Final report

1.1 Project details

Project title	Silicon for solar cells – scale-up and material recycling
Project identification (program abbrev. and file)	EUDP-13-II 64013-0505
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	Danica Greentech ApS, c/o Danica, Store Strandstræde 21, 1255, København
Project partners	SiCon
CVR (central business register)	Danica Greentech Aps: 15693290 SiCon: 28950071
Date for submission	8/2-2016

1.2 Short description of project objective and results

Danica Greentech has identified a new chemical route for manufacturing of silane. The objective has been to establish research infrastructure capable of running the chemical synthesis in a new reactor concept under safe conditions, to establish gas-storage infrastructure, to analyse, test and assess solutions for recycling of side-products and to develop a business case.

All tasks has been successfully completed although delay in the installation of our new reactor made it impossible to obtain a final conclusion on the manufacturability and thereby the commercial potential of this new technology.

Danica Greentech har identificeret en ny kemisk fremstillingsmetode for silane. Formålet med projektet har været at etablere forskningsmæssig infrastruktur der gør det muligt at køre processen i en ny reaktor under sikre betingelser, at etablere mulighed for komprimering og opbevaring af gassen, at analysere og teste gassen, at undersøge muligheder for at optimere side-materialestrømme samt at udvikle en forretningsplan.

Alle opgaver er blevet succesfuldt løst, selvom installationen af den nye reaktor blev forsinket og forhindrede os i at finde en konklusion på spørgsmålet om processens egnethed for produktion og dermed om realismen bag forretningsplanen.

1.3 Executive summary

Danica Greentech has identified a new chemical route for manufacturing of silane and investigated if this method can be implemented in largescale operations and lead to a decrease in the manufacturing price for solar grade silicon and thereby solar generated electricity.

Whereas the chemical process it selves is not new, it has so far never been used in commercial scale, most likely due to difficulties in reaching a soft-spot combination of price and performance. Other technologies may provide higher purity and higher cost in larger facilities, but today in the market we see a need for manufacturing technology that can deliver sufficient purity and lower cost in smaller facilities. Our ambition with this project has been to verify our assumptions with respect to process chemistry and upscaled laboratory operation (compared to a very small scale lab experiment) in a proof-of-concept of a new reactor design, handling of raw-materials and side-streams as well as developed business concept and strategy.

During the project we successfully managed to upgrade our research facility with laboratory equipment capable of running the process at higher pressures, in larger volumes, complying with the strongest safety regulations while also adding a gas-filling station whereby large bottles of gas can be filled and transported to external partners for further analysis and test.

During the project we identified means to upgrade our waste-material and in the same process reduce the cost of pre-treatment of our main raw-material. These very promising results could result in an even lower manufacturing cost in the future, but will require additional research before it's ready to implement in our process flow.

A business case for commercialisation of technology has been developed in close collaboration with our Advisory board consisting of experience industry professionals.

The overall business opportunity is very interesting and has potential to generate turnover and profit in the billion kr. level, however additional investigations are still required before the technology is ready for commercialisation, and these activities include investigating the process conditions under more realistic laboratory conditions.

1.4 Project objectives

The project objectives follow from the Mission, Vision and Strategy of Danica Greentech:

1.4.1 Mission

To reduce the cost of PV electricity by commercialising a new low-cost manufacturing process for Solar Grade Silicon.

1.4.2 Vision

To disrupt the market for SG-Si by introducing an alternative low-cost process for silane manufacturing combined with innovative CVD processes (as opposed to the traditional methods of very large scale TCS/Siemens or Silane/FBR methods).

1.4.3 Strategy

To develop the technology until proof-of-business is demonstrated at which point external investors and partners will be invited to participate in the more capital intensive ramp-up and world-wide roll-out phase.

1.4.4 Objective

The objectives of the project team during the current phase 3 of the project has been to:

- establish research infrastructure capable of running the chemical synthesis with an updated semi-continuous reactor concept under safe conditions
- establish gas-storage infrastructure that facilitate transport of small and large quantities of gas to external partners for chemical analysis and further processing
- analyse, test and assess solutions for recycling of side-products
- test and analysis of scaled-up concepts

- validate the usefulness of the product
- develop the business case and assess the commercial potential of the new technology

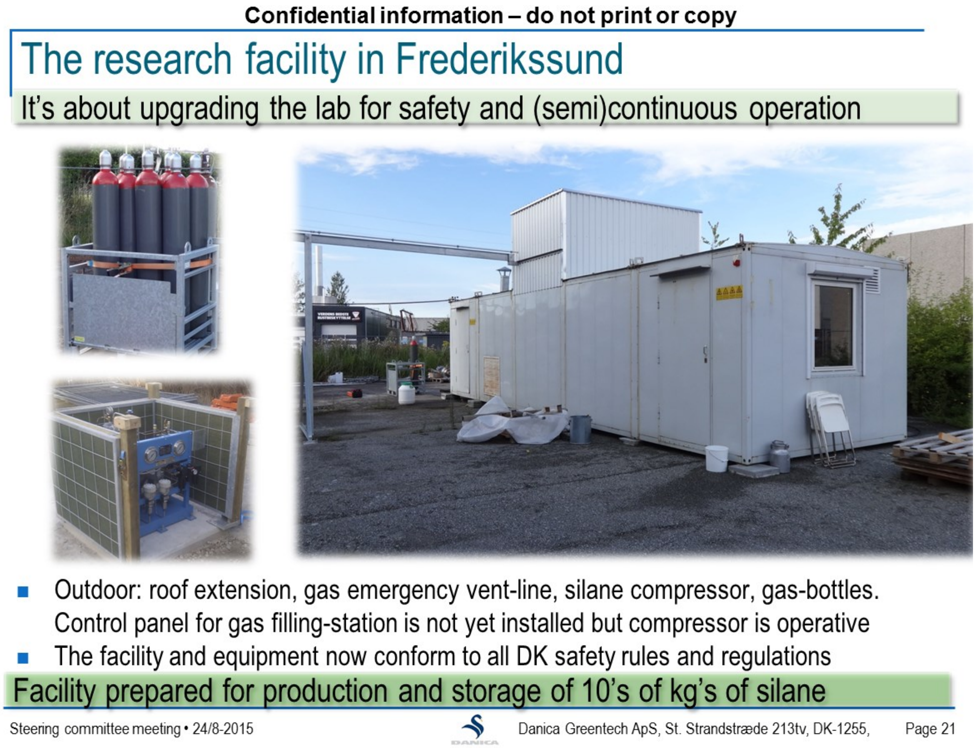
1.5 Project results and dissemination of results

During the project the team has successfully completed all tasks related to the above objectives that also are reflected in the work program.

The most challenging task has been to establish an upgrade of the laboratory infrastructure. This showed to be much more expensive, complex and time-consuming than first estimated.

Basically we just wanted to introduce a larger synthesis reactor that could be operated at a higher pressure and also allowed for semi-continuous feeding of process materials. The problems we encountered related to material compatibility (corrosion), back-diffusion of the gasses, feeding of slippery powder, liquid and gas through different feed-troughs, a specialised professional engineering company that didn't manage internal information transfer when changing their project manager more than 6 times, consequential upgrades where other equipment suddenly also had to be upgraded and modified as consequence of upgrade of the reactor pressure. And first of all extensive safety upgrades in order to comply to all safety rules and regulations including work environment, handling og pressured equipment, gas-filling stations, safety zones, environmental impact etc. etc.

In the end all equipment was successfully installed, safety checked and operated such that the team was able to demonstrate that the updated design concept is useful, despite a significant delay was observed for this part of the project.



To establish gas-storage facilities at the site also was not easy. For many months we were not able to find a vendor of gas-bottles that was approved for silane-gas. We even had to initiate a sub-project in order to perform this bottle-design and construction our-self, before we finally identified a supplier of these bottles. Also solutions to compress this explosive gas was difficult ot identify, but finally we was able to design, purchase and install all equipment required for to construct and operate a gas-filling station.

The analysis of closed-loop recycling methods was mostly done in collaboration with partners and colleagues abroad. We identified solutions to all specified problems related to recycling of our metal catalyst, and also made detailed economical evaluations of the various solutions. During this investigation we also identified a possible new route to prepare our raw-materials for the synthesis in a cheaper and more efficient way. Via a research partner in Germany we managed to generate several promising experiments that identify these new raw-materials as very promising.

The product usefulness for solar cells were tested with the help of partners at Institut for Energiteknik (IFE) at Kjeller i Norge. They received samples of our gas in gas-bottles that was filled in our facility with silane produced in our reactor, and they made chemical analysis of this gas by use of Mass-spectroscopy. The conclusion corresponds to measurements we performed ourselves, stating that the purity is of sufficient high quality to make this gas useful for the solar industry.

Development of the business case is also a task that was taken very seriously. The fundamental market conditions and opportunities has been studied in great detail, and it's possible to conclude that our technology do fill a gap in the market both technology- price and volume-wise. A detailed cost model based has been developed that is based on the chemical mass balance and estimates on both cost of raw material, power and consumables, manpower and capital expenditures. An advisory board consisting of industry professionals in the area of green energy, industrial chemistry and silane & silicon production has been established and a business strategy has been developed. One message from the advisory board is to focus on soft-money from R&D programs in the near term development phase, as the project is still not sufficient mature to attract external investors at reasonable conditions.

1.6 Utilization of project results

During this project the research infrastructure has been established and also positive indications has been obtain as to the technical feasibility and commercial potential of this new technology in addressing the need for solar silicon to reduce to cost of PV power in the future. Based on these results the company aim to raise additional private investor financing that can be leveraged by public research support in order to finalise the experimental verification of the production method under realistic conditions.

We're currently in seeking additional funding from the Eurostar, InnoBooster and EUDP programs.

1.7 Project conclusion and perspective

Due to shortage of funding, the ambitions for the actual phase of the project "Silicon for solar cells" unfortunately were reduced from the original Proof-of-business ambition to a more narrow ambition to reach Proof-of-concept. During this project we managed to successfully establish the laboratory platform and was able to perform the sufficient experimental test to be able to conclude that the concepts is useful and the usefulness of the product for the manufacturing of solar cells has been validated.

The next task in the project will be to use this laboratory platform in order to study and optimise the kinetics and yield of the chemical reactions under higher pressure and in the new reactor environment, in order to obtain a proof-of-manufacturability, i.e. to verify that the concept will also work and generate the required results when operated under realistic manufacturing conditions (continuous operation in an homogenises reactor environment).

As we’re still in a phase where the exact process conditions is susceptible for change it’s considered unwise to disclose information about the concept and operation – not even in patent applications. We therefore so far have only disclosed the details of the process to a handful of partners, potential investors and advisors (including EUDP følgegruppe) under NDA’s and we therefore have not made any external public presentation of the projects.

Annex

Relevant links

(the guidelines should be deleted – they should NOT be included in the final report)

GUIDELINES FOR FINAL REPORT

General

Depending of project type, project size and project complexity the **number of pages** in the final report may vary. For smaller **demonstration** projects the final report normally should not be more than 20 pages plus possible relevant appendices. For **research and development** projects the final report should not be more tha 50 pages.

The final report will be used for dissemination purposes and the information given in the final report should be suitable for dissemination, cf. point 1.4.

1.2 Short description of project objective and results

The short description should be in two versions:

- an *English version* and
- a *Danish version.*

Each version should be brief, not more than 600 to 800 characters.

1.3 Executive summary

Brief summary of the project and its results and expected utilisation of project results.

1.4 Project objectives

Description of the project objectives and the implementation of the project. How did the project evolve? Describe the risks associated with the project. Did the project implementation develop as foreseen and according to milestones agreed upon? Did the project experience problems not expected?)

1.5 Project results and dissemination of results

Description of main activities and technical results in the project as well as description of commercial results and expectations of the project.

Did the project succeed in realising its objectives? If not, why? Did the project give answer to the problem stated in the project proposal which the funding has been based on. Did the project produce results not expected?

Did the project so far result in increased turnover, exports, employment? Do the project partners expect that the project result in increased turnover, exports, employment?

How has project results been disseminated?

1.6 Utilization of project results

How do the project participants expect to utilize the results obtained in the project? Do any of the project participants expect to utilize the project results - commercially or otherwise? Which commercial activities and marketing results do you plan for? Has your business plan been updated? Or a new business plan produced? What future context is the end results expected to be part of, e.g. as part of another product, as the main product or as part of further development and demonstration? What is the market potential? Competition?

Do project participants expect to take out patents?

How do project results contribute to realize energy policy objectives?

Have results been transferred to other institutions after project completion? If Ph.D.s have been part of the project, it must be described how the results from the project are used in teaching and other dissemination activities

1.7 Project conclusion and perspective

State the conclusions made in the project. Try to put into perspective how the project results may influence future development.

Annex

Add links to relevant documents, publications, home pages etc.