November 28, 2000

Evaluation of the Competence Centre for Environmental Assessment of Product and Material Systems, CPM at Chalmers University of Technology, Gothenburg

1. Preface, Methodology, and Acknowledgement

On Monday evening, November 27, and Tuesday morning, November 28, 2000, three of us, the scientific experts of the evaluation team, Thomas Graedel, Steven P. Frysinger and Helias A. Udo de Haes, were briefed by the Director, project leaders and graduate students of the Competence Centre for Environmental Assessment of Product and Material Systems (CPM), on the range of projects under investigation.

On Tuesday afternoon, November 28, the entire team made up of the scientific experts and the two Competence Centre experts, John S. Baras and Marshall M. Lih, was briefed on the present state and future strategy of the Centre as well as on its status within the university organization by the Director of the Centre, Margareta Wester, Board members Thomas Hjertberg, Oliver Lindqvist and Jan Strömblad, the Vice-President of Chalmers University, Johan Carlsten, several project leaders, graduate students and representatives of industrial partners. The presentations were accompanied by lively discussions.

We appreciate the high quality of the presentations during the evaluation. Open and informative discussions were conducted on technical, strategic and leadership issues with the members of the evaluation team.

We would like to thank the whole CPM team for the efforts they made in preparing these two days of briefings. We were very pleased by the frankness and the informative discussions that helped us to prepare this report. We also thank Göran Uebel and Staffan Hjorth of NUTEK for the invitation to the evaluation and their assistance in all aspects of the review.

2. Development as a Competence Centre. Added Values

Long Term Strategies and Progress of the Centre

The Centre for Environmental Assessment of Product and Material Systems, CPM, has made considerable progress towards achieving the goals of a Competence Centre since the evaluation of 1997. Led by an effective Director and a closely working group of academic researchers and industry representatives, CPM has developed a focused research programme of several well coordinated projects on methods and tools for environmental assessment of product and material systems.

The Centre leadership has succeeded in building a cross-disciplinary programme involving two Universities and five Departments. The technical competence of CPM is

strong. The Vice President and two Deans of Chalmers University confirmed that the university would support CPM in the future. The University appointed one senior faculty within the area of CPM following recommendations from the review of 1997.

Following an additional recommendation from 1997, Chalmers performed a university-wide review of environmental studies and launched the Environmental Initiative. All administrative officers present at our visit emphasized that this initiative is expected to strengthen CPM considerably. Currently there is lack of participation by senior faculty in the CPM programme. Centre and university management are aware of the problem and expect that this situation will be corrected from the new faculty hires associated with the Environmental Initiative.

The Centre leadership has developed a programme focused around three interrelated technical thrusts: databases and validation, modelling of technical systems, and modelling of natural and socio-economic systems. A fourth thrust on applications runs across the three other thrusts linking them in relevant research and technology transfer. Technology transfer is an integral part of the overall effort in each project. Significant research and development progress has been achieved in formats for LCA data documentation, in goal and application dependent LCA methodology, in end-point modelling and in estimation of damage costs for the EPS weighting indices. The Centre leadership is strongly encouraged to continue this progress towards a strategic plan by developing a conceptual road map with a five year horizon.

During the last three years the number of industry partners increased from 12 to 14, and the budget increased from 10 million Swedish crowns per year, for the first two years of operation, to 17 million Swedish crowns per year for the second phase. The value added of the Centre was evident from the enthusiastic participation of academic researchers, the appreciation of the Centre expertise by the industry members, and the enthusiastic and impressive presentations of the PhD students and industry participants.

The number of PhD students has increased to 8, including 2 industry PhDs. In addition 10 MSc students have completed each year. Students work closely with industry engineers and spend considerable time at industry sites. The quality of students is very good. Development of a more extensive programme of industry PhDs as well as a substantial increase of MSc students will benefit the CPM programme. The scientific output has been good in terms of quality of journal papers. Increased scientific output production must be an important goal for the next phase of development of CPM.

It would appear that CPM has not yet made significant contributions to the educational programmes of Chalmers. Centre management must undertake efforts to increase substantially educational contributions from CPM, in such an important for Swedish industry area. This should involve both graduate and undergraduate teaching. Based on the presentations given at our visit there are several opportunities through which this can be accomplished. CPM should pursue these vigorously.

CPM met the goals set for its development during the second phase. We were presented very interesting preliminary plans for the Centre development in phase three. These center around the following themes: Integrated Product Policy on the European society

level, Environmental Informatics research, and Seller/Buyer information sharing. The latter represents a new direction. CPM must develop a strategic plan around these themes, which should guide project selection and funding. The Centre research programme could benefit from injection of more advanced computer science and software development and modelling methodologies in its research programme. Centre management has taken initial steps to accomplish this.

International Collaboration and Ranking

Centre management and researchers are well aware of the major research centres world-wide where research relevant to the CPM work is being conducted. The Centre participates in several Nordic and EU international consortium projects.

CPM has established a competence profile that is internationally recognized, especially in the area of environmental informatics. Notably researchers at CPM were the initiators and leaders of the international format standardization for LCA data documentation, ISO 14048. The development of the environmental data structuring embodied in the database SPINE, and its various applications has brought distinction to the CPM research output.

Evidence of the recognition enjoyed by the CPM team is also provided by the facts that CPM is entrusted to maintain and further develop the EPS system, and that EEA commissioned CPM to develop and host the new web site LICADA (Life Cycle Assessment Data Network), which introduces a consensus tool to facilitate Life Cycle Inventory (LCI). CPM participants contribute regularly to major Environmental Engineering conferences, and some have given invited lectures at such conferences.

The current programme of international visitors, and visits of CPM personnel at other competing centres worldwide is rather limited. The Centre should increase bilateral active exchange of visitors with other research centres. This would increase the reputation of CPM, as well as provide much needed feedback and assessment of relative strengths and weaknesses with respect to other teams.

Collaboration and Linkages within the Centre

CPM has research personnel from the Departments of Computer Science, Environmental Systems Analysis, and Geology at Chalmers, as well as from the School of Economics at Gothenburg University. More recently, personnel from the Control and Automation Laboratory of the Department of Signals and Systems at Chalmers have been included, and plans call for increasing such participation. There appears to be good cross-disciplinary collaboration among these academic researchers, focusing on approaches from industrial environmental management, environmental systems analysis, computing science and industrial quality management.

CPM has developed a well functioning organizational and administrative structure. The introduction of the Advisory Group, with one representative from each company, to screen and organize projects and project proposals has helped in the development of a cohesive programme.

Chalmers has been supportive of CPM. It has provided financial support and a favourable organizational arrangement. Plans call for CPM to get its own new offices. The development of the Environmental Initiative and related faculty recruitment efforts, provide further opportunities for CPM to add faculty with relevant expertise.

There was ample evidence presented that demonstrated close and productive collaboration between academic researchers and industry participants from applied research projects to development. Academic researchers and students get access to industrial tools, experience, data and benchmarking. In return, industry benefits from transfer of results, systematic new methods and tools for environmental data management and staff training.

Identity and Management of the Centre

CPM has made a number of significant improvements based on recommendations made at the 1997 evaluation. A full-time Director was appointed in early 1998. The Director has established an efficient management structure and has successfully focused the research programme of CPM. Students working on industrial projects are working closely with industrial staff. CPM leadership and Chalmers University need to develop and implement policies that improve the image of the Centre and provide identifiable rewards and benefits to faculty joining the Centre.

CPM has a well balanced Board which works very well with the Director. Evidence presented indicates that there is a common vision, well articulated by several members of the Board and industry participants. A strategic plan is still lacking, although we were told that one is under development as part of the planning for the third phase programme of the CPM. We highly recommend that such a plan be developed and form the basis for project selection and funding.

The fact that the first outside technical evaluation of the CPM programme was conducted in June 2000, is a positive development. The Director and the Board want to establish an International Scientific Advisory Board, which will periodically review the CPM programme and provide recommendations. This is really long overdue, and we recommend most strongly that this action be completed as soon as possible.

Chalmers University is to be commended for the administrative and organizational placement of all its Competence Centres under a Vice President. The new Environmental Initiative and various associated faculty recruitment efforts provide excellent opportunities for CPM to grow and become a prominent unit within Chalmers. We urge Chalmers to continue innovating by establishing progressive policies that allow further recognition of CPM as a unit, including more favourable financial arrangements from sponsored research won by CPM. Such policies will prove to be an important reward and attraction for faculty participation in CPM. Further rewards for faculty participation must also be established.

3. Scientific and Technical Achievements

3.1 Life Cycle Assessment

Research Programme

The current research programme has a main focus on Life Cycle Assessment (LCA). Within this field research topics are chosen from a broad perspective, including LCI modelling and databases, characterization and weighting.

Technical Results

Specific contributions have been made clarifying the allocation problem, with special relevance for the translation of the ISO 14041 standard into workable practice. Another result concerns the further development of the SPINE database. This includes an exchange format between different databases, a database structure and format and options for linkage with specific LCI models. A further result lies in the further development of EPS, a well functioning LCIA programme, including weighting, which has recently been adapted to ISO 14042.

Scientific Production and its Quality

a. General

In general the CPM programme is quite productive. It employs a broad range of outputs, including scientific articles, conference papers, contributions to scientific working groups and to ISO. The scientific quality is in general high. However, the number of scientific publications has been limited in relation to staff involved; this has not been a priority up to now, compared with contributions to conferences and workshops. It is recommended that scientific publication will become a higher priority in the next phase of the programme, where possible also aiming for some publications in higher ranking scientific journals.

CPM rightly supports the idea that attention to commonality of approaches may well end up by developing an information system which is no longer linked to specific institutes; more specifically, to a situation which does not use the terms SPINE and EPS anymore in BAP for LCA. This by no means precludes new scientific developments initiated and/or performed by CPM for specific parts of the LCA methodology, like characterization of less developed impact categories.

It is recommended that CPM strengthens its input in international cooperation in the field of BAP; in particular it is recommended that CPM is actively engaged in the coming SETAC/UNEP initiative aiming at the identification of best available practice in LCA.

b. Life Cycle Inventory Modelling

Allocation rules
A significant contribution was made to the ongoing effort for further specification of the allocation rules. Particularly, guidelines were given how to define allocation rules for accounting vs. change oriented applications. It is recommended that this is further developed taking also the time perspective into account, and taking the limitations into account of the system expansion approach.

SPINE database
The SPINE database is a very transparent and well documented data system, which is exemplary in the field of LCA. The SPINE exchange format has been merged with the SPOLD exchange format in the framework of ISO 14048. It is recommended that CPM will actively participate in harmonizing the nomenclature with the SETAC-Europe working group on Data Availability and Data Quality. A challenging future perspective could be an automated LCI modeling dependent on chosen starting points for allocation and system boundary setting, including all relevant data sets.

c. Impact Assessment and Weighting

EPS
The EPS system was the first in the field of LCIA which promoted modeling up to the damage level; for this it is internationally well recognized; it has particularly made specific contributions in the field of resource depletion. In the last version of EPS the transparency has been improved, amongst others aligning EPS to the ISO framework.

The chosen willingness-to-pay method is one of a number of options for weighting across impact categories. It fits well with characterization at damage level, but the link with the chosen type of characterization of metals depletion is not fully convincing. Together with the specific choice for modeling at damage level, EPS provides a consistent but limited option for LCIA, given the broad spectrum of possible LCA applications. The undertaken broadening of the options for weighting, attached to the SPINE database, is recommended.

A further recommendation is that EPS-information will be included in a more encompassing framework for LCIA, preferably to be developed within the coming SETAC-UNEP framework. This should include a free choice of the category indicators at midpoint or endpoint (=damage) level, depending on the type of application.

Specific impact categories
A new focus is put on the development of characterization factors for specific impact categories, particularly toxicity and land use. This is very relevant, given the clear gaps that are present here. The international approach, chosen for the toxicity project, which also aims at the inclusion of modeling techniques developed in Environmental Risk Assessment, is highly appreciated. The focus is well chosen, aiming at a science based, yet practical approach for establishing characterization factors. This may well enable CPM to include a larger number of substances than the usual 300-500. For land use such an international orientation may also yield fruitful results. Here a careful distinction

between transition and use is advised, in order to accomplish a clear fit within the LCA framework.

3.2. Relations with corporate associates

Step 1: Identify environmental scientific challenges	MFA, SFA, Global change science, Land use science
Step 2: Evaluate effect of products on environment	LCA
Step 3: Implement improvement	DfE, Inviolates list, CAD/CAM integration

Research Programme

The principal goal of CPM is to decrease the environmental impacts associated with products. This might be pictured as a three-step process, as shown in the figure above. The first step is to identify and evaluate the environmental challenges potentially related to the product. This requires detailed and continuing input from the environmental science community, and the use of tools such as material flow analysis, substance flow analysis, and environmental risk assessment.

The second step is to use a tool like LCA or streamlined LCA to evaluate the environmental attributes of the product. The third step is the process of changing a present or prospective product design so as to minimize the environmental impact potential; this is the process of Design for Environment, supplemented by such tool as lists of inviolate actions and integrated into existing design tools such as CAD/CAM.

Technical Results

CPM has done well with the intermediate (assessment) step, as evidenced by the high degree of acceptance of the LCA work by the industry partners. The environmental science input is discussed in detail in the LCA section; much of it is competent, some sections still need work. The biggest need is to devote more attention to approaches that would better link into the corporate structure in such a way that product environmental improvements would readily follow. An important task will be to face streamlining of the LCA methodology while maintaining the scientific quality; this will be especially useful in smaller corporations without large environmental staffs. The second is to pay attention to methods and tools for environmental improvement; several are named on the diagram.

It might at first be thought that the improvement stage is not CPM's business, that it is corporation-specific. CPM's overall goals can readily be interpreted so as to include this step, however, and (like LCA) many aspects of the tools are sector-independent. An additional benefit of research on improvement analysis is that students addressing such issues in concert with corporations will gain an intense understanding of the challenges and benefits of the implementation activity.

Scientific Production and Its Quality

Several CPM-initiatives within LCA are particularly worthy of mention. They relate not to "filling in the blanks", which is necessary but not always scientifically challenging, but to research on new or poorly-treated activities within the LCA framework. The first of these is the work on industrial manufacturing process LCA; it does not yet include aspects such as the manufacture of the equipment used in the process, but is a useful step forward. A second initiative is the incorporation of regionalized data from the forest products sector into LCA; in its first implementation, this treats site-dependent inputs, and the next challenge will be to look at site-dependent impacts.

Education and Training

The involvement of graduate students in the activities of CPM has been very good, and the students as a result have strong corporate interactions. There is also the opportunity to involve undergraduate students, which would serve CPM, Chalmers, and the corporations all at once. CPM also needs to become centrally involved in the Chalmers Environmental Initiative.

Conclusions and Recommendations

The planned focus on LCA in daily operations is very good. As this project goes forward, it need not necessarily be closely tied to EPS. Other approaches might be better. It could be the case that comprehensive LCAs are most appropriate for accounting studies and prospective studies with long time scales, and streamlined LCAs are more appropriate for short time scale studies.

CPM should consider the use of ordinal rankings to get toxicological information to designers more quickly and completely than is currently possible in LCA as well as other systems engineering and analysis approaches. From the perspective of the designer, ordinal information may frequently be perfectly adequate, and it can be implemented very rapidly.

The focus of CPM has been too heavily-weighted towards product evaluation by LCA techniques. To fulfill the CPM goals, more effort needs to be directed towards additional tools such as substance flow analysis and environmental risk analysis, and a broad approach to improvement analysis as a follow-on activity to LCA/SLCA. This will be especially important for small and medium-sized corporations.

3.3. Environmental Informatics

Research Programme

CPM's phase 2 initiative in Environmental Informatics is a positive and relevant undertaking. Much of the effort in product environmental management, and indeed environmental management in general, may be formulated as an information gathering and management problem. While LCA data collection and analysis is discussed elsewhere in this report, the Environmental Informatics initiative has the potential to go well beyond LCA. CPM's programme in this area, an outgrowth of the LCA database work which preceded CPM, represents a very good start and has obviously been well-received by the user community. This work offers the exciting prospect of promoting deeper integration of product impact analysis within line organizations in the company structure.

Research in the Informatics area is primarily associated with two ongoing projects, SPINE and PHASETS, with some case-study work exemplified by RAVEL. SPINE and PHASETS will be addressed in turn below.

SPINE

SPINE constitutes a data format and quality control system, the purpose of which is to accommodate LCA data from a variety of sources, ensuring that these data are fully documented and accompanied by appropriate metadata and satisfying certain quality criteria.

PHASETS

The PHASETS project aims at data documentation which goes well beyond life cycle assessment to capture all product related environmental data associated with the product's manufacturing phase. While this information constitutes only a portion of that needed for LCA, it also has the potential to support such other applications as pollution prevention, environmental management systems (e.g. ISO 14001), right-to-know reporting, EPD, and labeling, particularly Type III product declarations.

Technical Results

SPINE

SPINE has proven to readily satisfy the service component of CPM's mission in that representatives of member companies identify this database as a principal source of added value accrued through their association with CPM. Hundreds of datasets have been added to the national system (SPINE@CPM), and many private versions of the database have been ported and augmented by industry. Separation of these proprietary versions is of some concern because of the inconsistency that inevitably results from redundant databases. While it may be unavoidable because of intellectual property concerns surrounding some data, this should be minimized by encouraging users to refresh local versions with data held in common with SPINE@COM on a regular basis.

PHASETS

Results of the PHASETS effort are still preliminary, but are very promising. A unit process modeling approach has been adopted, but this needs to be made more robust,

ideally integrating this with process modeling results available from process engineers of the companies' line organizations. This will help to avoid redundancy, and will also facilitate maintenance of the model by line staff for their own purposes.

Scientific Production and its Quality

CPM's work in the Environmental Informatics area is of a high quality. Though it is not pushing the state of the art in information technology, it has the potential to revolutionize environmental information management within manufacturing firms by integrating environmental information with other management information already required in the ordinary conduct of business. In the long run this will not only help to contain the costs of environmental product management, but will also help to ensure that environmental data are provided by appropriate line personnel and are well-maintained.

Education and Training

Some of the work in the Informatics area has been performed by Master's and PhD students, but there is much more opportunity to include students in this research, including undergraduates, especially as new and robust approaches to accommodate process model expression are investigated.

Conclusions and Recommendations

The Environmental Informatics initiative is an excellent addition to the CPM portfolio and should continue to be pursued. As has already started to happen, the scope of this research should be taken beyond LCA to include all environmental information management aspects of product/service manufacturing/delivery. This serves the dual purpose of promoting more robust environmental data management while enhancing the direct economic benefit of CPM's work to user companies.

Portability, both in terms of data architecture and software, will be a constant concern to this effort, and will be especially exacerbated by the prevalence of multiple computing platforms used in industry. Therefore, special attention should be paid to the use of architectures that are relatively independent of operating system and hardware. In the development of these tools, careful attention should also be paid to the needs of the ultimate users, many of whom are or should be non-environmental workers associated with the production process.

Scientists trained in human factors analysis, with a specialization in computer-human interfaces, will be a great asset in this regard, but a solid base of representative users should be consulted in any case to ensure delivery of tools that are not only functional but usable. Among other benefits, this will encourage companies to build and maintain models for their own (unit) processes and (re)calibrate with their own data.

4. Industrial Relevance and Benefits

Industrial Involvement and Commitment

There are fourteen companies involved in CPM, a net gain of two from the previous evaluation in 1997. Each company contributes SEK 100,000 in cash and SEK 400,000 in kind per year. The in-kind support indicates that there is active participation by industrial personnel, all the way from the Board level to project level, including industrial PhD studies. Such participation has brought reality to CPM´s work, in a subject that might become abstract and irrelevant otherwise.

There are informal interactions as well. For example, some projects have been initiated as a result of dialogues between industrial and academic personnel. Such healthy interactions are likely to continue.

Industry participants contribute in a substantial way to identification of the key problem, in environmental data representation and in management. In the words of several of the academic researchers "industry is an efficient laboratory and testbed" for the research ideas and methods of CPM. We believe, that greater success can be achieved, if a broader perspective is employed by the academic researchers in these interactions; i.e. include several additional methods and topics to LCA in these joint efforts with industry.

Strength in Technology Transfer and Implementation of New Technology

The strength in CPM´s technology transfer rests with the active participation of industrial personnel and their close interaction with the academics. While academic researchers are well connected to their industrial counterparts, they seem to be less so with industrial designers which have a more direct impact on technology transfer and the products.

Nevertheless, industry seems to be quite satisfied with the benefits obtained through CPM. For example, a number of companies have successfully implemented the SPINE data documentation format, or use it to create databases of their own.

Masters level students seem to be more effective technology transfer agents which is not surprising since the master's degree level is universally more practice-oriented than the doctoral level.

Several projects were presented, where we found ample evidence that the project conception involved good coordination between academics and industry personnel, where special implementations were tried out by industry engineers, and where research from the academics resulted in practise by industry. Thus technology transfer has an effective implementation within the CPM programme.

5. General Conclusions and Recommendations

After the evaluation in 1997, CPM has made considerable progress in achieving the goals of a successful Competence Centre. Led by an effective Director and a closely knit working group of academic researchers and industry representatives, CPM has developed a well focused and productive research programme on methods and tools for assessing the environmental impact of product and material systems. The new area of environmental informatics has been created. There is every reason to believe that this positive development will continue.

For the further enhancement of progress we want to make the following recommendations:

- We strongly recommend CPM establish an International Scientific Advisory Board.
- CPM should undertake a concerted effort to increase scientific output including efforts to publish in scientific journals of higher ranking.
- We strongly recommend that CPM develops their Best Available Practise through international collaboration. Specifically CPM should be actively engaged in the SETAC / UNEP initiative.
- We most highly recommend that the scope of the CPM research programme be broadened beyond LCA to include all environmental information management aspects of product / service / manufacturing / delivery. In particular a more general systems engineering perspective should be employed, and additional tools such as substance flow analysis and environmental risk assessment. A major focus should be on tools to implement improvement analyses with industrial partners.

Gothenburg, November 28, 2000

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