photosynthesis. The research outputs, entitled the Monograph Series on Engineering of Photosynthetic Systems (MSEPS) reflected a philosophy of integrated holism and involved an interdisciplinary team of scientists, engineers, and amateurs right from the start.

The point of departure from other research centers in India was MCRC's biomass emphasis and focus on algae as food instead of as fertilizer or effluent treatment. Algal cultures were preferred over conventional plants from an agricultural aspect as they gave high output per hectare, consumed little water per unit of useful biomass yield, allowed for whole cell or plant utilization, possessed high protection and vitamin output per hour, and were amenable to several engineering improvements because they could be cultured in liquid media.

The algal work at MCRC was given a boost when Jeeji Bai, an algologist at the Madras University, joined on an honorary basis. The scientists screened large numbers of algal cultures for a suitable selection and successfully isolated *Spirulina fusiformis* from a phytoplankton collection from a pond in Madurai. The isolate was then adapted by growing it in village conditions using unskilled labor.

This was followed by open-pond *Spirulina* cultivation with different nutrient media compositions using cheap raw materials (seawater of varying composition, crude sea salt, biogas effluent, and nutrient bag methods were tried). Unlike other parts of the world that focused on large-scale cultural systems requiring sophisticated and costly engineering design, the scientists felt that Indian conditions demanded small decentralized algal systems operated by non-technical hands. This approach was also a break from the general practice in Indian scientific establishments that paid little attention to adaptation to local conditions. Thus, while the CFTRI work with German collaboration was capital-intensive, MCRC work was cost-sensitive. Conscious efforts were made by the scientists to incorporate local materials and local conditions in the design.

Feeding trials were done on fish (at MCRC), dogs, and calves (at NRDI, Bangalore), and *Spirulina* was found to have an edge over other protein supplements. The uses of *Spirulina* in a few popular Indian dishes were also tried to determine its palatability. Experiments on algal milk farming using solar-boosted energy were tried out, and the feasibility of growing algae and fodder grass in a single area was explored.

The initial work at MCRC was thus one of vigorous experimentation over a wide range of activities. The simultaneity of basic and applied work and the design of experiments to suit Indian conditions and budgets set MCRC apart, not only from research carried out elsewhere, but also from ‘normal’ science in India. By the end of 1981 there was sufficient confidence to increase the scale of operations.

Large-scale cultivation and commercialization

Building on the laboratory investigations in the early stages, a pilot-plant feasibility study was initiated in the early 1980s. This indicated promise as a potential rural activity for food and feed production using waste materials ecologically and economically. In this phase the work was directed at mastering the cultivation of *Spirulina* from test tubes to flasks and small outdoor ponds. A separate group of nutritionists developed recipes for use with algal slurry and sun-dried flakes. The technology was sufficiently matured by 1984 for a pilot-scale facility to be commissioned.

Collaboration with the Murugappa Group companies and Industrial Credit and Investment Corporation of India (ICICI) saw the establishment of India’s first completely indigenous *Spirulina* production facility. Technical innovations included the ‘Prakara pond’, the ‘Raji’ filter system, and a paddle-wheel agitation system that resulted in cost and materials economies. MCRC was also involved in test marketing the product and in formulating the Indian standard for processing of *Spirulina* alga, IS 12895: 1990. India was then perhaps the only country in the world where such a standard existed. The specifications covered minimum protein and vitamin levels in the dried product besides specifying its contents and tolerance levels.

A severe funding shortage affected the future of the project even as commercialization began. The timely involvement of NRDC allowed an inspired agreement to be devised to finance the project. This agreement, while protecting the interests of MCRC, also ensured continued interest by the Murugappa Group of companies. NRDC believed that the process was a breakthrough in indigenous technology development. This was recognized when Seshadri and BV Umesh of MCRC were awarded the NRDC President of India Award for Invention in 1991.

Simultaneous studies on village-level production

Simultaneous to the commercialization push of *Spirulina* there was a parallel effort aimed at the social objective of nutritional self-sufficiency for villagers. MCRC initiated experiments in downscaling the technology to suit village women. It is the rural client focus of civil society organizations that allowed for such a strategic shift in research direction. This again was a major departure in the work of MCRC from formal scientific establishments. Cultures using mud pots were tried out in late 1982. They were chosen because mud pots were easy to handle and good as transient cultures from laboratory to open-air conditions. Along with the technical innovation there was social innovation. Laboratory data were promising and it was felt that this would be a suitable simple technology to teach village women and training programs were initiated. The work was carried out on the hypothesis that *Spirulina* processing and marketing would make it an expensive proposition for the people who need it most, ie, village women and children. It was also felt that technologies that were developed exclusively for women had a better chance of social and cultural acceptance than technologies that were designed for men but later 'diluted' for women or for rural areas. The vision was to demonstrate that microbiological skills could be taken down to the personal level for nutritional self-sufficiency (Seshadri 1985; Jeeji Bai 1986; 1992).

Yet another experiment where MCRC did not work directly, but through others, was with the organization Nutrition on Wheels (NOW) based in Chennai. Here MCRC provided the *Spirulina* culture and NOW, in collaboration with Antenna Technologies, identified two villages near Chennai (Madras) for cultivation. Transtech, whose founder was associated with NOW, later marketed the *Spirulina* under the trade name Progen®. Village-level kits for 4–10 m^2 ponds were distributed amongst selected beneficiaries, and the women were able to augment their income by up to Rs 100 $month^{-1}$. The program had to be moved after a year due to unforeseen social problems and local conflicts in the villages (von der Weid 1993). This experiment is an interesting case in partnership, and in fact a precursor to MCRC's own extension outreach. Transtech importantly helped to develop the market for the product while creating an awareness of the usefulness of *Spirulina* amongst the general public.

MCRC-led All India Co-ordinated Project

In 1990 MCRC approached the GoI for large-scale field trials. The Department of Biotechnology (DBT) evinced interest and an All India Co-ordinated Project was initiated in 1991 with MCRC coordinating it. This was to have four components:

a. Large-scale nutritional supplementation (LSNS) with *Spirulina* alga
b. Preparation of feasibility reports on suitably sized plants
c. Maintenance of germplasm and quality improvement of strains
d. Preparation and testing of formulations for various applications.

The LSNS was preceded by experiments done at the National Institute of Nutrition (NIN), initiated by MCRC, which had demonstrated the toxicological safety of *Spirulina* and the bioavailability of beta-carotene (Annapurna et al. 1991).

With a view to exchanging notes among the larger community involved in *Spirulina* and reviewing the state of the art in India, MCRC hosted a national symposium titled '*Spirulina*: Ecology, Taxonomy, Technology and Applications (ETTA)' in 1991. This broad-based symposium resulted in the publication of a comprehensive treatise (Seshadri and Jeeji Bai 1992), which is cited extensively in contemporary *Spirulina* literature. The Indian effort was the only large-scale endeavor in the world dedicated to the therapeutic uses of the whole alga.

As part of LSNS, a well-monitored nutritional supplementation program using *Spirulina* was undertaken in a rural population of 5000 pre-school children in Pudukkottai district, Tamil Nadu, for one year. The unprecedented scale of operation of this program required major institutional innovations from MCRC that went beyond its professional mandate as a research organization. It involved collecting and analyzing nearly 9 million data points. Recognizing the need for beta-carotene administration in the form of a natural foodstuff, MCRC introduced *Spiru-om,* a mixture of *Spirulina* and *omum* or *Ajjwain* (*Trachyspermum ami*) mixed with icing sugar. This was administered to the children in the form of noodles and the results were monitored.

The results of the study showed statistically significant reduction in Bitot's spot and night blindness with several interesting anecdotal results as reported by *Anganwadi* [community childcare center workers and teachers in schools. The study demonstrated a cost–effective substitution of expensive imported vitamin A. It also provided conclusive proof of the benefits of *Spirulina,* setting to rest the motivated efforts by several multinational companies that sought to show *Spirulina* as toxic and their own vitamin substitutes as more effective. The cost was estimated at Rs 1.5 (US$ 0.03) per dose that could be reduced to Rs 1 (US$ 0.02) and even further if the product was made locally (Seshadri 1993a; Seshadri and Thomas 1993).

The LSNS experiment is an interesting example of partnership by an NGO that was ahead of its time and involved a wide range of actors from scientific bodies, research institutions, universities and medical colleges, to local health workers, extension workers, teachers, parents and children in the villages.

Extension activities – *Spirulina* as income generation 1993–97

With the potential of *Spirulina* having been demonstrated, scientific agencies such as the DST and DBT sought to extend its possibilities through such specific projects as biotechnologies for scheduled caste (SC) and scheduled tribe (ST) women. This was first tried out in villages in Pudukkottai district amongst nine women using medium-sized ponds. The concept was then extended as part of earthquake relief in Latur in Maharashtra under a project called *Spirulina* for Employment Generation and Rehabilitation of Victims of Earthquake (SERVE). Two hundred women were trained and a decentralized production facility, the first of its kind, was established.

Post-MCRC extension of village-scale technology 1997–2003

Work at MCRC on *Spirulina* has more or less stopped in recent years, although the organization maintains the culture, and is willing to train NGOs. The *Spirulina* work now has gone beyond MCRC in non-linear ways. NGOs inspired by the nutritional potential of *Spirulina* have taken to village-level production. The extension of *Spirulina* production in the 1990s is noticeable for the diversity of approaches in construction of tanks, processing, products, marketing, and distribution. It has entailed technical and institutional innovation beyond mere replication.

CSV in Wardha, Maharashtra, and Auroville in Pondicherry are two NGOs that have been involved with *Spirulina* activity for 20 years. Ripley Fox initiated CSV's work at Karla in 1982 through an integrated system involving sewage in the nutrient medium (Fox 1993). There has since been product diversification into skin creams (a combination of beeswax and *Spirulina*) and face packs for the local market, apart from the usual tablets. At Auroville the work has had a revival in the 1990s. Seven 30-m^2 ponds now in operation harvest 500 kg annually. The farm uses solar power for water pumping and over a thousand people consume *Spirulina* regularly. Auroville has also trained several people to set up their own farms.

The Antenna Trust based in Madurai with technical support from Antenna Technologies, Geneva, is a leading training center in *Spirulina* cultivation with a well-equipped laboratory and training manuals. An interesting case of innovations in the extension of a technology is the work done by the Reorganization of Rural Economy and Society (RORES), in Kolar, Karnataka. Enthused by the potential through an article in the journal *Health Action* (Anon 1997) that described the potential of the alga in combating malnutrition, RORES contacted MCRC for technology transfer. Stabilizing the production involved an iterative process of experimentation and visits to the Antenna Trust and a *Spirulina* factory apart from contact with MCRC. The technology has been modified substantially through several ingenious applications for an expanded capacity of 6 kg per day. Irregular rural electrical supply necessitated local innovation wherein the paddle agitator was solar-powered using an unused photovoltaic panel from a local NGO. The agitator was designed using high-grade stainless steel 316 blades chosen for its inert media and proven anti-corrosion properties. The 'high tech' blades and the motor were procured secondhand from a Bangalore scrap market and suitably redesigned.

The *Spirulina* activity fits in well with the NGO's agricultural extension activity. The laboratory for *Spirulina* does additional work on soil analysis. Greenhouses for the nursery were incorporated for solar drying of *Spirulina*. Markets are both rural and urban, the latter cross-subsidizing rural consumption. Farmers are encouraged to use *Spirulina* for cattle feed, and there has been a positive effect on cattle fertility. RORES feels confident about transferring the technology to innovative farmers but State support has not been forthcoming (RORES 2002). The RORES case highlights the iterative process of technology transfer where field conditions have given rise to interesting innovations in the process. This innovation by a local NGO has taken *Spirulina* production far beyond what MCRC had envisioned.

Spirulina cultivation has now spread to many production centers in India particularly in the south. In northern India, a university botanist – Pushpa Srivastava, a participant in the ETTA symposium – has innovated the use *of Spirulina* for income generation by underprivileged women belonging to the SCs and STs at Bassi near Jaipur, Rajasthan, and a larger experiment on the lines of Latur for Gujarat earthquake victims. It is thus evident that much activity is going on at the field level with diverse results and experiences in use and even in the health benefits of *Spirulina*. Most of these activities have been without State support and some are now sustaining themselves. The field-level experiences also indicate the possibility of greater scientific involvement especially with regard to exploring heath care uses of *Spirulina*. These grassroot workers would like to undertake studies to validate what are now largely anecdotal experiences with the notable exception of the study initiated by Antenna Trust with Madurai Medical College (Thinakarvel and Edwin 1999).

The future

If the story of *Spirulina* so far is anything to go by, the innovation trajectory may yet take new directions and present new possibilities. Thus, while many of the funding agencies have been looking at the *Spirulina* work as technically closed, with activities restricted to extension alone, field visits indicate that this is hardly the case. There have been several ideas at MCRC and elsewhere that have not been tried (eg, processing *Spirulina* in the form of easy-to-make processed foods like curds or cheese) and that such ideas are in need of scientific intervention. Similarly, no major effort has been made to repeat the nutritional study in another district or State on a similar scale. Even if not on that scale, it is clear that *Spirulina* consumption has been taking place in rural India for several years. No scientific input has gone into trying to assess its health impact or to make scientific sense of the wide range of anecdotal experiences in these areas. There is much work to be done.

Table 4 captures the evolution of the innovation architecture of *Spirulina* in India. Quite clearly, not only was MCRC critical in the *Spirulina* innovation trajectory, but there was also something unusual and valuable about the way MCRC viewed the task of innovation and its role in that process. In the following section this work is placed in context and the research culture that enabled the development of this technology by civil society is explored through an analysis of various writings of MCRC, both published and unpublished.

Innovation in context: research culture at MCRC

The *Spirulina* work was shaped by the unconventional research culture at MCRC. A central influence shaping the philosophy of MCRC was its Director during this period – Dr CV Seshadri. By many measures he was an extraordinary individual, a gifted visionary whose ideas (almost always) challenged conventional thinking and received wisdom on issues as fundamental as the laws of thermodynamics and the concept of time (Seshadri 1993b; Balaji 1996; Visvanathan 2002). Undoubtedly MCRC provided space for a fuller expression of Seshadri's ideas that would have probably otherwise not seen the light of the day in his earlier stint as an academic and researcher in formal scientific establishments. However it is also important to recognize that there was more to the research culture of the place than the genius of an individual scientist. The heuristics of such a culture of science are revealed in many of the technical notes of the organization and merit attention for their role in enabling innovation.

The unconventional ways in which problems were defined at MCRC is evident in the very first monograph of the MCRC group entitled *A total energy and total materials system using algal cultures* (Seshadri 1977). This monograph outlines the philosophy of work, while also positing a fresh approach to the role of a scientist or engineer in a developing world. It calls for the articulation and definition of an engineering problem based on a keen context sensitivity to the social issues of a developing country. This philosophy of 'holistic invention' was to form the key to the MCRC approach to problems of science and technology and rural development. The features of this research culture at MCRC are discussed below.

Table 4. Players, partnerships and process: the evolving architecture of the *Spirulina* innovation system.

	1953–72	**1973–78**	**1978–84**	**1984–91**	**1991–93**	**1993–98**	**1995–2002**
Activity focus	Taxonomy, maintaining cultures	All India Co-ordinated Programme on Algae; sewage water treatment, food, feed and biogas	Vigorous and diverse experimentation leading to cost-sensitive designs suited to Indian conditions	Innovation towards commercialisation, India's first plant set up	Coordinated program on *Spirulina* including a large-scale study among 5000 children	Demonstrated possibilities of income generation	Extending outreach of *Spirulina* to the poor, *Spirulina* in export and urban markets
Process / defining feature	*Setting the stage*	*Diversified knowledge generation*	*Rooting* Spirulina *in India*	*Commercialization of technology*	*Broadening the* Spirulina *base*	*Extension to new social groups*	*Diffusion by non-public agencies*
Main actor	IARI	IARI	MCRC	MCRC	MCRC	MCRC	None
Other actors		Other public research institutes, Indo-German Plant/MCRC	Murugappa group and few research institutes	Financial institutions industry, NGOs on nutrition	Scientific agencies, health departments, village-level institutions	Scientific agencies, local NGOs, earthquake victims	Private industry and NGOs
Innovation system features	Single actor basic research focus	Expansion through multi-institutional division of research. Separation of basic and applied (pilot plant). Emergence of new player outside formal science	Integration of basic and applied research, collaboration. Contextualization. Concurrent work on village scale	Partnerships with NGO, industry and research center towards large-scale technology and decentralization. Partners bring agendas and expand domain	Diverse partnerships between research and non-research actors allows for large-scale expansion	Social innovation for new groups – quake-affected, women	MCRC not active player, new entrants, lack of ownership of innovation system. No involvement from public research

The importance of visions

A guiding feature of research at MCRC was the way it was driven by visions of an extraordinarily ambitious kind. The technical ideas presented in the 'total energy total materials' monograph were novel in their use of energy analysis to determine the choice and definition of research problems at the Centre. Some of the technical ideas on carbon sequestration or recycling from power plants were ahead of their times. The idea to use both the energy of stock gases and the materials to fix the carbon in one of the most efficient photosynthetic systems, namely algal culture, was indeed novel and formed the basis of the *Spirulina* work at MCRC.[4] Even though the actual application of stock gases for algal photosynthesis did not materialize, the philosophy behind such an approach shaped the day-to-day practice of science and the research culture of the Centre.

In a rather bold and ambitious statement on the role of the engineer scientist in a developing country, Seshadri outlined his vision by proposing that creating integrated systems of sophisticated and appropriate technologies, marrying the vices of the former (modern technology with unlimited growth-oriented devices) with the virtues of the latter (traditional resource-conserving technologies) was the way for the future. He outlined two proposals based on such a reading. The first, an integrated technology to grow food, fodder, fertilizer, and fuel, and the second, to use the wastes of sophisticated industry for an agricultural application. He argued that the need was to have the best of both sets for an optimal mix, stating that "this kind of synthesis was necessary to better understand how affluent technologies can help sub-affluent people."

Setting the agenda for the future work on algal research at MCRC and in India, Seshadri proposed three objectives of the work, the primary one being feasibility studies for a pilot plant of 1 t day^{-1} of food and fertilizer-grade algae using waste materials and energy from large power plants. Dissemination and use of the products of the facility, and integrating aspects of low-cost technology to minimize capital investments and employing as many skilled and unskilled workers as possible were the other objectives. There was a caveat to this broad agenda that realized the need for play in its actual implementation. Seshadri added that, "the division into objectives is arbitrary and not the basis of priorities. The attempt has been to think of integrated systems of technology to maximize common good." The proposal, he believed, outlined one way by which pre-industrial man could use the wastes of industrial man to make a post-industrial product.

What the monograph indicates is that sources of creativity and invention for research ideas often do not conform to traditional readings of the history of science and technology that are based on a linear narrative of successive stages in the development of a particular technology or discipline. Non-linear and lateral narratives in other disciplines, including those from the social sciences and real-life situations, are often sources of creativity for scientists and cannot be ignored. The monograph provides us with a vision of the MCRC and also indicates the source of the ideas for future work on algae. Importantly it also highlights the experience in research that often not all ideas generated at an early stage translate into reality. Some are, in fact, ahead of their time.

Valuing failure

Another feature of research at MCRC relates to valuing failure. Conventional project evaluations with a strict success/failure framework do not value processes and 'failures' of ideas. On this point Seshadri had the following to say

> "One important aspect of developing systems of science and technology that is integral to our paradigms of development is the recognition that failure is an essential part of innovation; it is an important part of learning. In India today we are thought to perceive knowledge as a 'finished product'... It is a massive effort, to develop a 'knowledge system' for India, and we must recognize and learn from the failures in the process, wherever they occur" (Seshadri in PPST 1990).

Interviews with scientists who worked at MCRC and the manner of reporting used in technical and project reports at MCRC indicate an openness to share not-so-successful experiments. This was valued both as research culture and philosophy at the Centre. The MCRC had planned internal reports as a forum where such not-so-successful ideas would nevertheless find articulation (MCRC 1977). If not documented, these nascent ideas are lost to the research community, and it is probable that this could affect the tradition of innovation in the research center in the long run.

Staff at MCRC remarked in interviews that they were encouraged to make mistakes and learn from them. "The nature of the problems often was so unconventional that we had to make mistakes and learn from them." One of the scientists (an aeronautical engineer) remarked that when he first joined MCRC he was asked to make paper from silk cotton. The work involved various kinds of experiments that helped determine the technical constraints in the process. These crude experiments conducted by an amateur using tools such as pressure cookers later led to one of the more innovative projects at MCRC. All of this could not have happened without a research culture that promoted learning by 'thinking with hands' and making mistakes.

Interdisciplinary research at MCRC

The above instance of an aeronautical engineer working on problems not of direct disciplinary relevance was not an isolated instance. Multidisciplinary teams of scientists, technologists, and amateurs worked at MCRC, doing much of the early scientific work on *Spirulina*. The research center emphasized multifunctional tasks, and there were several instances in the *Spirulina* story where physicists were engaged in marketing and scientists in training, extension, etc. Resource constraints often created conditions for institutional innovations – staff having to do tasks simply because there was nobody else to do them. There were also programs at MCRC that enabled meetings across disciplines and encouraged the scientists to come out of their laboratories. In early times there were periodic campus-cleaning drives and activities that involved manual work that cut across disciplines and involved everyone in the organization. This research culture encouraged staff to drop their disciplinary labels.[5]

Problem definition and accent on innovation

The way problems were defined indicated an approach that set MCRC apart from conventional R&D centers. Balaji in the first Seshadri Memorial Lecture, 'Inventing the Future', elaborated on this:

> "That famous dictum – 'Technology is the solution', or 'technology is the answer' – was often questioned by Dr Seshadri, who asked, "Where is the problem, first?" Technology or invention must arise out of a problem, not as a result of market pressure or organizational restructuring alone ... they must address a very serious developmental issue. And, with this, he went around nurturing inventiveness and innovativeness in all kinds of people. School drop-outs, semi-literates, and PhDs all came with some kind of a new product or the other, some kind of new idea, under his guidance." (Balaji 1996).

Seshadri was once asked in an interview, "Are you not trying to reinvent the wheel?" He responded by stating that you need to re-invent the wheel to understand the process of innovation, creativity, and technology, and to write the operation manuals for current conditions. Importing a technology will not solve the problem. Much of the work at MCRC revolves around this accent on invention and the need to introduce a culture of invention, both at MCRC and within the communities with whom they worked. There were thus no blueprints for invention either, but approaches that they sought to follow in their work.

However, it needs to be emphasized that this accent on innovation was not innovation for innovation's sake, but was seen as critical to the whole innovation process of an idea being translated into reality. Table 5, taken from a 3-year review of MCRC, indicates an appreciation of the innovation chain and where each piece work or experiment was situated.

Learning across projects.

One of the features of the organization is the cross fertilization of ideas across projects. From the narrative of the *Spirulina* project it is noticeable that there were major shifts in research directions, especially in the manner of applications. A look at the projects of MCRC in the last 25 years indicates several activities happening simultaneously in different projects. This enabled learning in the *Spirulina* project and vice versa. Two of the earliest programs in a cluster of villages focused on providing nutritional and energy self-sufficiency. A significant outcome of these efforts was the conception of the notion of 'Integrated Energy Systems' that views waste(s) from one part of a system as input for another. This concept was used in the *Spirulina* project. Similarly, training women in using workshop tools or income-generation activities led MCRC to experiment with *Spirulina* production by rural women. Several small-scale experiments fed into the large-scale trials both in *Spirulina* and in other projects. Nutritional requirement studies in the early 1980s helped create the atmosphere and capacity required for LSNS in the 1990s. These LSNS helped the Latur project and so on.

At another level, developing algal cultures gave the group a chance to explore a whole range of renewable energy devices. Windmills were designed and built to agitate the cultures. The solar energy based devices were developed to dry algae after harvesting.

Table 5. Evaluating work in progress in MCRC.

Area of research	Idea stage	R&D	Proto-type	Field test	Technology transfer	Publica-tion
Identification and separation of algal strains	X	X				X
Spirulina culture in inorganic nutrient	X	X		X	X	X
Spirulina culture in modified biogas media	X	X		X	X	X
Biogas and sea salt	X	X		X	X	X
Biogas, sea salt, and bone meal	X	X		X	X	X
Biogas and sea water	X	X		X	X	X
Spirulina culture in sewage	X					
Development of harvesting equipment for *Spirulina* culture	X	X	X	X	X	X
Wind agitators	X	X	X	X	X	X
Feeding trials of cattle and fish	X	X		X	X	X
Human feeding trials	X	X				
Protein estimation in *Spirulina* incorporated in food	X	X				
Nitrogen estimation in *Spirulina* incorporated in food	X	X				

Source: MCRC. 1980.

Innovations in low-cost digesters were made to use carbon dioxide from biogas plants. From each of these innovations a further set of devices and technologies grew. The work on biogas and improving its quality in turn enabled identification of cellulose-degrading bacteria. This led to the development of a microbial pulping process for papermaking. The solar drier work led to development of water-distillation units that use sunlight as an energy source (Thomas 1996).

What is clear from this is that MCRC viewed all its activities (both research and development) as learning exercises. And because these different sets of activities ‘talked’ to each other this learning could be used to stimulate innovation. The lack of barriers between research and developmental activities together with a culture of viewing these as both important with valuable contributions to make, was an important feature of MCRC.

Sources of innovation

Seshadri believed that the Indian experience in making technologies so that technology comes to fruition through sale of product or process was marginal, and that often the professional bodies of science are unclear and lacking in judgment about when a technology was ready. He added that what was considered invention and/or creativity in India was import substitution at all levels including the idea, need, market, development, and sale. In this scenario, he argued, it was hardly surprising that creativity and innovation seldom take root. Indeed, he stated that:

> "Invention is a social act. The fact that the science and technology establishment has sequestered this for themselves is a sad feature of Indian life. Invention cannot be categorized, classified, displaced and disposed of, and can take place anywhere. Further, the recognition that it costs money and efforts to convert inventions into products is also absent. If science cost Rs1, technology may cost Rs10. Hence support must be available all the way" (Seshadri 1991).

The wider institutional context of MCRC and its philosophy

What was the context to which MCRC was responding? What was the larger context within which the MCRC work needs to be placed? Some of the critiques of development and research in Indian science to which MCRC felt there needed to be an alternate model are presented here. MCRC started primarily as a private research center, though its character soon changed to that of a non-governmental civil society initiative. In the early period Seshadri at MCRC reflected on science in India and commented that "a sad feature of the profession (of science) is the way private sector scientists are treated by government scientists with a lot of suspicion and hostility, almost as though they were non-Indians" (Seshadri 1984). This was one of the contexts to which MCRC was responding, ie, that of science being treated exclusively as an elite activity of the scientific establishment, with the rest of scientific activity having to fight for their legitimacy in their practice of science.

Science and innovation in alternative institutional settings

This paper began by suggesting that post-harvest innovation processes are characterized by a degree of complexity with which conventional R&D arrangements in the public sector have difficulty coping. In contrast, despite being overlooked in policy debates on this issue, it was argued, civil society organizations are active in this domain and, in fact, are practicing science and promoting innovation in ways that hold many lessons for research policy. The main empirical section of the paper has presented an innovation trajectory that has been played out to a large extent within the institutional context of a civil society organization. What is striking about this case is the way it so amply demonstrates the systemic nature of the innovation process and thus seems to support the growing calls for the use of innovation systems ideas in agriculture and post-harvest research planning and evaluation (Hall et al. 2001; 2003; Biggs and Messerschmidt 2004).

What then can this case tell us about: 1. the nature of post-harvest innovation processes and systems; 2. the nature of that institutional setting that promotes innovation; and 3. the policy measures and analytical perspectives that should be brought to bear, so that not only does public R&D perform more effectively, but also, civil society organizations are valued for the role they play in innovation systems?

Features of innovation processes and systems

Evolving groupings and diversity of players and roles. The *Spirulina* story demonstrates the way innovation involves a large number and diversity of players and over a considerable period of time. Furthermore, it demonstrates that the players change, that groupings or partnerships emerge and evolve, and that the roles of different players can also change. For example, what had started with the agricultural establishment in India being the major player initiating basic research in the 1950s shifted to the current situation where the scientific establishment had virtually no role. In between there has been one major player – MCRC – that has transformed the way *Spirulina* was seen in the country, a role that has now been taken on by other organizations. The inventory of actors in Table 4 shows that innovation is a process involving a large number of players – formal and informal, research and non-research actors. The roles of actors involved in innovation also seem to be diverse. Some are scientists, some are development practitioners, and some are entrepreneurs. Some are even visionaries. Moreover, these roles are not necessarily fixed. Note how at certain times MCRC needs to play a scientific research role and at others it needs to play the role of disseminating technology – the more stereotypical role of the NGO. Another example is the way RORES, an NGO involved in extension, became an important source of technical innovation when it became involved in developing village-based production systems. These cases illustrate that there is a non-linear progression from a research to a dissemination role (or vice versa), but instead, non-linear organizations play the role most appropriate to achieving objectives at a given point in time. A key feature of the innovation system associated with *Spirulina* has therefore not only been the diversity of the players involved, but also the way both the composition of players and their roles evolve over time.

Partnerships. The *Spirulina* story demonstrates some of the reasons partnerships are important to innovation and shows that important partnerships are often between research and non-research actors. The case of partnerships between village women that the NOW initiative and the LSNS studies illustrates is an example. Here the value of partnerships has been to:

a. Bring **new agendas** to the research process that go beyond the scientific focus and perspective of the researchers involved. In this case the client focus (rural women) of research was sharpened.
b. Bring **new skills, resources and networks.** The collaboration with NOW helped MCRC develop the market and greater public awareness of the benefits of *Spirulina*. Similarly the LSNS study enabled greater access to the medical community leading to several independent studies on the health benefits of *Spirulina*.
c. Raise the levels of **accountability** of MCRC and the *Spirulina* innovation system. MCRC could no longer rest on its glory of commercializing the product, but had to

become an important player and partner in a new system with different norms of accountability for nutrition in rural areas. While MCRC always believed in the concept, the partnerships actualized the possibilities.

An important point here is that the *Spirulina* innovation system has a capability that is more than the sum of its parts. It concerns levels of skills and resources, but also concerns the way the system behaves – ie, the agendas it pursues and the patterns of accountability to which it responds.

Reworking the stock of knowledge. The MCRC experience suggests that innovation is all about drawing from the existing stock of knowledge and using, adapting, and diffusing it in new ways. Algal technology had originally been conceived as a biofertilizer. Knowledge of *Spirulina* was reworked by MCRC to produce a food supplement technology. This idea has subsequently been further reworked to meet diverse objectives such as rural employment, enterprise development, nutritional security, and disaster relief – all innovations on the *Spirulina* theme. As Edquist (1997) points out, innovations involve creations, which may be brand new, but are more often new combinations of existing elements.

Responding to evolving opportunities. The *Spirulina* story indicates innovation is often a response to emerging opportunities and that successful organizations are those that can seize these opportunities when they arise. There has also been a gradual evolution of objectives and trajectories along the way – eg, food, fodder, energy, large-scale, small-scale. The use of *Spirulina* for the earthquake relief work was another such response. Successful innovation systems are those that respond quickly and flexibly to changing circumstances in response to both opportunities and constraints.

Interplay and iteration between research and technology application tasks. It is also clear from the way *Spirulina* developed in India that there was no linear relationship between basic and applied research, or between applied research and diffusion. There has been a lot of iteration between these stages that are conventionally compartmentalized as strategic and applied tasks. For example, the changed client focus (rural women as producers) necessitated several changes in scientific research; the large-scale application requirements for food instead of fodder necessitated basic nutritional research. As we have seen this has allowed a gradual evolution of objectives and directions along the way. At MCRC this was often brought about by cross learning between research and applied projects undertaken by the organization. This is, of course, non-linear. An important point here is that throughout the life of an innovation trajectory, research questions arise that need to be addressed by science. The idea, therefore, of innovation as a systems concept does not diminish the importance of science, but instead locates it in different relationships and points in the innovation trajectory.

Learning. Many of the points above allude to an underpinning process that seems to be driving forward the innovation trajectory. This process is learning and it confers the evolutionary dynamic that characterizes innovation systems. See, for example, the way lessons from applied tasks suggest new research tasks and technical possibilities. Similarly, look at the way the LSNS provides opportunities for MCRC staff to work in new domains – nutrition – and how this allows them to develop further activities in this area. And also notice the way learning comes from different contexts – for example, from the experience of NGOs establishing village-level production systems. Notice also that some of these lessons are technological and some are institutional, ie, how to do something, with whom to work, how to test results and validate findings. Sometimes it was necessary to fail in order to learn how to move forward; in fact, while many of the ideas and designs failed, considerable useful insights were learned. Learning is thus a fundamental property of the innovation system.

Features of institutional settings that promote innovation. Table 6 summaries the main differences between the research cultures of MCRC and public scientific establishments. Some of the key features of the institutional setting that promoted innovation will now be discussed.

Creating opportunities to learn. A number of features about MCRC meant that learning was facilitated. By reducing internal barriers and hierarchies, cooperation and communication was encouraged across the organization. This allowed MCRC to learn

Table 6. Contrasts between research cultures at MCRC and public scientific establishments.

Aspect	Public scientific establishments	MCRC
Vision	Often not articulated, instigated from above, not reflective of work culture	Outlined very early, articulated in writings, 'Integrated Systems' and 'Holistic Invention'
Definitions of problem	Only in technical terms	In social and technical terms, open to ideas from social science and real life
Failure	Product focus, processes not recognized, reporting of success alone	Reporting of mistakes encouraged and seen as part of process. Failure as adding to stock of knowledge
Interdisciplinary	Not encouraged, strict disciplinary boundaries between scientists and technologists and social scientists, tasks as domain of specialist	Encouraged, professionals made to drop labels and work across disciplines, tasks are multi-functional, place for the amateur
Learning	None across projects	High across projects, large spin-offs within the Centre
Research accent	Import substitution	Innovation
Relationship between technology and development	Linear, market seen as taking care, diffusion not part of mandate	Seen as involved and complex, cannot be left to market alone, appreciates time-lag involved, cost sensitivity
Stakeholders	Rarely involved, if at all, at diffusion stage	Active involvement at both idea design and diffusion stages
Partnerships	Few, not seen as important	Large, seen as critical to innovation, and to enable survival beyond MCRC

from its own experiences, especially across projects. The fact that it had both basic research projects and applied field-based projects made this cross-project learning particularly powerful. For example, lessons on projects not directly connected with *Spirulina* helped the *Spirulina* project by bringing in such new possibilities as the approach of integrated energy systems, the focus on nutrition, or the possibilities of women being the main producers and users of technology. This learning was helped by an organizational culture that saw research not just as some specialized activity but also as capacity building for the whole organization. That the organization saw the need for ‘reinventing the wheel’, if only to rewrite operation manuals, illustrates an approach that valued learning in different cultural contexts.

Encouraging interdisciplinarity and flexible professional mandates. MCRC shows the value of a flexible approach to professional mandates, especially in evolving innovation scenarios. The involvement of trained physicists in marketing, or the involvement of amateurs in research teams broadened the research. The close contact of MCRC with field-level realities on the one hand and scientific organization on the other were strengths that facilitated better problem definition. Related to this was an institutional setting that encouraged and valued partnerships as a way of extending the reach and source of inspiration of the organization into both research and application domains.

Constructive treatment of failure. For MCRC, failure has been an important source of learning and was valued as such. In other words, failure was used to add to the stock of knowledge from which innovation can emerge. As Watts et al. (2003) have indicated, institutional contexts and professional behavior that can take this constructive approach to failure and learning have much to recommend them.

Ways forward

The *Spirulina* story has a number of lessons for research policy, particularly for public research organizations that still conform to linear modes of operation which are seeking to play a more effective role in innovation. These concern: 1. general policy prescriptions and analytical perspectives, and 2. specific comments about the role of civil society science and technology policy and implementation.

General prescriptions

- Conceptualizations of non-technical and non-quantifiable aspects of research need to be encouraged. There are presently few means for scientists to pick research questions from the field or user. The ‘field’ has a critical role in defining problems and not just as a space for diffusion of technology. Civil society organizations bring to the research agenda this critical dimension.
- Research projects that involve partnership, grouping or coalitions of diverse stakeholders have greater possibilities of success.
- There is a need for a change in organizational culture that encourages broader-based pursuits across the basic to applied continuum and that values failures, allowing for learning across projects and disciplines.

- It is necessary to spend resources on reflecting on the past and on institutional lessons of projects that have a bearing on the culture of research within an organization. In other words, there are learning possibilities through case studies of institutional and innovation histories that need to be more fully explored.
- In general, research activities need to be conceived as part of the larger process of innovation. Concepts such as the innovation systems could usefully be employed to help map out the architecture of these systems, helping identify missing links, and institutional failures.
- Research policy needs to pay more attention to building the capacity of these systems. In this task institutional innovations will be critical.

The role of civil society

The notion of innovation as systemic phenomenon allows the consideration of the role of civil society to go beyond the dualities of formal versus non-formal science. There is nothing in the *Spirulina* innovation trajectory that represents single ownership of ideas or concepts. For far too long, civil society and State science in India have seen each other's activities as in opposition. With the increasing realization that there is a lot of technical content in extension (as indeed this case has demonstrated), formal science needs to extend the domain from whence it chooses problems and research ideas. Within the new framework of the innovation system creativity can be celebrated irrespective of its institutional contexts. More than any increased funding allocation, this requires a change in approach in the way State science looks at the field and the complexities of technology transfer. Formal science needs to recognize the 'hidden histories of science' in civil society initiatives and incorporate them as part of the 'legitimate' narrative if science has to have a pro-poor human face. The *Spirulina* case study in fact illustrates a critical and underutilized role of an alternative paradigm of learning and innovation.

Endnotes

This paper is the output from a research project funded by the United Kingdom Department for International Development (DFID). The views expressed are not necessarily those of DFID [R7502: Crop Post-Harvest Programme].

1. This report has benefited immensely from the several discussions with research staff (both past and present) of the Murugappa Chettiar Research Centre and the NGOs and researchers who shared their experiences on *Spirulina* cultivation. The views expressed however are those of the author alone.
2. For more details on the Nimbkar Institute see www.nariphaltan.virtualave.net and for the Rural Innovations Network see www.rinovations.org, also see www.sristi.org.
3. For various applications of *Spirulina*, see www.nrdcindia.com, www.spirulinasource.com, and Seshadri and Seshagiri 1986.
4. Seshadri (1977) points to the enormous energy in the form of waste heat of thermal plants and estimated that the waste heat of a 100 MW plant as sufficient to supply the energy requirements of 20,000 village households. This figure would swell to 10,000,000 village homes if all fertilizer and cement plants, blast furnaces, and oil refineries were included.
5. For a fuller discussion on the difficulties in implementing interdisciplinary research in universities, see Feller 2002.

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