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International Energy Affairs, Strategy and Policy Division
Section Evaluation and Controlling

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Evaluation of the „Solar Chemistry / Hydrogen“ Research Program

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Abbreviations

CORE: Federal Energy Research Commission

CTI: Innovation Promotion Agency

ETH: Swiss Federal Institute of Technology

IEA: International Energy Agency

SER: State Secretariat for Education and Research

SFOE: Swiss Federal Office of Energy

SNF: Swiss National Science Foundation

SolarPACES: IEA Implementing Agreement - Concentrating Solar Power and Chemical Energy Systems

Summary

The Federal Energy Research Commission (CORE) and the Swiss Federal Office of Energy (SFOE) initiated this evaluation to gain an external opinion on the organisation of the research program “Solar Chemistry / Hydrogen”, the program focus and the priority setting. The research program “Solar Chemistry / Hydrogen” currently undergoes several changes. Program restructuring will be based on the evaluation of selected project areas. In order to gain expert judgments on the more strategic elements of the research program, the expert team focussed on groups of projects of a few institutes and selected research goals. In addition, the external experts were asked to give their advice on improving the effectiveness of the program. The evaluation also gains momentum as the research program currently undergoes several changes (emeritus professors, staff of federal office).

The main project areas as defined for the evaluation were hydrogen production, hydrogen storage, solar thermochemical processes, solar driven material technology such as catalytic CO_2 chemistry and glass surface coatings, and dissemination activities in solar and hydrogen research. The project area „other storage technologies and applications“ was not evaluated in detail.

Strategy and structure of program

Main findings:

- The structure of the part on “Hydrogen” is obvious and the selection of topics was based on the competence available in Switzerland. The excellent international positioning of Swiss institutions as leading players in the IEA Hydrogen Implementing Agreement has been strongly influenced by the SFOE Program. The existence of excellent bilateral cooperation and international cooperation at both the European and worldwide level (IEA Hydrogen, SolarPACES) is a clear strength of Swiss research program.

- The subdivision of the part on solar chemistry into solar production of commodities and metal oxides cycles is less obvious and a dilution of limited program resources might possibly occur.

- In view of program focussing, the evaluators found the research on improved sun protection glasses less obviously related to this program and suggest it be moved to other SFOE programs dealing with solar thermal topics. Also the catalytic CO2 chemistry research seemed better placed in other research fields, possibly “green chemistry” or chemical synthesis of fine chemicals.

- The program part “other storage technologies and applications” is especially unclear, where almost any topic of specific interest to the researchers and program management is possible. The projects do not seem very consistent with program goals.

Main recommendations:

- All project areas should be further supported because of its excellent scientific output. However, support should be reallocated to other more appropriate SFOE programs for all project areas not dealing specifically with either hydrogen production (through Photo-Electro-Chemistry (PEC), solar thermochemical cycles or biomass conversion) or hydrogen storage. Support should be redirected towards both Research and Development (R&D) and Prototyping and Demonstration (P&D) especially in the area of biomass

conversion (to H2), PEC and solar reactors (for H2) in order to facilitate the construction of large (or strong) facilities (or devices) for demonstration.

- Clarify program objectives by differentiating and weighting goals such as academic competence building and international scientific leadership, innovations for national industry (e.g. clean energy systems), attracting new industries, or exporting knowledge (knowledge society). By simplifying the project areas (e.g. focus only on hydrogen production and storage) targets may be visualized more clearly.

- The development of program strategy and implementation should involve more market players, those in industry in particular.

- Ultimately, investments in market-oriented research should develop the image of technology for potential investors, explore and identify new R&D areas and increase chances for market benefits.

Program implementation

Main findings:

- The scientific quality is very high, in parts even outstanding from an international point of view. The researchers are very well known and have strong scientific output and international contributions.

- Some of the demonstration projects in the hydrogen storage and biomass conversion area were good examples of directing R&D.

- One of the success factors of research on solar thermochemical processes was the continuity of funding, in combination with a clear roadmap with intermediate milestone derived from a systems analysis approach. This concept may serve as a “best practice” example for other project areas of the program.

- The work is often basic research and the scope of the output sometimes too wide.

- The cooperation between research groups is generally rather limited.

- The financial efficiency is high, primarily because of the high scientific quality and international networks established. The funding seems mainly directed towards research institutes, and it appears that new funds are approved before related projects are finished.

- There is rather limited involvement of industry, except in the area of biomass conversion. Potential market benefits seem unclear; as a result of which industrial interest is generally low. This limits the bridging opportunities.

Main recommendations:

- To improve program implementation incentives need to be set for a self-coordination of research activities such as joint projects, publications and student exchanges (e.g. in PEC area). Bundling funds should be reconsidered, for example by cooperating with CTI and the private sector.

- In order to improve program organisation, a program steering committee should be installed. The committee would support the functions of the SFOE project area leader and program manager regarding transparency and work division, and reduce conflict of interest regarding proposal evaluations and project output evaluations. The steering group should also represent the view on the knowledge demand and commercial aspects.

- The program management could be further strengthened through project portfolio management, organized competence centres and incentives for industry to participate as project leader, adviser or observer (steering committee). Separate financial and organisational support is advised to promote and guide IP issues

- Approve new funds only after successful termination of related projects.

Impacts of activities

Main findings:

- Activities towards the commercial market were clearly attempted but not yet successful. Their market impact was limited to commercial activities in niche markets. Corresponding IP rights were often sold directly to businesses outside Switzerland (this loss of IPR is generally difficult to prevent).

Main recommendations:

- More detailed systems comparisons should be performed in several project areas. The pros and cons of working towards applied system concepts and cooperating with industry at an early developmental stage should be continuously reconsidered in view of building a bridge to the market.

- The expert networks disseminate the gained know-how and output of interdisciplinary R&D and should have a consistent strategy to develop technology from start to application. Improved coordination of basic research towards applications may increase the chance for more solid impact. Niche market opportunities need to be reviewed case by case and IP issues addressed through research policy.

Zusammenfassung

Die Eidgenössische Energieforschungskommission (CORE) und das Bundesamt für Energie (BFE) lassen mit dieser Evaluation die strategische Schwerpunktsetzung und die Umsetzung/Organisation des Forschungsprogramms „Solarchemie / Wasserstoff“ extern begutachten und beurteilen.

Um eine Beurteilung der strategischen Elemente und Ziele des Forschungsprogramms im gesetzten Rahmen zu ermöglichen, konzentrierte sich das Expertenteam auf die Beurteilung der wichtigsten Projektbereiche des Programms und die entsprechend involvierten Forschungsinstitute. Zusätzlich erarbeitete das Expertenteam Empfehlungen zur Verbesserung der Umsetzung des Programms durch das Bundesamt.

Die wichtigsten Projektbereiche, welche für die Evaluation definiert wurden, waren für die Wasserstoff-Forschung: Wasserstoff-Produktion, Speicherung und Verbreitung von Resultaten ("hydrogen production”, “hydrogen storage” und "dissemination of hydrogen technology research“). In der Solarchemie unterscheidet die Evaluation zwischen solar-thermischen Prozessen, Materialien und Verbreitung (“solar thermochemical processes“, “solar driven material technology” und „solar platform/dissemination“). Darüber hinaus liessen sich einzelne weitere Speichertechnologien und –anwendungen finden ("other storage technologies and applications“). Das Expertenteam konnte sich trotz engem Zeitplan zu fast allen Projektbereichen vor Ort ein Bild machen (Ausnahme: "other storage technologies and applications“).

Strategie und Struktur des Programms

Wichtigste Ergebnisse:

- Die Struktur des Programmteils “Wasserstoff” ist gelungen und plausibel. Die Auswahl der Themenbereiche basiert auf der verfügbaren Kompetenz in der Schweizer Forschungslandschaft. Die Unterstützung des BFE erleichterte die ausgezeichnete internationale Positionierung von Schweizer Forschungsinstituten als führende Mitglieder des “IEA Hydrogen Implementing Agreement” deutlich. Die exzellente Kooperation auf europäischer und globaler Ebene ist eine klare Stärke des Forschungsprogramms.

- Die Struktur des Programmteils „Solarchemie“ ist weniger naheliegend, auch innerhalb von einzelnen Projektbereichen wie "solar thermochemical processes“ und "solar driven material technology“ (hinsichtlich "solar production of commodities“ und "metal oxides cycles“). Mit der vorgefundenen Struktur ist nicht auszuschliessen, dass die limitierten Ressourcen suboptimal ausgegeben werden.

- Aus Sicht einer Programmfokussierung sind die im Bereich „solar driven material technology“ durchgeführten Arbeiten zur Verbesserung der Glasoberflächenbeschichtungen als Sonnenschutz und jene der chemischen Katalyse in CO_2 als Lösungsmittel nicht von erster Priorität. Das Expertenteam sieht diese Projekte besser aufgehoben in Forschungsprogrammen zur Solarwärme bzw. der chemischen Synthese von Feinchemikalien.

- Die strategische Ausrichtung im Teil “other storage technologies and applications“ ist unklar. Der Teil vermittelt den Eindruck, dass je nach Interesse der Forscher oder des Programmmanagers auch Projekte gefördert wurden, die mit den eigentlichen Zielen des Programms nicht unmittelbar konsistent waren.

Wichtigste Empfehlungen:

- Da der wissenschaftliche Output aller im Detail beurteilten Projektbereiche exzellent war, sollten diese Bereiche weiterhin unterstützt werden. Bereiche, die nichts mit Wasserstoffproduktion oder Wasserstoffspeicherung zu tun haben, sollten aber mit anderen besser geeigneten Forschungsprogrammen des Bundesamts assoziiert werden. Insbesondere gestärkt werden sollte die Unterstützung in Richtung F&E (Forschung und Entwicklung) und P&D (Prototyping und Demonstration) für die Bereiche Photoelektrochemie (PEC), Solarreaktoren und Biomassekonverter die spezifisch für die Wasserstoffproduktion eingesetzt werden können. Dadurch könnten Demonstrationsprojekte von Grossanlagen oder Hightech-Apparaten/Geräten erleichtert werden.

- Die strategische Zielsetzung des Forschungsprogramms sollte überprüft werden. Das Expertenteam empfiehlt, strategische Ziele zu benennen und zu gewichten, bspw. die akademische Kompetenzbildung, internationale wissenschaftliche Führerschaft, die Innovationsstärkung der heimischen Industrie (z.B. im Bereich sauberer Energiesysteme), Förderung heimischer Industrien, Wissens- bzw. Know-how-Export. Eine Vereinfachung der Projektbereiche (z.B. Fokussierung nur auf Wasserstoffproduktion, wie PEC, solar thermochemische Zyklen oder Biomassekonversion, und der Wasserstoffspeicherung) könnte helfen, die Ziele übersichtlicher und Zielgrössen fassbarer zu machen.

- Bei der strategischen Programmentwicklung (und –implementierung) sollten Vertreter der Industrie und Privatwirtschaft beteiligt werden

- Marktorientierte Forschung sollte unterstützt werden, unter anderem auch um das Image der Technologie bei potenziellen Investoren zu verbessern.

Programmumsetzung

Wichtigste Ergebnisse:

- Die wissenschaftliche Qualität des Forschungsprogramms „Solarchemie / Wasserstoff“ kann als sehr hoch bezeichnet werden, im internationalen Vergleich zum Teil sogar als exzellent. Die Forscher sind bestens bekannt und haben einen starken Output auch an international anerkannten Beiträgen.

- In einigen Demonstrationsprojekten wurde Forschung und Entwicklung besonders gut gelenkt, namentlich in den Bereichen Wasserstoffspeicherung und Biomassekonversion.

- Erfolgsfaktoren im Forschungsteil „solar-chemische Prozesse“ waren einerseits die kontinuierliche finanzielle Unterstützung durch das umsetzende Bundesamt für Energie, andererseits auch der professionelle Einsatz einer “Roadmap” mit klaren Zwischenzielen, die von einer systemanalytischen Denkweise geprägt waren. Das Expertenteam sieht das Forschungsmanagement in diesem Bereich als “best practice” - Beispiel für andere Projektbereiche des Forschungsprogramms an.

- Die Arbeiten der verschiedenen Projektbereiche waren meist geprägt vom Typ der Grundlagenforschung und ziemlich breit angelegt.

- Die Kooperation zwischen den verschiedenen Forschungsgruppen war im Allgemeinen eher begrenzt.

- Das Expertenteam schätzt die finanzielle Effizienz insgesamt als hoch ein, weil die wissenschaftliche Qualität des Outputs hoch ist und tragfähige internationale Netzwerke etabliert werden konnten. Es besteht aber noch der Eindruck, dass die Mittelzuflüsse hauptsächlich auf Forschungsinstitute ausgerichtet wurden. Eher negativ ist, dass teilweise neue Geldmittel für Folgeprojekte schon vor dem erfolgreichen Abschluss laufender Projekte gesprochen wurden.

- Die Industrie ist eher wenig involviert. Im Allgemeinen scheinen die potenziellen Marktnutzen unklar, in Folge ist das industrielle Interesse tief, sodass auch eine Brückenbildung zwischen Industrie und Forschung erschwert wird. Eine Ausnahme stellt der Bereich Biomassekonversion dar.

Wichtigste Empfehlungen:

- Es ist zu prüfen, ob mit geeigneten Anreizen die Koordination im Inland noch verbessert werden kann (z.B. gemeinsame Projekte und Publikationen sowie Studentenaustausch zwischen den involvierten Gruppen innerhalb eines Projektbereichs wie PEC). Nach Möglichkeit sollten Unterstützungsbeiträge, beispielsweise auch unter Einbezug von KTI und der Privatwirtschaft, vermehrt miteinbezogen werden.

- Zur Verbesserung der Programmorganisation sollte eine Begleitgruppe mit Lenkungsaufgaben eingerichtet werden. Die Begleitgruppe sollte den Bereichsleiter und Programmmanager unterstützen und die Transparenz der Arbeitsteilung erhöhen. Mit der Begleitgruppe sollen allfällige Interessenskonflikte bei der Beurteilung von Projekteingaben, -durchführung und –output vermindert werden. Die Begleitgruppe sollte die Bedürfnisse im Bereich Wissenstransfer, Industrie und Wirtschaft einbringen und repräsentieren.

- Das Programmmanagement könnte durch ein Projektportfoliomanagement (regelmässige Portfolioanalyse), gut organisierte Kompetenzzentren und eine Teilnahme der Industrie wesentlich gestärkt werden. Das Expertenteam empfiehlt eine separate finanzielle und organisatorische Unterstützung um den richtigen Umgang mit geistigem Eigentum (IP) zu fördern bzw. zu begünstigen.

- Neue Mittel sollten in der Regel erst wieder an Forschungsinstitute gesprochen werden, wenn laufende Projekte erfolgreich abgeschlossen wurden.

Wirkung der Forschungsaktivitäten

Wichtigstes Ergebnis:

- Marktorientierte Aktivitäten wurden zwar klar angegangen, haben aber mit Ausnahme von Nischenmärkten keinen Erfolg gezeitigt. IP Rechte (IPR) wurden oft direkt an Firmen im Ausland verkauft (dieser Verlust von IPR ist jedoch auch in anderen Bereichen zu beobachten und schwierig zu verhindern).

Wichtigste Empfehlungen:

- Die Vor- und Nachteile von Forschungsarbeiten, insbesondere die mögliche Brückenbildung zum Markt, sollten im Sinne angewandter Systemkonzepte und in Zusammenarbeit mit der Industrie früh während der Entwicklungsphase überprüft werden.

- Expertennetzwerke, die zur Verbreitung des erarbeiteten Know-hows und interdisziplinären Forschungs- und Entwicklungsoutputs aufgebaut wurden, sollten über eine konsistente Strategie zur Technologieentwicklung verfügen. Das Expertenteam empfiehlt für dieses Forschungsprogramm, auch weiterhin Nischenmärkte zu nutzen. Die genannten Schwierigkeiten im Zusammenhang mit dem geistigen Eigentum hingegen sind über die Forschungspolitik im Allgemeinen anzugehen.

Vorwort

Die schweizerische Energieforschung befasst sich seit den 1970er Jahren mit Wasserstoff und Solarchemie. Heute stehen wir am Beginn von konkreten Anwendungen entsprechender Technologien. Die von der Eidg. Energieforschungskommission CORE gewünschte Evaluation der Aktivitäten sollte einerseits darlegen, ob sich die Schweiz in dieser wichtigen Übergangsphase mit den Forschungsaktivitäten auf gutem Wege befindet und andererseits darlegen, ob Verbesserungsvorschläge bei der Betreuung der Arbeiten durch das Bundesamt für Energie (BFE) möglich sind.

Die Ergebnisse zeigen, dass wir uns bezüglich der Qualität und internationalen Einbettung mit der Forschung in diesem Bereich die eingeschlagene Richtung weiter verfolgen können, dass hingegen bei der Fokussierung der Arbeiten, der Organisation, der Begleitung sowie der Marktorientierung der Projekte Korrekturen angebracht sind.

Der Zeitpunkt der Evaluation war günstig, da personelle Wechsel anstanden. Die Umsetzung der Empfehlungen konnte denn auch unmittelbar nach Abschluss der Evaluation in Angriff genommen werden:

Die Wichtigkeit der Forschungsgebiete haben wir verdeutlicht, indem wir das bisherige Programm zweigeteilt haben in ein Programm Wasserstoff und in ein Programm Solarchemie mit je eigener (aber koordinierter) Leitung.

Es sind in diesen beiden Bereichen – trotz Sparrunden in der Forschungsförderung - keine weiteren finanziellen Abstriche der BFE-Forschungsmittel vorgenommen worden.

Die neuen Programmleiter sind angehalten, in ihren Konzepten die Empfehlungen der Evaluation zu berücksichtigen. Insbesondere:

- Umlagerung und eventuell Beenden von „artfremden“ Projekten.
- Klarere Definition, Gewichtung und Darstellung der strategischen Ziele unter Miteinbezug von Vertretern aus der Privatwirtschaft. Daselbst verstärkte Betonung der Marktorientierung.
- Bessere Unterstützung der Kompetenzzentren beim Portfoliomanagement und bei der Behandlung des geistigen Eigentums. Gleichzeitig auch stärkere Vernetzung der Forschungszentren untereinander und mit der Industrie.
- Weiterhin aktives Aufspüren und Ausnützen von Nischenmärkten.

Die Programmleiter haben 2007 die Detail-Forschungskonzepte Wasserstoff sowie Solarchemie für die Periode 2008 – 2011 der CORE vorzustellen. Die Kommission wird daselbst prüfen, ob den Empfehlungen des Evaluationsteams genügend Rechnung getragen wird.

Gerhard Schriber, Bundesamt für Energie, Leiter Sektion Forschung und Ausbildung

1 Introduction

Research program “solar chemistry and hydrogen” of SFOE

The research program „solar chemistry and hydrogen” aims at contributing to the development of CO_2-free or CO_2-neutral energy systems. The main routes transform, store and use solar energy in order to achieve sustainable delivery of heat, production of hydrogen and synthesis of useful materials. Thermal and chemical processes are developed to harvest energy directly from solar radiation or in combination with using natural stocks of biomass or biogas (stored solar energy). The integration of these products and processes into existing energy systems and material processing industry is most important.

The program is organized into three main research areas:

- Hydrogen technology for production and storage – hydrogen as a secondary energy carrier
- Solar energy high temperature processes which directly generate materials or chemicals (commodities)
- Complementary technologies necessary for practical implementation and other energy storage systems - mid to low temperature regimes

These areas can be expanded to assess the potential of technological substitution for reducing CO_2-emissions and for efficiency gains. Correspondingly, efforts towards technological diffusion and specific material technology are necessary to support the goals of the program.

Why an evaluation?

As the research program “Solar Chemistry / Hydrogen” will go through several changes over the next few months, an evaluation of selected projects was planned in order to help SFOE to restructure the program. Besides the fact that the term of office of the program manager and head of division is ending, there will be changes of principle investigators at the related research institutes in the near future as well. This adds to the uncertainty of future program development.

SFOE and CORE initiated this evaluation especially to gain an external opinion as to the organisation of the program, the program focus and the priority setting. The external experts were also asked to give their advice on improving the effectiveness of the program

The aim of the evaluation was not to audit single projects or operational details of the program management. In order to address the more strategic elements of the research program, the expert team focussed on the main project areas (i.e. groups of projects focussing on few institutes and research goals).

The description of program management and project areas and the evaluation of the impacts of these activities are based on the legal mandate of the Swiss Federal Office of Energy to continually evaluate instruments of the federal energy policy (Federal Law on Energy, Section 20).

Outlook on further sections

Section 2 starts with a brief overview on Swiss energy research, the role of Swiss Federal Office of Energy and the particular contents and strategic aims of the research program “solar chemistry / hydrogen”.

Section 3 summarizes the scope and procedure of the evaluation, including a short description of the expert team members responsible for this report.

Section 4 includes the main findings and recommendations for different project areas (i.e. groups of projects).

Section 5 describes additional findings and recommendations for the program management.

Section 6 concludes with the main findings and recommendations (compare “summary of overall conclusions”).

2 Preliminaries: Swiss energy research and the research program "solar chemistry / hydrogen"

2.1 Role of Swiss Federal Office of Energy in energy research

By being in partnership with industry, academia and administration, the Swiss Federal Office of Energy (SFOE) aims towards having a sustainable energy system for the long term. In order to provide important milestones, the Federal Energy Research Commission (CORE) updates a Swiss Federal Energy Research Master Plan every 4 years. SFOE coordinates national and international activities in energy research and fosters collaboration between academia and industry in order to achieve these milestones.

The Swiss Federal Office of Energy has its own funds for implementing the master plan. Their subsidiary funds are used in addition to funding by private and public research institutes (Figure 1).

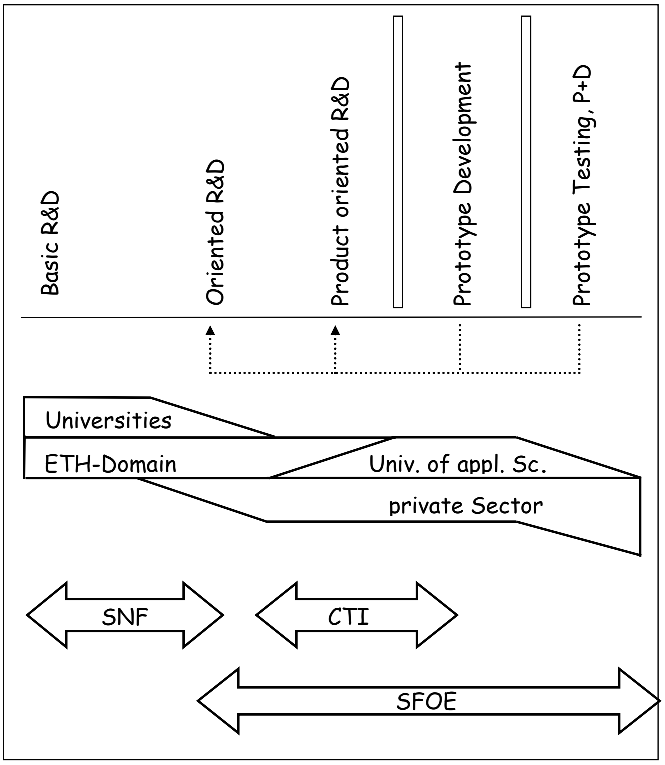

Figure 1: Swiss research funding system and institutional coverage of different types of research. Source: SFOE

Federal Energy Research Commission: The Federal Energy Research Commission acts as consultative body for the Federal Council and the Department of Environment, Transport, Energy and Communications (DETEC). It defines the Swiss Federal Energy Research Master Plan, reviews and supports Swiss energy research programs, comments on other energy research activities by the federal government and provides information concerning findings and developments in the area of energy research. It comprises of 15 members who represent the industrial sector, the energy industry, the federal institutes of technology, the National Fund, the Commission for Innovation and Technology, universities, colleges of technology, the cantons and other promotional bodies.

Energy research represents an important pillar of energy policy in Switzerland as in common with other industrial countries. Here, public authorities spend some 200 million CHF per year on energy research. The objective is to create a secure and sustainable energy supply, maintain the high quality of Swiss research, and strengthen Switzerland's position as a marketplace for technology. High priority is attached to the implementation of research results. The energy research supervised by the public authorities is detailed in the Swiss Federal Energy Research Master Plan, which is updated every four years by CORE.

2.2 Research program "solar chemistry and hydrogen"

2.2.1 Concept

In its research program "solar chemistry / hydrogen", SFOE is investing in mid to long-term research areas of solar chemistry including hydrogen technology in order to enlarge the solar share of the energy portfolio. In turn, this contributes to the reduction of the CO_2-intensity of the Swiss economy. The program's concept defines the main research areas and postulates strong implementation and networking between all the different program activities.

The concept for the years 2000 to 2003 emphasized not only the energy aspects of the projects but explicitly targeted the closing of material cycles and promoted the application of environmentally lean materials. The concept also pointed out the importance of clarifying the economical potential for sustained support and of increasing the chance for a direct integration of applications into competitive process and added value chains.

The concept for the years 2004 to 2007 states that the program focus should be prolonged for the efficient use of concentrated solar energy to produce storable process energy, the secondary energy carrier hydrogen and commodities with high added value. Storage technologies should be strengthened especially for gaseous energy carriers. Materials research efforts should be integrated more often into the corresponding research of processes. Special attention should be given to the substitution of fossil energy carriers and corresponding technology, the reduction of CO_2 emissions, and applications based on secured resources and clean value chains.

Main areas of the concept 2000-2003:

- Energy harvesting which included production facilities, equipment and processes to convert concentrated solar energy into hydrogen, methanol and metal / metal oxides
- Energy storage which addressed chemical and physical storage systems important for solar energy systems and distributed generation
- Energy use which covered the direct conversion of solar energy into commodities with high added value
- Energy system build-up which supported activities for the integration of system components from different research often outside the program focus
- Encouraging spin-offs so as to increase the chance for direct involvement of research in industrial R&D with possible market impact

Main areas of the concept 2004-2007:

- Solar process energy; continuous support of absorption systems for direct solar radiation in cooperation with the programs ‘Solar Thermal Energy’ and ‘Buildings’, achieve optimization of solar concentrators, high temperature receivers, reactors and incinerators, proceed with the direct solar production of metals from ores and other commodities, develop thermoelectric systems and solar thermal storage systems
- Hydrogen production; achieve optimization of photoelectrochemical water splitting with the Tandem Cell and related systems, improve the preparation of reliable membrane and electrode materials for high pressure electrolysis of water, proceed with the solar based catalytic production of hydrogen or syngas from biomass or fossil energy carriers (decarbonisation), optimize the solar chemical production of hydrogen based on the metal / metal oxide cycle
- Hydrogen storage; proceed with the characterisation of metal hydrides, organic hydrides, zeolites and other carbon based structural nano materials for hydrogen storage, optimize high pressure storage vessels from composite materials including diffusion barrier layers
- Use of hydrogen; proceed with research on the reduction of metal oxides or silicates with hydrogen or methane (SynMet processes) for the production of pure materials, the synthesis of basic chemicals based on catalytic transformation of CO2 with hydrogen and ammonia
- Supplemental energy technologies; intensify program spanning and international network and coordination activities for building-up of energy systems, several components are being discussed like storage of solar energy with compressed air including Stirling compression units for pumps and reverse osmosis, and photocatalytic surfaces for water detoxification systems

The concept also included the suggestion to keep up the program funds and increase finances based on extended third-party funds from industries and participation in international research programs. Special importance was placed on the dissemination of results towards industry and the public in order to gain more attention. The Hydropol internet platform was believed to cover some parts of this role.

As pointed out previously, the aim of the evaluation was not to audit single projects or operational details of the program management. In order to focus on the more strategic elements of the research program, the expert team focussed on the main project areas (i.e. groups of projects focussing on few institutes and research goals). Figure 2 shows the main project areas as defined for the evaluation and based on the strategic documents of the research program.

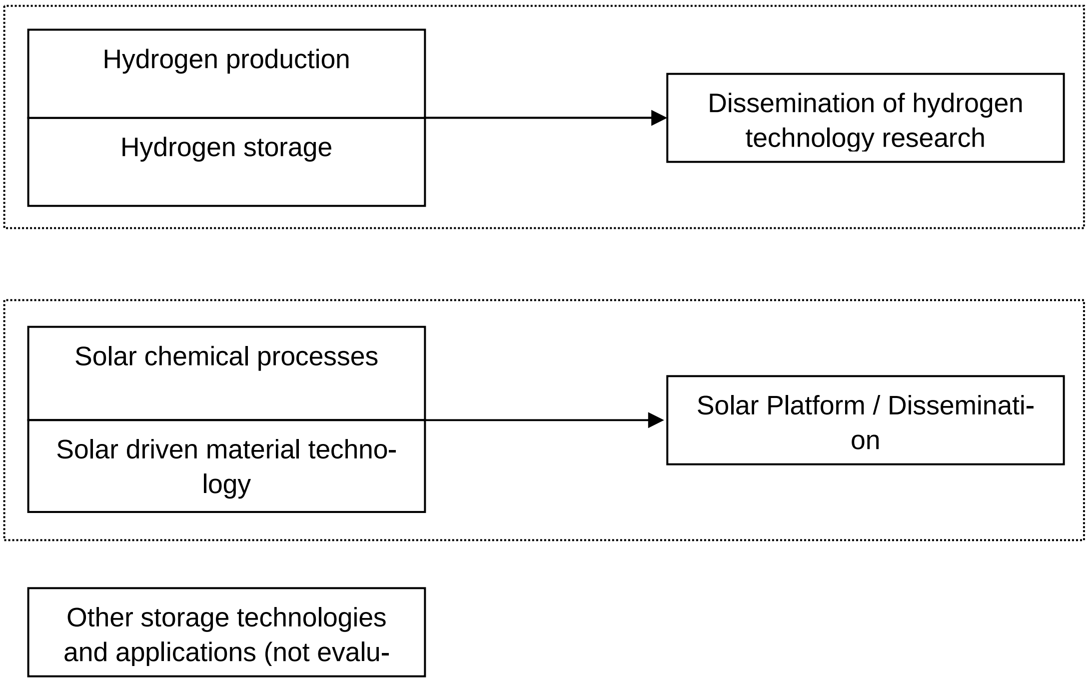

Figure 2: Main project areas of the research program “solar chemistry / hydrogen”, showing the hydrogen and solar chemistry program parts bounded by a dotted lines

2.2.2 Funding

In 2003, the SFOE fund for energy research was CHF 36 Mio., out of which about 36% was used for P&D projects. For the program ‘Solar Chemistry / Hydrogen’ the average contributions of SFOE in the years 2002 and 2003 was about CHF 2 Mio./a. Total support for the program was on the average CHF 11.3 Mio. a year (2002 and 2003) including all funding institutions, the canton and others (Table 1). For the years 2002 to 2003, P&D projects in this program amounted on the average to about 0.7 Mio./a (6%).

Table 1: Percent contribution[1] of different Swiss funding institutions to the evaluated project areas in the program 'Solar Chemistry / Hydrogen'

Project areas	**SFOE**	**ETH Council**	**SNF**	**CTI**	**SER**	**Canton[2]**	**Others**
	[%]	[%]	[%]	[%]	[%]	[%]	[%]
Hydrogen production	4.2	1.3	1.9	0.0	0.3	4.1	0.0
Hydrogen storage	2.3	0.0	0.3	0.0	0.6	8.7	0.0
P&D hydrogen research	0.0	0.0	0.0	0.0	0.7	0.0	0.7
Solar chem. processes (Zn/ZnO)	4.7	29.7	0.0	0.0	3.4	0.0	4.2
Solar chem. processes (non H_2 commodities)	2.8	18.2	0.0	0.0	0.0	0.0	0.3
Solar driven mat. tech. (cat. chem., coatings)	2.3	4.4	0.1	0.0	0.0	2.5	0.0
Solar dissemination (IEA SolarPaces, etc.)	0.7	0.4	0.0	0.0	0.0	0.0	0.0
Hydrogen dissemination (IEA Hydrogen, etc.)	0.9	0.0	0.0	0.0	0.0	0.2	0.0
% Total contributions	17.7	53.9	2.3	0.0	5.1	15.6	5.3

[1] The percentage of the contributions is derived from the average funds of the years 2002 and 2003

[2] funding mostly by the cantonal universities

The evaluated project areas of the program were funded up to about 74% by funding institutions like the ETH council, cantonal universities, SER and SNF, which often foster basic research. The total funding contributions of the years 2002 and 2003 to the project area "other storage technologies and applications" (not evaluated) was less than 2% and all considered applied research. The rather low contributions of SNF to the evaluated project areas (Table 1) gave the impression that this funding institution had a different focus and was less involved in this kind of energy research. In turn, the important but smaller supplemental funding of SFOE implied that only a part of this research was dependant on directing research towards successful applications for the market. No funding from CTI suggested that either the research of this program was still far away from possible market benefits or that there was a suboptimal integration of potential synergies between SFOE or CTI funding systems (compare Figure 1).

The utilised SFOE funds for the evaluated project areas of the program “Solar Chemistry / Hydrogen” over the last few years are listed in Table 2.

Table 2: Utilised SFOE funds for the different project areas evaluated (kCHF). Source: SFOE

Project areas / program parts	***2001***	***2002***	***2003***	***2004***	***2005***	***Total 2001-2005***
Hydrogen production	480	473	469	455	235	2'112
Hydrogen storage	210	250	280	320	5	1'065
Hydrogen dissemination (IEA Hydrogen, etc.)	8	130	65	91	42	337
Sum hydrogen part	698	853	814	866	282	3'514
% of S&H program	33%	36%	43%	49%	26%	38%
Solar chem. processes (Zn/ZnO)	465	495	565	365	269	2'159
Solar chem. processes (non-H_2 commodities)	188	382	240	210	200	1'220
Solar driven mat. tech. (cat. chem., coatings)	535	405	105	258	288	1'591
Solar dissemination (IEA SolarPace, etc.)	180	80	75	29	46	249
Sum solar chemistry part	1'206	1'362	985	862	803	5'219
% of S&H program	56%	57%	53%	49%	73%	56%
S&H Program management [1]	247	168	82	40	10	546
% of S&H program	12%	7.0%	4%	2%	1%	6%
Total S&H program [2]	2'151	2'383	1'881	1'768	1'096	9'278

[1] Internal expenses for the SFOE S&H leader not included (ca. kCHF 60/a)

[2] without other storage technologies and applications

SFOE contributions for the hydrogen and solar chemistry part of the program showed a continuous and rather stable proportion between 2001 and 2005. Most prominently, support was given to the solar thermochemical metal cycles and the production of hydrogen from tandem cells and biomass conversion. Although more funds were available to the solar chemistry part, less support was given to its dissemination as compared to the hydrogen part. Interestingly, more support was given to research activities addressing catalytic chemistry in CO_2 as solvent and glass surface coating technology as compared to hydrogen storage and solar thermochemical research on CO_2 reduction and corresponding commodities other than hydrogen. The expenses of the program management declined through out the five years. This might indicate either great efficiency gains at the beginning or signify programmatic changes towards the end of this period.

The evaluated project areas place different emphasis on basic or applied research. Figure 3 compares how SFOE and all funding institutions supported basic or applied research in these project areas. The figure shows that many project areas are still focussed on basic research. In some of the project areas, a few projects are funded with a link to application and most of them are supported by SFOE, except in the area of solar chemical processes. Based on this data, hydrogen production, hydrogen storage and solar driven material technology seem surprisingly less developed compared to the solar chemical process areas. The expert team does not agree with this fact, which seems rather distinctive to the funding strategy of this program. Compared to the other project areas, solar thermal chemical processes seemed somewhat closer to possible commercialization. In this case, SFOE participates more or less equally in basic and applied research. The same holds true for non-H_2 related commodities project area. In contrast to this distribution, the expert team believe that H_2 production from biomass may be considered as closest to the market, so that more applied research grants may be envisaged in the future.

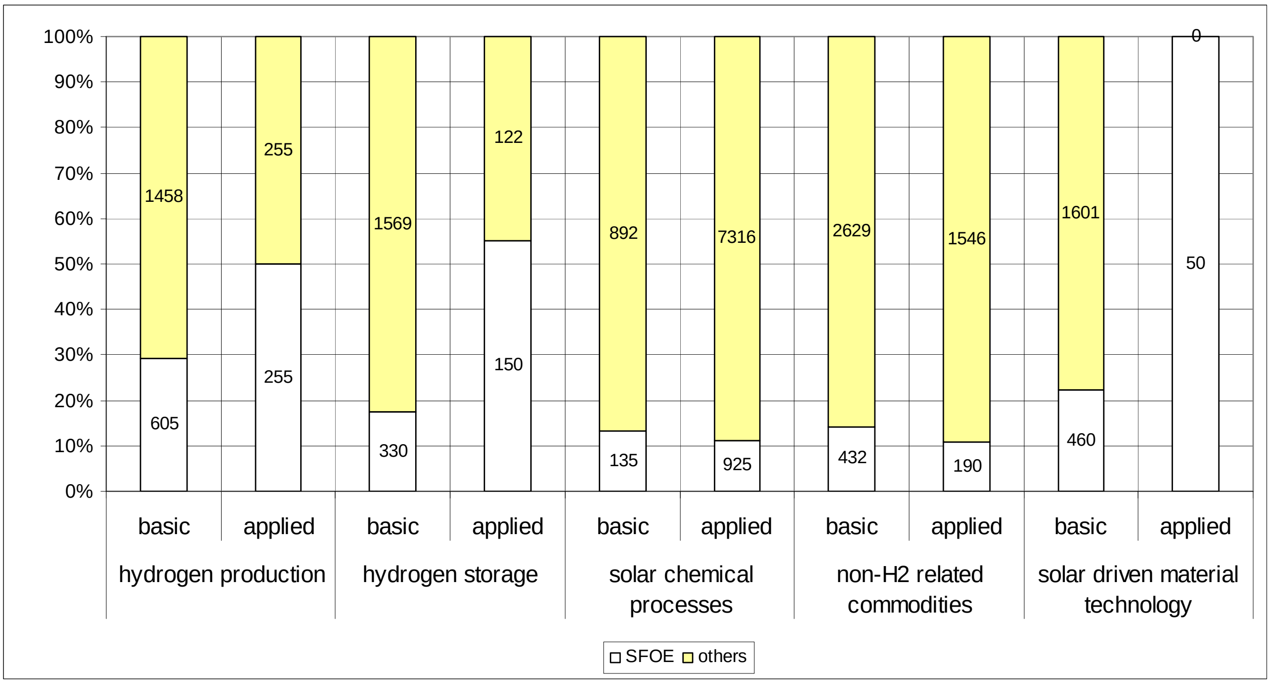

Figure 3: Funds of SFOE and other funding institutions for basic and applied research per evaluated project area 2002/2003 (in kCHF). Project area “solar chemical processes: non-H_2 related commodities”: funds for projects with combined basic and applied research parts were all summed up in the column “applied research”. Source: SFOE

3 Scope and procedure of evaluation

3.1 Scope

The program evaluation was targeted towards the information needs of the client (CORE/SFOE). The scope of the evaluation was limited for reasons of practicality in planning and execution, (i.e. the international expert team coming together for the evaluation for only one working week). It was also necessary because of the time and cost restrictions placed on the evaluation study. The selection of material, project areas and evaluation procedure was designed to minimize disturbance to the researchers involved and the time of preparation for the expert team.

A different evaluation approach is required for assessing early-stage research programs as compared to later-stage programs, which are closer-to-market. While in the former case evaluations at a single project level are necessary, for the latter, evaluations at a more aggregated level (i.e. project areas) may be sufficient for analysing inputs, outputs and impacts of the program. Both the utility and feasibility of the method may change as a program develops.

Since the maturity of the program is more or less advanced, expert judgment at a level of pre-selected project areas was chosen as the methodological approach. The judgment may be expressed in terms of descriptive narratives (as in the present case), quality ratings or as numerical scores. The method ultimately has to consolidate the results at the program level, having assessed, for example, its strategy and structure, implementation, and its impacts especially on the industrial sector (compare Figure 4).

Basically, responses about the scientific and economic relevance of the representative project areas as well as their positioning within research and markets are most important. Program coverage and consistency regarding scientific, technological and economic topics need to be addressed. Attention has also to be given to international positioning and to the degree of coordination between research and industry, which in turn encourages knowledge transfer.

Implementation of the program is evaluated by looking at the quality of representative project areas and its efficiency. Basically, inputs in term of utilised funding (cost) are compared with output, impacts or results (benefits) in order to derive the implementation efficiency. In terms of consistency, the agreement between program goals and projects implemented (is/should be) is revisited at the level of the pre-selected project areas and their outputs.

The project areas' outputs and impacts may or may not result in a significant effect at levels of the predefined program target or goals (results). To evaluate these results from the perspective of the present research and market situation and from a hypothetical projection beyond a manageable horizon of 3-5 years is very challenging.

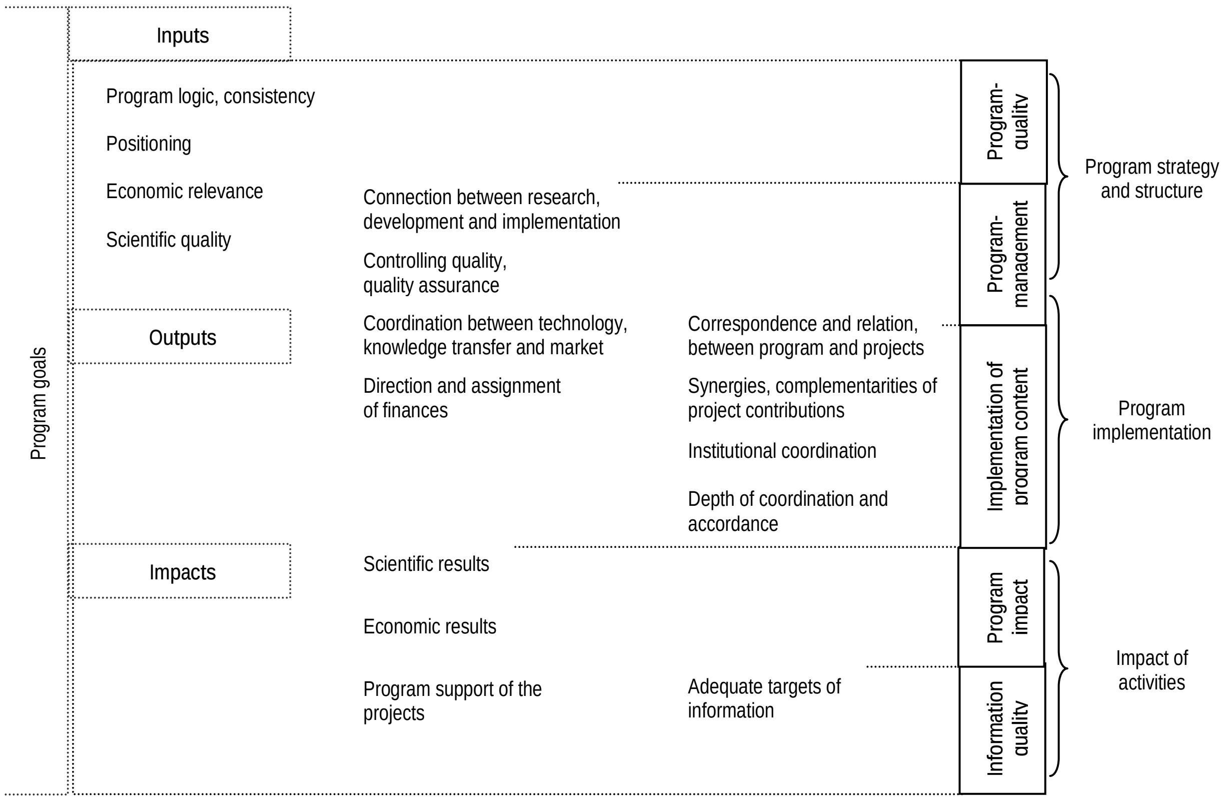

Figure 4: Basic scheme for structuring the evaluation of research programs

Looking at publication records and having an insight into their own technological field of expertise, the experts evaluate scientific quality and economic potential based on the output of the pre-selected project areas and the corresponding industrial interest induced. In addition, the information quality especially regarding dissemination of the project area's output is analysed by the expert team.

The impacts are analysed based on the output of the pre-selected project areas and related to the degree of support from the program. The kind of impacts may include the influence on science and on markets including niche markets, which often co-appear with successful spin-offs. The related question about the degree of knowledge transfer from basic to applied research and ultimately to industry may be answered by looking at specific efforts being undertaken within the specific project areas.

3.2 Organisation

The evaluation project was planned to be diplomatic in nature and performed with a sense of fairness regarding the researchers, and executed in a safe environment for information exchange (i.e. confidentiality). After selecting and confirming three international experts as evaluators and one evaluation leader (Figure 5), the evaluation project was officially started at a kick-off meeting of the evaluation leader with the SFOE and CORE delegates as project advisors and steering committee.

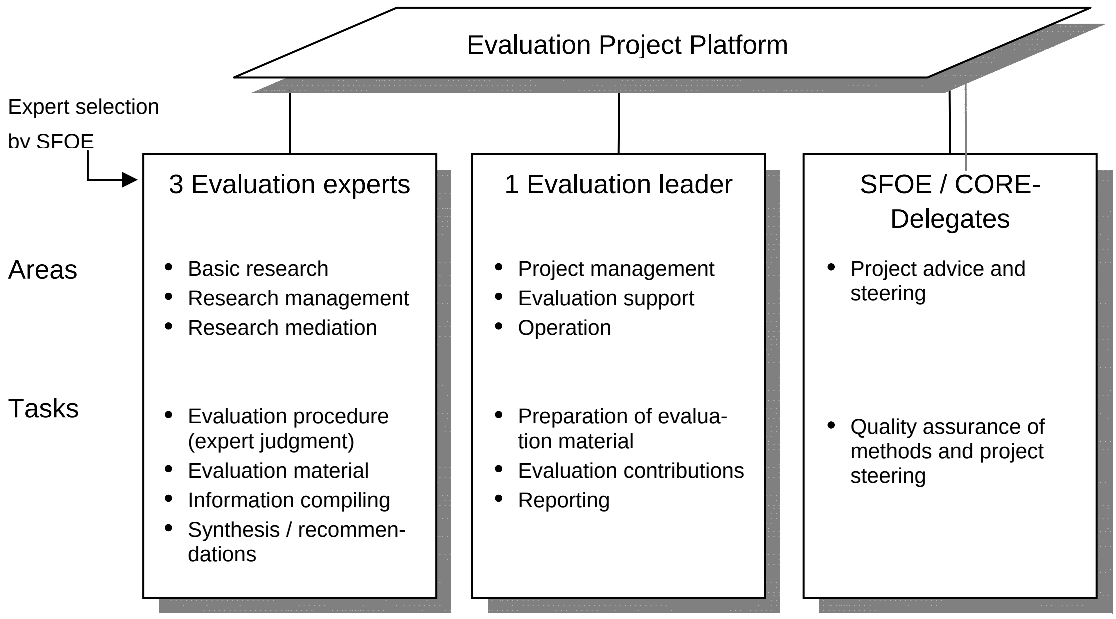

Figure 5: Organisation chart of the evaluation project

The evaluator's perspectives and presumptions have been summarised in Table 3, in order to improve transparency regarding the reference of evaluation results, interpretations and recommendations. The selection of evaluators turned out to be slightly underrepresented in the area of hydrogen storage technology. The expert team consisting of the three international experts and the evaluation leader covered the different parts of the program and project areas including experience in basic research, research management and mediation. The different tasks were dynamically divided between the members of the newly formed expert team. It was clearly important for the team to be consistently unprejudiced and to maintain a neutral character during the evaluation process.

First, the evaluation material consisting of research concepts and reports were compiled and made available to the international experts. Thereafter, the expert team confirmed the selection of representative project areas for the evaluation. Having chosen the project areas, research leaders were selected according to SFOE suggestions and confirmed by the expert team. The research leaders were invited for technical discussions about their projects and relationship to the program. 2-4 research leaders were interviewed collectively per project area. 4 sessions with a total of 13 research leaders were organised for the evaluation week which took place at different locations throughout Switzerland (EPF Lausanne, SNF Bern, PSI Villigen).

Table 3: Details of the expert team members

Function	Name	Institute / Firm	Position	Affiliation	Degree	Research interest	Assigned program part
Expert	Dr. Henk Barten	SenterNovem (Netherlands Agency for Energy and Innovation), Utrecht	Senior Program manager Hydrogen Chairman of Netherlands Biohydrogen Network	Member of the Executive Committee of the IEA Hydrogen Program, Co chair IEA H2 Coordination Group	PhD in chemistry	Hydrogen technologies, fuel cells, biomethane, biohydrogen	Hydrogen
Expert	Prof. Dr. Robert Pitz-Paal	Deutsches Zentrum für Luft –und Raumfahrt, Institut für Technische Thermodynamik, Solarforschung, Köln	Head of Solar Research		Diploma in Physics PhD in mechanical engineering	Applied research for sustainable energy systems and concentrating solar power for heat -, electricity - and fuel production, High temperature systems, thermal energy storage, combined heat transfer	Solar chemistry
Expert	Prof. Dr. Gilles Flamant	CNRS, Laboratoire Procédés, Matériaux et Energie Solaire (PROMES); Perpignan/Odeillo	Director of PROMES-CNRS		PhD in chemical engineering	Solar processing of nanomaterial and hydrogen, and chemical storage of solar energy, Radiation heat transfer in semi transparent media, Reactive media: Gas-solid systems (fluidized beds) and excited/ionised media (thermal plasmas)	Solar chemistry and hydrogen
Evaluation leader	Dr. Marco Semadeni	Energy & Environment Consultant Dr. M. Semadeni, Birmensdorf	Manager	Swiss Association of Energy Economics	PhD in environmental chemistry	Photo-oxidation, dehalogenation, redox chemistry, hydropower resources development, energy storage technologies, 2000 Watt society, risk perception of energy technologies	

4 Evaluation of selected project areas

4.1 Project area ‘hydrogen production’

4.1.1 Presentation of main projects in project area

SPF Institute, University of Applied Sciences, Rapperswil

Introduction to hydrogen research

Work on technology innovations (cleaner fuels, increased energy efficiency, CO_2 reduction) was intensified in the nineties. Decentralized power and heat generation was promoted in countries using natural gas, and by challenging national energy resource dependence, countries gained strong interests in fostering their own renewable energy sources.

An increasing mix of primary energy sources to start from may require focusing on a few secondary energy carriers to choose from. Hydrogen may be a serious candidate especially as a transportation fuel. The application of hydrogen for example, in combustion engines or in local heat and power generation, is beneficial for the environment since it does not produce CO_2 or air pollutants.

Internationally, substantial programs in Europe, the USA, and Japan have boosted the use of hydrogen. International cooperation is part of an efficient collaborative work for mutual benefits, like increasing quality, improving cost efficiency and speeding up the pace of development by sharing experimental results. Switzerland has quickly become a leading player in the International Energy Agency (IEA) Hydrogen Program structuring and anchoring the activities in the field of PEC.

Photo-electrochemical (PEC) conversion: The major task of PEC conversion is the improvement of the direct use of solar energy to split water into hydrogen and oxygen. Since 1972 this process has been under development, while international cooperation within IEA (Annex 6) gave a global basis for communication and collaboration. In 1994, Switzerland introduced the tandem-cells as a possible efficient way for water splitting. In the meantime, up to 12.4 % efficiency has been demonstrated (USA). After closing Annex 14 in 2004 (report at the IEA site: www.ieahia.org), the new Annex 20 directed by Switzerland attracted over 50 experts from 46 research groups from 16 countries; stressing the importance of this subject. Switzerland has definitely been a catalyst. From this point of view, SFOE funding has been very efficient. The motivation to work on hydrogen is manifold and its relationship to solar electrochemistry remains important.

Selected projects on photo-electrochemical energy conversion

Laboratory of Photonics and Interface, Swiss Federal Institute of Technology, Lausanne

The scientific work presented has covered research in the field of the photoelectric tandem cell. This field is highly acknowledged in the scientific community and has opened up a new research direction in hydrogen production. Presently, the work is focusing on the use of Fe_2O_3 as material for the photo anode. This approach is considered high risk, due to challenges in material stability. If successful, this approach would be a real breakthrough for the photo-electrochemical production of hydrogen, because of the low material costs.

An additional research activity has started more recently and is dealing with the development of a solid-state photoelectric tandem cell with voltage characteristics adapted to electrolysis. This approach is considered to be of lower risk from a scientific point of view; on the other hand it appears more difficult to achieve a cost breakthrough.

As for commercialisation, one UK firm has licensed the tandem cell patent involving the Swiss inventor. Work on spin-off options seems close, e.g. WO_3 nano-crystalline films. Examples of new photo electrochemical concepts are under development, e.g. hybrid junctions with a solid state cell (WO_3-Si).

Department of Inorganic, Analytical and Applied Chemistry, University of Geneva

Another focus of the program is research on tandem cell materials, especially WO_3 for photoanodes resulting in a modified Sol-Gel method and a heat treatment optimisation for the deposited WO_3 layers. Moreover, amplification of doped Fe_2O_3 by spray pyrolysis was studied. The scientific quality of the research is high, especially concerning material properties and the stabilisation of the photoanode material.

In the area of PEC conversion for H_2 production, various ways leading to potential commercial applications were illustrated. As a result, the WO_3 manufacturing method (in the presence of PEG300) was patented. In the meantime, this patent has been licensed to Hydrogen Solar Ltd (UK). In addition, photo degradation of organics by WO_3 layers could be a niche application, which should be further demonstrated, whereas the photoelectrolysis of sea water seems more questionable. Industrial interest for WO_3 nanocrystalline films is clearly present in the field of gas microsensors for cars (detection of NO_x, CO and C_nH_m) and probably of electrochromic windows.

Results from the improvement of durability and reliability of photo-anode materials and of nanostructured tungsten oxide films for gas sensors show clear impact hence the transfer of research to applications has been successful so far and not limited to PEC for hydrogen production. The market impact is not significant for hydrogen production but might rapidly become effective in the field of gas sensors.

Department of Chemistry and Biochemistry at the University of Bern

Additional tandem cell research was presented using $AgCl_2$/Ag photoelectrodes for water splitting. The poor performance of the system has pushed this research towards developing dye-sensitized photoelectrodes. The concept is based on light antenna at nanoscale. The material consists of cylindrical zeolite which has channels that can be filled with dye molecules. Thus the light absorbed by the crystals is transported by the dye molecules inside the nanochannels. The goal is to direct the absorbed photons to the end of the zeolite rod. Filling the channels with different dyes permits to tune light emission. Recent success was obtained in orienting the zeolite molecules in structured layers, which led to a patent in July 2005. The possible applications are, for example, nanoscaled laser materials and solid state solar cells with thin semiconducting layers that can be sensitised by energy transfer.

This research has strong industry relations: three industries are involved in financing several projects (Roche, Clariant etc.) CTI-funded projects exist, and 2 patents are pending. Clariant bought licences for the dye-loaded-zeolites including a pay back regime for the development costs over the last few years. It appears that a spin-off is likely for producing colour changing materials for the textile industry.

4.1.2 Findings and recommendations

Tandem cell research: The scientific quality of the research work was, without doubt, outstanding and well known in the global scientific research community (well beyond the Swiss research community). A number of important publications in prestigious scientific journals were produced, thus achieving world leadership in this field.

Both activities (i.e. standard photoelectric tandem cell and solid state photoelectric tandem cell) were clearly considered basic research. It does not appear possible to predict whether or not this research will result in products relevant to the energy economy. Based on that fact, the expert team was surprised by the involvement of a venture capital investment group, which bought intellectual property and supported the research activities. Hopefully the market introduction will be propelled by this involvement. In addition, questions were raised about why the capital involvement was not coming from within Switzerland but from other places in the world. Perhaps Switzerland does not have sufficient incentives for the industry to apply research from academia.

Additional tandem cell research: The research was clearly of excellent quality, original and innovative. Looking at the previous works presented earlier, the question arose whether the SFOE funding was being used for strengthening research on new photocell-materials or for continuing research efforts on light harvesting surface molecules (i.e. “antenna” molecules). Despite the very interesting results, the possible impact on the energy issues do not seem demonstrated yet.

It was mentioned in the evaluation session that SFOE funding has gone down significantly in recent years, and lately, was only a minor fraction of the budget of these research groups. This made it difficult to steer the activities and to distinguish the output based on SFOE funding from that of other sources. Even the researchers stated that it was difficult to distinguish results based on SFOE funds from results based on other resources.

The most visible impact of SFOE funds was that the Swiss groups were cooperating to a certain extent in this field. The groups identified research areas in order to avoid overlap and to develop an overall joint objective and vision. In particular, one group remained clearly focused on direct water splitting with PEC and was intensifying development and testing. The evaluators believe that the level of cooperation between the research groups could be strengthened to the point of joint publications and student exchanges. To achieve this, an increase of the budget for specific joint projects is recommended.

The program has played a key role in bundling research activities through continuous financial support and in turn has stimulated collaboration and cooperation between the existing research groups. Future involvement of SFOE should reflect more clearly its role in transferring know-how from basic research to product oriented development. This would make the outcome more clearly distinguishable from the activities funded by ETH Council. These funds have definitely been important for basic research. The expert team also recommends involving the Universities of Applied Sciences more strongly, in order to develop a photoelectric cell demonstrator jointly with the research groups. The expert team expects that this effort would generate essential, early feedback from engineering challenges to the basic research activities.

Although industrial interest was present in several projects (e.g. Toyota expressed an interest in taking a licence out on a patent to produce gas selective surfaces), the expert team found it difficult to make a judgement on economic potentials because they only had very little information on the cost development of the technology presented. In addition, market impacts are hard to recognize if products or at least indirect market effects cannot be observed (e.g. price of raw materials for potentially valuable catalyst production).

The experts propose that a clear understanding about the potential impact of this technology on the energy economy should be explicitly expressed. If an analysis of variables does not exist, it should be acquired in order to guide future work. In addition, since industrial participation was not yet established, a check between achievements and further challenges with respect to the resources required may be necessary.

4.1.3 Overview: main contracts of the evaluated project area

	Long term collaborations: Photoelectric production of hydrogen (integrated in IEA Annex 14)
EPF-Lausanne	Generation of hydrogen by water splitting with visible light (tandem cell) [Photolyse de l'eau et la production d'hydrogène et d'oxygène au moyen de l'énergie solaire]
University of Geneva	Photoelectrochemical studies pertaining to semi-conducting oxides and to carbon materials Photolysis of water and the production of hydrogen and oxygen using solar energy [La photolyse de l’eau et la production d’hydrogène et d’oxygène au moyen de l’énergie solaire]
University of Bern	Photo-chemical and photoelectro-chemical transformation and storage of solar energy [Photochemische und photoelektrochemische Umwandlung und Speicherung von Sonnenenergie]

Dissemination of hydrogen research

HSR Rapperswil

Management of the IEA-Program “Photo-production of hydrogen and case studies of integrated systems”

4.2 Project areas “hydrogen storage”

4.2.1 Presentation of main projects in project area

Swiss Federal Lab for Material and Technology Sciences; and Metal-hydride and Energy Storage Group in the Physics Department of the University of Fribourg

Hydrogen storage is a major issue in a ‘hydrogen economy’ especially if a high percentage of renewable energy has been implemented. Hydrogen storage is essential for allowing hydrogen to become a viable logistic fuel in transportation. Solid state storage and storage vessels for pressurised and liquefied hydrogen are options being studied world-wide. Although liquid hydrogen is already a commodity today, this option will probably not be the long-term winner due to its high, fundamental energy cost in the liquefying cryogenic process (about 30% of the total cost). Good progress in pressurising hydrogen with working pressures of 700 bar have been made using new technology for the construction of light-weight non-metal pressure vessels.

The research presented focuses on hydrogen storage in metal hydrides and complexes there of. The current emphasis is on $LiBH_4$ for automotive applications. The goal is to understand the thermodynamics and the kinetics of hydrogen sorption and desorption while influencing the reversible reactions through dopants.

About 40-50% of the research funding originated from SFOE, the rest was provided by the University of Fribourg (20%), the EU (20-30%), and industrial sources (10%). Funding is presently also obtained from Japan's Ministry of Economy, Trade and Industry (METI).

Besides bilateral cooperation (e.g. with the Vrije Universiteit Amsterdam, NL), international cooperation is intensive at the broader European level and world wide through the IEA Hydrogen Program Annex 17. Bilateral cooperation also exists with Toyota MC (Japan-Europe) and more industrial interest has been expressed at different levels.

In the case of LiBH4 hydrogen storage system, for example, special attention should be given to the working (desorption) temperature of 350°C when coupling this storage technology to the internal combustion engine (ICE). This hydrogen storage system could be a good candidate for a mid-term development goal especially if only a small number of fuel cell cars are actually on-road by then. In the mid to long term, good reasons exist to believe that the much more efficient low-temperature PEM fuel cell engines will be widely applied in the automotive fleet. Presently, the PEM fuel cell operates at temperatures of about 80°C. In the near future temperatures up to 150°C could be possible. Consequently, for integrated desorption systems low temperature desorption hydrides must be available.

Laboratory of Crystallography, University of Geneva

Additional research in the field of hydrogen storage is performed by designing metal hydride complexes. These complexes combine the relatively high hydrogen contents of the metal hydrides with catalysts that stimulate hydrogen (desorbtion) kinetics. As a result the complexes have lower hydrogen release temperatures than conventional metal hydrides. For example, the complex $LiBN_3H_{10}$ contains 10% hydrogen, which can be released at about 250°C, having a melting temperature of 190°C. Presently this research has no cooperative link with industry despite regular indications of interest from their side. According to the presenter, this situation has been chosen to avoid loss of know-how. International academic contacts appear established in order to collaborate with American colleagues through the IEA Hydrogen Program, Annex 17.

4.2.2 Findings and recommendations

The scientific quality of the work of these research groups is rated as outstanding worldwide. The publications in international refereed journals are impressive. Additional output involves patents, books, invited lectures and courses.

This research is very creative and shows interesting, sometimes unexpected results. The approach provides conditions in which new observations can be made. An example is the semi-conducting LiMg2NiH7 compound which seems suitable as hydrogen sensor.

The research partially addresses technological considerations. For example, in the case of solid storage media, the modification of the kinetics is a fundamental concern to be discussed in order to make solid hydrogen storage work in practice. The question should be raised if SFOE is able to assist in the hook-up of the development paths towards specific technology options.

Both the construction of the demonstrator hydrogen fuelled snow track “Swiss Alps“ and the actual storage application by Toyota, are seen as an efficient way to keep in contact with the practical conditions required for applications. This is a good example of directing successful R&D. The point is how to obtain further specific experience with practical conditions. Heat management and kinetics are main issues. Future SFOE support could stimulate the development and prototyping of innovative storage concepts on the basis of current selection of compounds, while teaming up with technical universities and innovative industry could be an efficient way.

The expert team recommends investigating options to increase the benefit of the high-standing output for the Swiss technology market. Regarding the applicability of options, a thorough comparison is needed at different levels of system integration, energy efficiency and cost/benefits based on life cycle assessment including the user’s perspective.

Regarding the research field presented in this session, detailed systems comparisons should be performed. The pros and cons of working towards applied system concepts and cooperating with industry should also be reconsidered in view of measurable output using SFOE funding. Financial support is required for building a bridge to the market with larger scale applied research including IPR, systems modelling, prototyping, and product development.

Research is a high-risk activity and the present approach could lead to a loss in focus if ill-defined by the plentiful structural choices to be made between possible complex hydrides. A clearer research strategy should be developed. Research also involves, at least in part, technological considerations. In this case of solid storage media, for example, the modification of the kinetics is a fundamental concern to be discussed in order to make solid hydrogen storage work. The question should be raised if SFOE is able to assist in the development paths towards specific technology options.

Insufficient resources for IPR protection on the academic side in an early development stage, where a high possibility of success still exists, locks out cooperation with industry partners. Support of IPR protection through SFOE may help to overcome this situation.

4.2.3 Overview: main contracts of the evaluated project area

University of Genève	Destabilisation of metal hydride complexes and theoretical modelling [Destabilisation of Metal Hydride Complexes and Theoretical Modelling] Complex Transition Metal Hydrides for Hydrogen Storage Structural studies of metal-hydrogen interactions in solid state
University of Fribourg	Development of low-temperature hydride alloys with high storage capacity Hydrogen in carbon structures and metals, Hydrogen storage in metal and complex hydrides [Entwicklung von Niedertemperatur-Hydridlegierungen hoher Speicherkapazität Wasserstoff in Kohlenstoffstrukturen und in Metallen, Wasserstoffspeicherung in Metall- und komplexen Hydriden]

4.3 Project area “solar driven material technology”

4.3.1 Presentation of main projects in project area

ESCA Group, Institute of Physics, University of Basel

Selected projects on material properties: Research on coloured glass cover panes for thermal solar collectors and research on sun protection glasses for buildings was presented in this part of the evaluation session. This research is rooted in the development of selective coatings for solar absorbers started in 1992, which finally led to a commercial product licensed by Ikarus (Germany). Later on, an improved product version was licensed by Vissmann.

The research team has a high reputation in the development and the tailor-made design of optical coatings for different purposes. A measurement technology has consistently been built that is capable of determining the quality of the optical and thermal performance of the coatings developed according to international standards. The unique measurement equipment can be used to characterize the heat transfer through windows and facade glazing. The measurement results of many industrial glazing products are accessible through an internet database. Modelling capabilities were also set up to evaluate the complex spectral heat and light transfer through sun protection glasses. Thus, a basis for optimizing corresponding coatings was achieved.

The development of coatings for solar energy systems seems to be only one of the group's working fields. They have successfully achieved the transfer of their research in the past as well as in the present to a technology useful for industrial application.

The funding by the SFOE program obviously gave sufficient incentive for the group to focus part of their earlier research on solar energy applications. The current research on the development of coloured glazing is considered important to increasing the acceptance of the solar collectors' look on buildings. The results presented show the feasibility of the market concept. Additional improvement of the optical properties by the development of low refractive index surfaces (anti-reflecting coatings) appears to be going in the right direction to enhance energy efficiency and heat management of buildings.

The expert team does not understand why this research was or still is associated to this SFOE program. They highly recommend associating it to a more appropriate SFOE program.

Catalysis and Reaction Engineering Group, Institute of Chemical and Bioengineering, Swiss Federal Institute of Technology, Zurich

Catalytic chemistry in CO_2: The research group works in the field of chemical synthesis using dense carbon dioxide, mostly at the supercritical state. Two main directions have been addressed: the use of CO_2 as a high grade solvent particularly in catalytic hydrogenation synthesis and as a reactant in chemical synthesis. The two main goals are the replacement of conventional organic solvents and the replacement of hazardous reactants like CO or phosgene, respectively. Another area is concerned with the immobilisation of CO_2. These activities seem far away from the project area "solar driven material technology".

The research group is composed of about 30 people (20 PhDs) among which only 2 PhDs are funded by SFOE. It is difficult to equate the research's output specifically to the SFOE support.

The scientific quality of the research is considered very high. Particularly in the field of catalytic reaction in supercritical CO_2, the group is well recognized at the international level. The introduction of specific synthesis routes at industrial scales is still at an initial stage. Although industrial interest exists, as seen by the investments in research infrastructures (Hoffman-LaRoche, Degussa), changing industrial processes is very difficult and needs strategic decisions with or without constraints imposed by new regulations.

The SFOE grants have at least partially made it possible for the group to study a new field in chemistry: the use of CO_2 both as solvent and chemical reactant. From this point of view the efficiency of the funding seems high.

However, two questions are pending: Could this CO_2 chemistry become significant in CO_2 emission mitigation? And what is the energy balance of this chemical route?

1) CO_2 chemistry is an interesting branch of chemistry in which this research group plays a significant role at the international level. However, the real impact on CO_2 mitigation is questionable. The amount of CO_2 that could be immobilised in the chemical products is probably negligible with respect to the total CO_2 emissions involved.

2) CO_2 is a very stable molecule. Consequently, additional energy for the reaction is required for chemical reactions. From the energy balance point of view the question is, 'what are the sources of energy and hydrogen used?' If renewable hydrogen is used such processes make sense, but it must be evaluated using life cycle assessment (LCA) methods. Moreover, it is not evident what the targeted products are: Are they chemical commodities or energy carriers? In the latter case, a comparison with methanol synthesis should be done. In the former case, the specific interest of CO_2 chemistry must be clarified.

4.3.2 Findings and recommendations

The expert team finds the research on improved sun protection glasses less obviously related to this program. A combined effort within other SFOE programs dealing with the overheating problem of buildings having glazed facades may be more adequate. The current lack of interest of the building industry in these developments may have been avoided if other platforms would have been consulted earlier in order to have checked for needs of this industry branch. Presently, cooperation with the Swiss railway company is underway. The company is interested in decreasing energy consumption of air conditioning in trains through the use of solar protection glasses.

The expert team is surprised that the developments have not been patented up to now. The university's limited resources allocated to patenting processes may be one of the reasons for this. In the future SFOE support should be considered for the Intellectual Property Right (IPR) protection as it is done in EU programs.

In general, the financial support of SFOE in this field is very much in line with its objective of fostering the transfer of knowledge from fundamental research to prototype development. SFOE support has helped to initiate this research and brought it to a critical mass for applied science and P&D. It appears that the funds have generated excellent value. From the SFOE viewpoint, the financial efficiency of these activities can be considered high, because only 35% of the manpower involved was paid from SFOE funds.

For the expert team it was not clear what the strategic interest of SFOE for supporting the CO_2 chemistry research is. SFOE supports this very productive and interesting activity. A justification (if any) based on impacting CO_2 issues at the Swiss energy system level is weak. To put it differently; the importance of the activities in this field seems to be in other research fields; possibly in the field of chemical synthesis of fine chemicals and substitution of toxic chemical solvents (environmental impact). The research on CO_2 chemistry can be of unexpectedly great importance, for instance in medicine and flavour production; it is far from the energy issue.

Funding of an activity by many sources could be a sign of under funding or problems fitting the program's objectives. It must be stressed that this is not always a negative sign. The expert team advises SFOE to make a specific analysis of the practical importance of this research, possibly leading to a more applicable funding basis perhaps in a new program. During this session, it was mentioned that almost no meetings, for example about a strategic layout of the program were discussed together with the SFOE program manager, although demands were made on the principle investigators' research output.

In addition, it was pointed out that for several years the funding system in Switzerland has become more and more cumbersome when trying to coordinate educational, research, and complex R&D projects.

The expert team is of the opinion that bottom up research should be organized through competence centres to simplify collaborations and to reduce administration. With proper and simple funding systems, high level applicants should be able to easily form groups of excellence working jointly along a clearly defined road-map. (The expert team feels that a framework of this kind has actually been provided by the SFOE if compared with funding agencies outside Switzerland).

Evaluation of fundamental research is more difficult and discipline oriented while the evaluation of applied research, as in case of SFOE funds, is simpler and more topic oriented. The latter however, has less money involved. SFOE should also coordinate with the CTI funding system and draw on their expertise and network in order to direct research and development.

4.3.3 Overview: main contracts of the evaluated project area

ETH Zurich	Catalytic synthesis starting from mineral carbon sources [Katalytische Synthesen ausgehend von mineralischen Kohlendioxid-Quellen]
University of Basel	Metal-oxides, ceramic and composite materials in solar technology [Metalloxide, keramische Materialien und Verbundwerkstoffe in der Solartechnologie] Materials for sustainable technologies in energy transformation and energy conservation [Materialien für nachhaltige Technologien in der Energieumwandlung und Energieeinsparung]

4.4 Project areas "solar chemical processes": STL / PSI

4.4.1 Presentation of main projects in project area

Introduction to solar chemistry research

Laboratory for Solar Technology, PSI Villigen

The introduction consisted of an overview on the strategic approach of PSI and ETH in the field of solar thermo-chemical cycles for fuel production. The group has been involved in this research field for more than ten years. With the help of SFOE support the group was able to study many different materials intensively in order to select the appropriate one for this purpose. Attention was drawn to the fact that the group aims at reaching industrial scales for their clean technology along a clearly structured development path.

The major focus of the group today is on the Zn/ZnO cycle. In addition, the group has initiated research on the carbothermic reduction of ZnO and on the decarbonisation of fossil fuels, more specifically the gasification of pet coke using SFOE funds. Industrial interests already exist for these two areas and scale-up projects pursued are funded by additional resources (EU, industry).

The direct reduction of ZnO presents a high-risk approach, because it has to be operated at about 2300K. Material problems and efficiency losses by re-oxidation of Zn are significant challenges and necessitate further research. As part of the need to fully understand the Zn/ZnO cycle, research on the oxidation of nano-scale Zn particles is needed in order to be applied for splitting water into hydrogen and oxygen. Creating a demonstration reactor to the order of 10 kW with an overall efficiency of 10% is the target of the group for the next five years.

The group cooperates with other PSI groups on the life cycle analysis of various solar hydrogen producing technologies. Being excellently positioned in international networks like the IEA SolarPACES program and the Alliance of European Laboratories for Research and Development on Solar Concentrating Systems (SOLLAB), the cooperation between ETH and PSI significantly benefits from these coordination efforts.

In combination with high quality analysis tools, a solar furnace and a newly built solar simulator, PSI has the appropriate foundational conditions to face future challenges and to guide scientific findings into engineering prototype solutions. The expert team is convinced that the group can lead the field of solar thermo-chemical production worldwide.

Cooperation with industry has been recently demonstrated for the development of gasification of pet coke, where a multimillion scale-up program has been completely funded by a big Venezuelan oil company. Industrial interest in the Zn/ZnO cycle is not expected to be attractive before the feasibility of a reactor on a 10 kW scale has been proven.

Review of selected projects on solar chemistry

Laboratory for Solar Technology PSI Villigen; and General Energy Research Departement, PSI Villigen

The development of research activities in this section is based on four integrated main tasks:

- Modelling of the interaction between a concentrated solar beam and reacting solids
- Development of measurement methods and apparatus to monitor the reactor performance

- Analysis of the elementary processes involved in the separation steps (metal/oxygen)
- Design, construction, and testing of pilot scale solar reactors at the level of 10 kW.

These activities are very complementary and the capacity for developing the four tasks at the same level of competences is one of the unique capacities of the STL, ultimately allowing solar reactor scaling up.

Modelling of interaction between concentrated solar beam and reacting solids: Being closely linked to ETHZ activity (through a PhD student), this action is necessary for future scale up of solar reactors. Besides the modelling, it opens up basic research on combined heat transfer in reactive complex media, which exist in high temperature gas-solid processes.

Development of measurement methods and apparatus: Reaction temperatures, reactor efficiency, process efficiency, off gas composition are important parameters for monitoring the reactor performance. For characterising and qualifying the reactor, measurements of the solar power and concentration level available in the reaction chamber, the temperature distribution inside the reactor, the stability and radiative properties of materials, and the on-line analysis of gaseous species at the outlet of the reactors need to have high standards. STL has developed specific methods and apparatus in order to achieve these goals. Because other partners could not fund all these activities, SFOE promoted a complete engineering approach that should now be further developed together with industry. Additional efforts to link model and radiative property measurements remain a necessary prerequisite for this.

Analysis of the elementary processes involved in the separation steps (metal/oxygen or metal/sulphur): Basic research approaches have been developed to determine the relevant parameters and mechanisms for Zn nucleation and oxidation; key steps of the zinc oxide cycle. Nozzle type experiments have been set up and are still in the calibration phase. Considerable efforts have been made to develop relevant models and diagnostic tools (PIV, PLIF) that aim at understanding and simulating Zn nucleation and oxidation. Original papers on these subjects will be published soon. Applications of these actions are possible in other domains, for example, in aerosol chemistry and in the production of nano-particles.

SFOE has provided additional seed money to investigate the solar thermal extraction of metals. Although this research is still in a chemical exploration phase (small scale), it has already attracted the interest of the mineral industry.

Design, construction and testing of pilot scale solar reactors at the level of 10 kW: The laboratory has designed, constructed and tested numerous reactors (solar reactor portfolio) for processing chemical reactions in the temperature range 1500K-2300K. Some of them have been patented and developed in collaboration with industry (Qualical, for example, in the case of lime production). These persistent engineering tasks made the team one of the world leaders (among few) in solar chemistry. This work should achieve strategic importance for the industry due to expected transfer steps, for example, useful for scaling down industrial high temperature chemical reactors. Recently, a significant demonstration of the solar reactors scale up capabilities (scale factor x30) was achieved during the SOLZINC EU project while testing a 300 kWth reactor at a WIS facility (Israel). This reactor was designed as proposed by STL. The results fit the project objectives very well.

4.4.2 Findings and recommendations

The scientific output of the group is considered to be very high. Numerous publications in peer reviewed journals have been published. The intellectual property of the group, specifically with respect to receiver concepts, is protected by a number of patents. However none of them have been licensed yet. Patents are essential to regain the R&D investment. Unfortunately, without licensing, a significant cost problem arises. SFOE should try to follow a more strategic approach and encourage IPR protection and licensing in order to reduce the patent risk of individual research groups.

Up to now, SFOE funding has served as an essential support in a number of projects for developing ideas to a status that industrial interest can be attracted. It has supported a consistent strategy to develop a promising technology option for bulk solar hydrogen production. This extended funding security has been especially important in this kind of research, since the development of processes and reactors is an iterative process (i.e. elaborate screening for the right materials).

The very ambitious technology development roadmap for scale-up and corresponding industry involvement is fostered by SFOE which funds no less than 5-6 group members (postdoctoral students, PhDs, technicians at the beginning of 2005). Together with institutional funding from PSI and ETH and the excellent research infrastructure available, the group has clearly achieved a critical mass required for leadership. The financial efficiency of SFOE funding is considered to be high especially because of the clear strategic focus and the substantial synergetic contributions of the other partners. After scale up it is expected that industry will take over the lead for technology integration by building up a development consortia.

The time of market entry for this technology which has been set for between 2007 and 2010 appears too optimistic. A real market entry depends on price incentives for producing clean fuels similar to today's incentives for green electricity. In addition, the cost for thermochemical H_2 production significantly depends on the cost for the solar concentrator field, an area the group is not involved in. Thus, industrial success relies on a number of external factors, which can hardly be influenced by the group. Since the direct application of this technology will not be possible in Switzerland itself, opportunities to influence successful industrial implementation are somewhat limited.

The R&D strategy is well defined and developed (reduction of CO_2 content of fuels using solar energy) but the possible specific investment/benefit of Swiss industry should be examined.

In the field of solar chemistry, the clearly directed long-term support of SFOE was important and effective to ultimately initiate large EU projects. The expert team noticed that the quality of the projects submitted to SFOE is actually checked beforehand by an internal PSI evaluation procedure, which could have been the reason for a clear and prolonged commitment of SFOE.

It must be stressed that one of the success factors of this research is the continuity of the funding in combination with a clear roadmap with intermediate milestone derived from a systems analysis approach. This concept may serve as a "best practice" example for other parts of the program, where sometimes more focus on fewer but more energy related activities appear to be beneficial.

SFOE has played a key role in driving solar chemistry to become one of the "domains of excellence" of Swiss research in energy. The PSI/ETHZ Team is now well recognised in the world and is able to initiate large international programs. The expert team suggests maintaining this effort in the future and encouraging further pilot/industrial developments.

4.4.3 Overview: main contracts of the evaluated project area

	Long term collaborations: solar chemical processes
PSI Villigen	Direct transformation of concentrated solar energy into chemical energy carriersOn the pathway towards solar fuel cells – physical-chemical contributions to the development of solar reactors. [Direkte Umwandlung von konzentrierter Sonnenenergie in chemische Energieträger Auf dem Weg zu solaren Brennstoffen – Physikalisch-chemische Beiträge zur Entwicklung von Solarreaktoren]
PSI Villigen	Solar thermal production of zinc Solar chemical reactor engineering for the solar thermal production of zinc SOLZINC: Solar carbothermic production of Zn from Zn0
PSI Villigen	Synthesis and spectroscopy of ZnO and Zn_xO_y in the gas phase [Darstellung und Spektroskopie von ZnO bzw. Zn_xO_y in der Gasphase]
	Short-term projects
PSI Villigen	Solar-chemical contributions to the reduction of CO_2 emissions [Solarchemische Beiträge zur Reduktion des CO_2-Ausstosses]
ETH Zürich, PSI Villigen	Solar decarbonization of fossil fuels – clean energy technologies for CO_2 mitigation Solar Thermal Production of Lime and Cement with Reduced CO2 Emissions
	Dissemination of solar research
PSI Villigen	Operating agent IEA-Program SolarPACES (Solar Power and Chemical Energy Systems, http://www.solarpaces.org)

4.5 Project areas “hydrogen production”

4.5.1 Presentation of main projects in project area

Laboratory for Energy and Materials Cycle, PSI Villigen

The introduction gave insight into the decision made to prioritise the biomass FICFB[1] gasification project. Initially, the various options for the use of biogas included:

- Wood gasifier with SOFC link-up
- Methane production for transportation purposes
- Gasifier with direct coupling of heat and oxygen transfer

The first option was set to produce synthesised gas or hydrogen through an internal redox reaction in a wood gasifier system. The redox reaction was based on oxygen transfer through an iron-oxide redox couple. Analysis of the energy flow scheme showed that this option was not energetically feasible.

Furthermore, it was concluded that depending on the level of tar in the produced biogas, the two other feasible options would be either the SOFC link-up or the transportation fuel option.

Thermal Process Engineering Group, PSI Villigen; and General Energy Research Departement, PSI Villigen

Wood gasification for methane production and successful coupling with SOFC strongly depend of the quality of input material. Improving the gas cleaning procedures is one impulse/demand/need in the development of wood gasification for combined heat and power, and fuel production. Depending on its application, tar may or may not be a problem.

Efforts to decrease tar content of the FICFB gasification by using oxygen transfer materials were presented. Continuous adaptations of process designs in FICFB gasification resulted in the use of olivine as fluidized bed material, which reduces the tar content significantly when compared to sand as the standard material. Olivine appears not only to transport heat but also to catalyse the lowering of tar by transferring reactive oxygen to the substrate. The process has not yet been well understood, although the progress made so far is a very good example of R&D pointing out that important outcomes can be achieved with the help of proper funding.

Additional material research activities concentrated on understanding the function of olivine in the FICFB gasification. Model reactions with methane and olivine have been studied. This identified olivine not only to catalyse the reactions but also to take part through active oxygen exchange. To extend the understanding of reactive oxygen, Perovskite LSCM[2] has been chosen as an oxygen transfer compound. Experiences with reactions on either methane or toluene provided both kinetic and some equilibrium data on the gases formed. In general, it appears that the application of new materials provoke a shift of the product gas to a higher hydrogen content and lower tar, although it has to be noted that the new materials are too expensive to be

[1] FICFB: Fast Internal Circulation Fluidised Bed
[2] LSCM: Lanthanum Strontium Chromium Manganate; a material applied in SOFC’s

applied in pilot plants.

As presented here, relatively high tar content even after gas cleaning forces the choice towards the use of the product gas in gas engines for combined heat and power generation. Low tar gas like synthesis gas is also applicable for the production of the higher valued liquid fuels for transportation through the Fisher-Tropsch reaction. Tackling the tar problem is therefore a major accomplishment.

In optimising an overall process from wood gasification to power generation, issues in gas engine optimisation should also be considered. In addition, the issue of investigating biomass availability for large plants has been recognised. It may be especially important to understand biomass as a resource to be developed as a commodity in a European market. In this context, the Swiss biomass may be too pricey relative to other fuels.

Beside some Swiss industrial interest, the laboratory is more involved in European cooperation. A patent exists for the technology but not for the materials involved. The question remains on how to quantify the benefit for Switzerland from this know-how export. The pilot plants and gained industrial partners in Europe (e.g. Güssingen, Austria) could possibly lead to the construction of a full-sized power plant in Switzerland by the end of this decade. This would be in line with the SFOE perspective for developing CO2-neutral energy technologies, which can operate throughout the year. The wood gasification technology could also strongly influence the target to double biomass utilisation in Switzerland by 2050.

4.5.2 Findings and recommendations

Impressive, well thought through activities were presented. The basic equations have been intensively studied and evaluated with respect to options of most realistic meaning. Different research priorities have been evaluated and different applications have been selected under different practical conditions for utilisation.

Interestingly, this research started very small with some PSI funding and then with funding from SNF and SFOE of about 20-30% for a single research person. With the continuous support and collaboration of other groups, also within the program, the project grew to 12 people.

This biomass activity at PSI is now performed in close contact with international projects including the combined biomass gasification pilot-plant in Güssingen, Austria. This EC co-funded system is linked up with the CHP gas engine to generate 2 MWe and 8 MWth. The project stimulates the exchange of information and the experiences feed new research issues. The concept fits into the vision of stimulating increased introduction of renewables and CHP in Switzerland.

Tar is acknowledged worldwide as a problem in biomass gasification. It affects the gasification system and can limit the applicability of the product gas. It is important to determine the practical limits in the different gas reactions and attempt stretching these for selected applications. Beside tar, gas-cleaning is an important issue to address. Especially higher temperature processes are required for increasing system efficiency and decreasing investment costs.

The potential of wood gasification in Switzerland is in the order of a few percent of the current energy needs. Options to extend the potential availability of suitable biomass resources should be identified and stimulate both in the national and international contexts.

Since R&D was at the pilot plant stage, seeking industrial guidance and participation is recommended. The vision behind it should be expressed in order to develop a clear understanding of the opportunities in the near future for Switzerland, and ideas on how to take advantage of these. Examples could be:

- to generally commercialise these types of systems and/or to export technology (employment, economic effects)
- to export knowledge or licensing patents (revolving funds)
- to consider choosing the most likely system to produce and to implement in Switzerland

The question should be addressed regarding the ratio of research work on the SOFC options because of limited availability, high costs and seemingly decreasing perspectives. In order to increase the competence in Switzerland, the expert team advises keeping and strengthening its position through a typical Swiss role in this field. This could be done through an increased presence in the Austrian Guessing pilot plant.

Construction of a real system in Switzerland would be advisable, provided industrial interest is increasing. This could lead to the integration of knowledge and further development of competence through its design, construction and operation. The new experiences and analyses will prioritise current and future (second generation) R&D activities. It would mean investing in an advanced pilot plant concept for Switzerland. Evidently budget coherence in R&D and 'bridging' funds would be a prerequisite for this.

4.5.3 Overview: main contracts evaluated in project area

PSI Villigen	Redox-cycle for the production of pure hydrogen from unrefined gas of a wood carburetor (REDOX-Filter) Redox-Kreisprozess zur Produktion von reinem Wasserstoff aus dem Rohgas eines Holzvergasers (REDOX-Filter)]

5 Evaluation of program management

5.1 Presentation of managment by internal and external program managers

Divisional manager of the research program in the Swiss Federal Office of Energy

The divisional manager gave an introduction on how the program “Solar Chemistry / Hydrogen” is linked to the SFOE structure. The divisional manager supervises the program and is supported by the external program manager. The program manager is responsible for reporting to CORE, controlling the projects and dealing directly with technical aspects of the projects. Cross cutting research and educational aspects are covered by the SFOE section “Research and Education”. Having formulated the four-year energy master plan, CORE acts as an advisory board to SFOE, which has to implement the energy master plan.

The program “Solar Chemistry / Hydrogen” defined in the master plan aims at setting-up a long term research strategy on internally accepted (or better selected) subjects where Switzerland can contribute to high level research. Funding should allow for continuous research in the selected subjects. Coordination of national and international activities should be performed (e.g. by active involvement in IEA Implementing Agreements). Research results should lead to networking and demonstration activities, which also lead to interactions with other programs. The integration into the Hydropole association is intended to foster cooperation between academia and industry.

The divisional manager showed that in general a major fraction of the SFOE money goes to the private sector. However the situation is different in this program where research institutes get the larger part of the program budget. A total of about 200 Mio per year is managed by a very flexible funding scheme. The annual budget is decided on each year by the parliament.

Since the divisional manager was also responsible for the coordination of other SFOE programs, he was limited in the time left available to this program. Therefore, he established a highly efficient and very flexible management strategy to run the program together with his program manager.

A funding request was handled in a flexible and informal way. Before a formal application was submitted for consideration, the focus of the proposal was first discussed with the researchers. Decisions could be made in agreement with the divisional manager and program manager very quickly. An external evaluation of the proposals was not foreseen. The originality and quality of the scientific work as well as the continuation of funding for highly recognized groups appeared to be the major criteria for the selection of proposals. Additional improvement of the quality of networking was essential for an efficient implementation of program.

The divisional manager pointed out that he will retire soon and his function will not be replaced. Also the contract with the program manager has expired and will not be extended. It has been proposed to split the program in two parts; the hydrogen part will be combined with the fuel cell program, whereas the solar chemistry program will continue separately.

Program manager

The external program manager introduced the general Swiss strategy on the production of hydrogen without CO_2 emission. The options considered are solar photochemical production, electrolysis based on nuclear or hydro power, the pyrolysis of biomass and the splitting of water using thermo chemical cycles with metal oxide. Hydrogen production, storage and transportation, as well as utilization, are important fields of research.

In addition, the program has two other branches: “solar chemistry”, which covers the production of commodities using renewable energy sources, and “supporting and innovative technologies (e.g. with spin-off potential)”.

All funded activities were associated to one of the three areas “harvesting”, “storing” and “utilising” solar energy. These categories appeared to be well thought through for the hydrogen part of the program, where harvesting activities covered the electrolysis activities and the photoelectrochemical work, the storing activities covered metal hydrides or organic hydrides and storage containers, and the utilization activities covered biomass conversion to hydrogen for reducing CO_2 emissions. The distinction made in the solar chemistry being less obvious. In project area “other storage technologies and applications” the “harvesting” covered stirling engines and thermoelectric systems, the “storage” subjects were in this case hot rock, CAES and ammonia, and in “utilization” wavelength selective materials and phosphors for advanced light systems were included.

The program manager pointed out that in all covered areas the development of functional materials is a key task in which Swiss institutions have achieved an excellent reputation. Obviously Switzerland performs energy technology research for export and it is important to increase chances for spill-over by continuous funding support. He gave a number of examples for activities, which are mentioned in the different sessions of the evaluation. Interestingly, from the program manager’s perspective, the administration of research is much more difficult today than 15 years ago.

5.2 Findings and recommendations

It appeared relatively clear as to why the hydrogen part is important for Switzerland. The subdivision into harvesting, storing and utilization was obvious. The selection of the individual subjects was clearly based on the competence available in the country and may contribute as a step towards a hydrogen economy. In contrast, the strategy behind the “solar chemistry” part was less developed. Solar chemistry addressed two main actions: solar production of commodities and metal oxides cycles.

The motivation to work on the solar production of commodities was less obvious than for hydrogen. It was limited in terms of the total CO2 avoidance potential in a specific production process (like limestone calcination) as compared to the production of a generic fuel like hydrogen. The potential market volume is smaller and specific incentive programs to facilitate the introduction of commodities produced with solar energy are less likely to be introduced compared to the hydrogen case. It should be reconsidered as to whether this subject dilutes the limited resources of the program.

Specifically metal oxide cycles appear to be better associated to the hydrogen part of the program, because they are used for the production of hydrogen. In these cycles, metals could hardly be considered as commodities or as energy storage materials, because the energy content (per weight) of many metals compared to H2 is very low.

Even more confusing is the “other storage technologies and applications” part, since it is almost without any technological linkage to the other two parts of the program. Although the quality of the research work supported is considered to be high, the strategic reason on why the focus is on stirling systems, thermoelectric converters or on selective coatings as mentioned in the presentation is not clear. The expert team feels that almost any subject of specific interest to the researchers and program management could be included in this program part. It is very important to restate, that we do not criticize the research work done in this program part, because it is of high quality, but the strategic idea behind it seemed unclear.

Based on the experience of the expert team, the program management was performed in an unusually flexible way. Simple changes of funds of other program objectives for on-going projects avoid administrative handling. However this method seemed not solid financially, i.e. allocation problems of project cost to actually used funds at defined points in time occurred. The decisions on changes appeared to fully rely on the program manager.

Project selection should be transparent and done under publicly known conditions. The writing out of tenders should be done regularly and submissions evaluated and ranked by an external expert group with criteria and names of members published, while involving industry as both a project leader and market observer.

The expert team believed that the scientists should be more actively involved in the structuring of the R&D program. This may strengthen the understanding of what kind of activities really support the long-term objectives of the program and may foster team building.

6 Overall Conclusions

The expert team felt that the objective of the program was developed more on academic competence building in the field of functional materials as applied to energy problems, rather than on prioritizing research activities with meaningful, maximum long-term impact on clean energy systems. If the former is really meant, we consider this as a reasonable objective of a research program.

The relevance of research activities should be continuously monitored with respect to the program concept and possible robust contributions to a clean future energy system, respectively. The handling of niche market opportunities should be reviewed case by case and include transfer options of research activities or abandoning some routes.

The involvement of industry and corresponding utilisation of the R&D results in many of the project areas were still limited. This is due to the fact that realistic markets chances for renewable hydrogen or commodities production is still more than 10 years away, a period which is far beyond the R&D investment time horizon of industry. Therefore, industry involvement can only be expected in the spin-off or spill over areas. Some smaller research activities attracted commercial attention, generally in initiating spin-off activities in niche markets. While these activities may help to attract industrial interest, they bear the risk that funding is diluted to non-energy relevant issues.

Since involvement of industry in the early stages of research is of high benefit, SFOE should consider acting as a funding institution that at least partially reduces development risks in order to increase the chance for innovations (importance of P&D projects). It has to be kept in mind that the expectation on technology development of the involved industry with their marketing strategies may not be realistic. Industry may underestimate material problems and complexity of technical details. However, based on the experience of the evaluators in their own countries, involvement of industry partners in an early stage leads to a higher likelihood of commercialisation. Potential strategies: (1) common full collaborative projects where industry receives 50% of their costs and academics 100% of additional costs; (2) collaborative R&D projects in which industry participates “in-kind” (for example, construction of a prototype, or characterisation of end-use properties of materials, or hours of engineers acting as a consultant for the project); (3) industrial R&D projects (industry receives the total funds) in which academics are sub-contractors. (4) Technology transfer projects where funding is provided on the basis of licensing agreements. In addition the rules may be different for SMEs and big companies.

The program should be designed in such a way as to stimulate the uptake of larger industrial investments in technology, e.g. for the benefit of new economic activities in Switzerland or exporting know-how from Switzerland. This may be achieved through further developing the funding system that assists in bridging knowledge to commercial stakeholders. The gap between the R&D result and the technology that commercial actors would welcome should be narrowed as follows:

- Actively support knowledge management, including patenting, IP handling and portfolio management of patents (otherwise commercial investment might miss the fundamentals)
- Involve industry at an early stage (when necessary) to guide the direction of developments

- Invest in field tests (the smallest meaningful size) which shows the state of the art, indicates further R&D needs (fundamental and technological) and updates the image of the technology to potential investors. As a side effect, it has been proven to attract international knowledge in white spots.

Research policy should address how to handle IP issues for Switzerland as being especially relevant in many research fields. Today many rights are directly sold to businesses outside Switzerland, a process which has also been stimulated by globalisation. However the fast loss of IP / patents is a problem for many countries.

In an interdisciplinary process, know-how and research directions of research groups are disseminated in an expert network, which may return diagnostic or system analytic input. Contacts and cooperation (e.g. in competence centres) have often been only possible by the continuous financial support of SFOE. Access to flexible funding has led to a favourable situation in Switzerland. In addition, good financial efficiency was also observed because of the high to very high scientific quality observed throughout the whole program.

The relationship between funding by SFOE and energy solutions was strongly seen in the basic and oriented R&D phases. However, the next steps involving possible R&D successes were not strongly developed. It has been recommended that R&D successes be identified and decided on as the way towards the next steps. The approach should be developed in cooperation with the CTI program and the private sector (the customer of the knowledge). Continuously monitoring of the designed trajectories, portfolio management of activities and patents, and additional identification of new R&D success is recommended.

Suggestions for research in the field of solar chemistry (in addition to H_2 production), for example:

- Thermochemical storage of solar energy
- High temperature selective coatings and more generally coatings of solar materials
- Nanomaterial and solar material synthesis

Based on experience in Germany, the evaluators recommend considering a stronger link between R&D program objectives and market penetration incentives like feed-in tariffs for renewable electricity or tax deduction for bio-fuels to stimulate industrials interest.

New fields of research with respect to hydrogen production through PEC and solar thermochemical routes may revolve around the question on the impact of water impurities in these processes, the identification of appropriate water production facilities and the reduction of water purification costs.

The success of research trajectories strongly depends on the coordination efforts of the different funding institutions and their contributions to balance under-funded situations.

Annex A: Project contracts of the program

Table A1: Portfolio of SFOE contracts of 2000 and 2001 arranged according to the program parts

	Title of Projects	Research Institute	Funding by	Volume 2000	Volume 2001
	Solar chemistry				
1.	Darstellung und Spektroskopie von Zn_0 bzw. Zn_xO_y in der Gasphase	PSI	ETH-Rat, BFE	**	**
2.	IEA-SolarPACES-Programm	Ausl	BFE	*	*
3.	Materialien für nachhaltige Technologien in der Energieumwandlung und Energieein-sparung	Uni	BFE, SNF, Kt BS	***	***
4.	Metalloxide, keramische Materialien und Verbundwerkstoffe in der Solartechnologie	Uni	BFE, SNF, Kt BS	***	T
5.	Molecules, Ions, Complexes, and Clusters in the Cavities of Zeolites.	Uni	SNF, Kt BE	**	T
6.	Physikalisch-chemische Beiträge zur Entwicklung von Solarreaktoren	PSI	ETH-Rat, BFE	****	****
7.	Production H2+O2 avec énergie solaire	EPFL, Uni	ETH-Rat, BFE, Kt GE	**	T
8.	Solar Decarbonization of Fossile Fuels	ETHZ	ETH-Rat, BFE	-	**
9.	Solar Thermal Production of Zinc	PSI	ETH-Rat, BFE	***	***
10.	Solarchemische Beiträge zur Reduktion des CO_2-Ausstosses	PSI	ETH-Rat, BFE	-	**
11.	Solare Herstellung von Kalk	PSI	ETH-Rat, BFE	**	**
12.	Solartechnik	PSI	ETH-Rat	****	**
13.	Solarthermische Prozesse in der Kreislaufwirtschaft	PSI	ETH-Rat, BFE	**	**
	Hydrogen				
14.	A clean process for carbon nanoparticles and hydrogen production from plasma hydrocarbon cracking	Priv	Bund		
15.	Complex Transition Metal Hydrides for Hydrogen Storage	Uni	BFE, Kt GE	*	*
16.	Destabilisation of Metal Hybride Complexes and Theoretical Modeling	Uni	BFE, Kt GE	**	**
17.	European Hydrogen Filling Station EUHYFIS	Priv	Bund	-	**
18.	Evaluation technico-économique de la commercialisation d'une tondeuse à l'hydrogène	Uni	BFE, Kt GE	*	T
19.	Experimentelle Untersuchung von extrem dünnen Schichten (Nanoschichten) für die Katalyse (Rekombination von Wasserstoff)	PSI	KTI	*	T
20.	FUCHSIA : Fuel cell and hydrogen store for integration into automobiles	Uni	Bund, Kt FR	-	*
21.	HYDROBAR, Diffusionssperrschichten für H_2-Hochdrucktanks	FH	BFE, Kt GE	-	**
22.	Hydrogen Supply from Liquid Energy Carriers	PSI	ETH-Rat, BFE	-	**
23.	HYDROPOLE	Priv	BFE	****	T
24.	IEA HYFORUM	PSI	BFE	*	*
25.	IEA-Wasserstoff-Programm	Priv, Ausl	BFE	*	T
26.	Photochemische, photoelektrochemische und photovoltaische Umwandlung und Speicherung von Sonnenenergie	Uni	BFE, SNF, Kt BE	*	*
27.	Photoelectrochemical studies pertaining to semiconducting oxides and to carbon materials	Uni	Kt GE	***	***
28.	Photolyse de l'eau et la production d'hydrogène et d'oxygène au moyen de l'énergie solaire	EPFL, Uni	ETH-Rat, BFE, Kt GE	*	T

	Title of Projects	Research Institute	Funding by	Volume 2000	Volume 2001
29.	Projet pilote d'utilisation de l'hydrogène comme combustible pour fauteuils roulants et une tondeuse à gazon	Kt	Kt GE		**
30.	Quasi-isothermes Füll- und Entladesystem für Hochdruckgasflaschen für H2	Priv	BFE	-	*
31.	Structural studies of metal-hydrogen interactions in solid state metal hydrides	Uni	SNF, Kt GE	*	T
32.	Synthesys, cristal structure and properties of new metal compounds	Uni	Kt GE	-	**
33.	Wasserstoff in Kohlenstoffstrukturen und in Metallen	Uni	BFE, Kt FR	*	T
	Einzelprojekte / Unterstützende Techniken			**	**
34.	Crystallization, phase stability, doping behaviour and photoelectrochemical characteristics of anatase	EPFL	ETH-Rat, SNF		
35.	Elektrophysikalisches System zur Verbesserung der Wärmeübertragung	Priv	BFE		
36.	EUBORA: Concerted action on boron dilution experiments	PSI	Bund	*	T
37.	Katalytische Synthesen ausgehend von Kohlendioxid	ETHZ	ETH-Rat, BFE	*	*
38.	RUCADI: Recovery and utilisation of carbon dioxide	Uni	Bund, Kt GE	*	T
39.	Bereichs-/Programmleitung "Solarchemie & Wasserstoff"	Bund, Priv	BFE	**	**

* Project volume < CHF 100’000

** Project volume CHF 100’000 – 500’000

*** Project volume CHF 500’000 –1 Mio.

**** Project volume > CHF 1 Mio.

T Project terminated

Table A2: Portfolio of SFOE contracts of 2002 and 2003 arranged according to the program parts

	Title of Projects	Research Institute	Funding by	Volume 2002	Volume 2003
	Solar Chemistry				
1.	Darstellung und Spektroskopie von ZnO bzw. ZnxOy in der Gasphase	PSI	ETH-Rat, BFE	**	**
2.	IEA Program SolarPACES (Solar Power and Chemical Energy Systems)	Ausl, PSI	ETH-Rat, BFE	**	**
3.	Solar Chemical Reactor Engineering for the Solar Thermal Production of Zinc	PSI	ETH-Rat, BFE	*	***
4.	Solar Thermal Production of Lime and Cement with Reduced CO2 Emissions	ETHZ	ETH-Rat	**	**
5.	Solar Thermal Production of Zinc	PSI	ETH-Rat, BFE	****	T
6.	Solar Thermal Recycling of Hazardous Waste Materials	ETHZ	ETH-Rat	**	**
7.	Solarchemische Beiträge zur Reduktion des CO2-Ausstosses	PSI	ETH-Rat, BFE	****	****
8.	Solare Herstellung von Kalk	PSI	ETH-Rat, BFE	**	**
9.	Solartechnik	PSI	ETH-Rat	***	***
10.	SOLZINC: Solar carbothermic production of Zn from Zn0	ETHZ, PSI	ETH-Rat, Bund	***	***
11.	The Solar Decarbonization of Fossile Fuels: Clean Energy Technologies for C02 Mitigation	ETHZ	ETH-Rat, BFE	**	**
12.	The SYNMET-Process: Co-Production of Zinc and Syngas	ETHZ	ETH-Rat	**	**
13.	Thermal Radiation Heat Transfer in Chemical Reacting Systems	ETHZ	ETH-Rat	**	**
	Hydrogen				
14.	Complex Transition Metal Hydrides for Hydrogen Storage	Uni	BFE, Kt GE	**	**
15.	Demonstration eines Metallhydrid-Speichers in einem mit Wasserstoff angetriebenen Pistenfahrzeug	Uni	BFE, Kt FR	-	*
16.	Destabilisation of Metal Hydride Complexes and Theoretical Modelling	Uni	BFE, Kt GE	**	**

	Title of Projects	Research Institute	Funding by	Volume 2002	Volume 2003
17.	Experimentelle Untersuchung von extrem dünnen Schichten (Nanoschichten) für die Katalyse (Rekombination von Wasserstoff)	PSI	ETH-Rat, KTI	*	T
18.	FUCHSIA: Fuel cell and hydrogen store for integration into automobiles	Uni	Bund, Kt FR	**	**
19.	HYDROBAR, Diffusionssperrschichten für H2-Hochdrucktanks	FH	BFE, Kt GE	**	**
20.	HYDROPOLE III (Wasserstoffforschung)	Priv	BFE, Kt ZH	*	*
21.	IEA-Wasserstoff-Programm	Ausl	BFE	*	*
22.	Photochemische und photoelektrochemische Umwandlung und Speicherung von Sonnenenergie	Uni	BFE, Bund, SNF, Kt BE	***	***
23.	Photolyse de l'eau et la production d'hydrogène et d'oxygène au moyen de l'énergie solaire	EPFL, Uni	ETH-Rat, BFE, Kt GE	***	***
24.	Projet pilote d'utilisation de l'hydrogène comme combustible pour fauteuils roulants et une tondeuse à gazon	Kt	Kt GE	-	-
25.	Solar Ammonia Power (SAP), Wasserstoff aus Ammoniak: Optimierung der Reaktions-führung und Oekobilanz	Ausl	BFE	*	*
26.	Solar Hydrogen - Thermochemical Production	ETHZ	ETH-Rat	**	**
27.	Solar Hydrogen via Steam-Gasification of Petroleum Coke	ETHZ	ETH-Rat	**	**
28.	Solarthermische Prozesse in der Kreislaufwirtschaft	PSI	ETH-Rat, BFE	*	T
29.	SOLREF (SOLar REForming) - Solar Hydrogen by Steam Reforming	ETHZ	ETH-Rat	**	**
30.	Structural studies of metal-hydrogen interactions in solid state metal hydrides	Uni	SNF, Kt GE	**	**
31.	Vorbereitung Welt-Wasserstoffenergie-Konferenz WHEC 2006 in der Schweiz	Priv	BFE	*	T
32.	Wasserstoffspeicherung in Metall- und komplexen Hydriden	Uni	BFE, Kt FR	-	**
	Diverses / Management				
33.	AD700-2 : Development of an advanced (700°C) power plant II	Priv	Bund	*	**
34.	Aluminium als Brennstoff und Speicher	PSI	ETH-Rat, BFE	-	*
35.	Beitrag an Diplomarbeit zur Wasserstofftechnik	FH	BFE, Kt LU	*	T
36.	Bereichs- und Programmleitung "Solarchemie & Wasserstoff"	Priv, Bund	BFE	**	**
37.	Druckluft - Ein Energiespeicher der Zukunft	Priv	BFE	**	*
38.	Elektrophysikalisches System zur Verbesserung der Wärmeübertragung	Priv	BFE, Kt ZH	*	-
39.	Katalytische Synthesen ausgehend von Kohlendioxid	ETHZ	ETH-Rat, BFE	***	***
40.	Materialien für nachhaltige Technologien in der Energieumwandlung und Energieein-sparung	Uni	BFE, SNF, Kt BS	***	**
41.	Optimierte Flüssiglichtleiter zum Transport von hochkonzentriertem Sonnenlicht	Ausl	BFE	*	T

* Project volume < CHF 100’000

** Project volume CHF 100’000 – 500’000

*** Project volume CHF 500’000 –1 Mio.

**** Project volume > CHF 1 Mio.

T Project terminated

Abbreviations used in Tables

BFE: Bundesamt für Energie (SFOE); PSI: Paul Scherrer Institute; Kt.: Canton; Ausl: abroad; ETH-Rat: ETH Council (council of all federal institutes of technology); Priv: private; Uni: University; Bund: Several Swiss Federal Offices combined (ARE, ASTRA, BAV, BBL, BBT, BFS, BLW, BAFU); FH: technical University; ETHZ: Swiss Federal Institute of Technology Zurich; SNF: Swiss National Science Foundation; KTI: Innovation Promotion Agency (CTI).

Annex B: Evaluation material

Evaluation of the Swiss federal Research Program “Solar Chemistry / Hydrogen”, Folder of evaluation material for the expert team, Swiss Federal Office of Energy (SFOE), Bern, September 2005

<u>Content of evaluation material:</u>

Organisation of the Swiss Federal Energy Research

- Summary of the Swiss Federal Energy Research Master Plan for the years 2004-2007, Swiss Federal Office of Energy (SFOE), Bern, March 2004
- Konzept der Energieforschung des Bundes 2004 bis 2007, Ausgearbeitet durch die Eidgenössische Energieforschungskommission CORE, Januar 2004, Bundesamt für Energie BFE, Bern, Januar 2004
- Energie-Forschung 2004, Swiss Federal Office of Energy (SFOE), Bern, Vorwort und Fortschritte der Energieforschung 2004, Seiten 1-8
- BfE_Projektliste 2000-2001; Forschung, Entwicklung und Demonstration im Bereich der Energie in der Schweiz, Liste der Projekte 2000/2001, Bundesamt für Energie, Bern, November 2002
- BfE_Projektliste 2002-2003; Projektliste der Energieforschung des Bundes 2002/2003, BfE, April 2005

Research Programme “Solar Chemistry / Hydrogen”

- Solarchemie und Wasserstoff, Konzepte für die Jahre 2000-2003 (BfE Nr. 66/4), Bundesamt für Energie, Bern, 2004
- BfE Forschungsprogramm Solarchemie / Wasserstoff, Konzept für den Zeitraum 2004-2007 Bundesamt für Energie, Bern, 2005
- BfE_Projektliste S&W 2002-2003 ; Projects of research programme „solar chemistry / hydrogen“ with financial support of SFOE (2003)
- BfE_Projektliste S&W 2000-2001, Projects of research programme „solar chemistry / hydrogen“ with financial support of SFOE (2001)
- Armin Reller, Solarchemie / Wasserstoff, Überblicksberichte zum Forschungsprogramm 2000, Bundesamt für Energie, Bern, 2001
- Armin Reller, Solarchemie / Wasserstoff, Überblicksberichte zum Forschungsprogramm 2001, Bundesamt für Energie, Bern, 2002
- Armin Reller, Solarchemie / Wasserstoff, Überblicksberichte zum Forschungsprogramm 2002, Bundesamt für Energie, Bern, 2003
- Armin Reller, Solarchemie / Wasserstoff, Überblicksberichte zum Forschungsprogramm 2003, Bundesamt für Energie, Bern, 2004
- Armin Reller, Solarchemie / Wasserstoff, Überblicksberichte zum Forschungsprogramm 2004, Bundesamt für Energie, Bern, 2005
- Publications 2000 - 2003 (annual extract form SFOE-Database), Bundesamt für Energie, Bern

Former Evaluations of Swiss Energy Research

- Audit of the PSI Solar Technology Laboratory, Final Report, International Committee G. Calzaferri, D. Favrat, G.Flamant, R. Pitz-Paal, M. Romero, A Weimer, and A. Yogev, PSI, May, 2003
- Begutachtung der schweizerischen Energieforschung der öffentlichen Hand. Bericht des Evaluationsteams des Bundesamtes für Energiewirtschaft. Januar 1993.