Stem Technology Initiative by Sahara Solar Breeder Project: Chemistry and Electronics of Oxides as Stem Material for Future Energy and Environment

A. Boudghene Stambouli[1, 2, 3], S. Flazi[1, 2], H. Koinuma[2, 3, 4, 5]

[1]University of Sciences and Technology of Oran, USTO-MB, Algeria, BP 1505, EL M'Naouer, Oran (31000), Algeria. Tel & Fax: 00 213 41 62 71 63. E-mail: stambouli@ssb-foundation.com, aboudghenes@gmail.com, flazis@yahoo.fr
[2]Sahara Solar Breeder foundation
[3]ARENA: Alliance for Research of North Africa, Tsukuba University
[4]Graduate School of Frontier Science, University of Tokyo, Japan.
E-mail: koinuma.hideomi@nims.go.jp
[5]Comet Inc. Ltd., Tsukuba and Kashiwa, Japan

ABSTRACT

The energy crises and challenges around the globe in the last few decades are a major concern to all countries. Solar energy is a widely used technology nowadays due to its availability. It has no negative effects on the environment as compared to other conventional energy such as the use of fossil fuel which eventually increases the earth's average temperature and pollution. The earth's surface accepts a solar amount of 108 kWh day-to-day, that is equal to 500,000 billion of barrels of oil, i.e., a thousand times any oil reserve identified to humans. This more than adequate availability makes solar energy less costly with no pollution. Every living thing preserves its life in a pseudo-steady state flow of energy and material to form a universal cycle for regenerating its origin, i.e. stem species, from the final product in the life cycle with the aid of sun light or other external energy. People start worrying about a serious effect that may be caused by losing the energy-material balance due to the rapidly growing fossil fuel combustion. The inevitable result is the CO_2 accumulation to threaten our sustainability by the global warming effect with CO_2, which is not only anticipated but also recognised scientifically. As we could assign the stem cell to branch into every part of animals and plants, it is presumed to be possible to propose the stem concept and technology for in-organic (non-living) materials as well. Although there is a big difference in the life span, rocks, metals, and even our cosmos are aged and changed into various forms to be the most stable species on the earth, i.e. mostly oxides.

In this article, we propose the stem technology initiative for recovering the balance in our future world, where human population and energy consumption keep growing, by developing a clean global solar energy supply system coupled with sustainable social security consensus. Our strategy for initiating stem technology R & D is based on the following scenario:

1. Define stem energy and stem material;
2. Design and propose the route to stem energy initiative;
3. Bridge the stem energy and stem material technology;
4. Sahara Solar Breeder (SSB) plan as a promising stem material/energy hybrid technology;
5. Extension to Middle East and North Africa (MENA) and central Asia;
6. Future prospect: Si renaissance and High critical Temperature Superconductor (HT_cSC) transmission.

1. INTRODUCTION

The sun, a natural fusion reactor, is located far enough away to safely bring 10,000 times as much energy as we need to the earth. In principle, all the global energy demand could be afforded in the form of electricity by covering 4% of the world's desert surface with photovoltaic (PV) panels. Although various semiconductors are available for PV, we can deduce that 100 GW annual solar cell productions is the minimum requirement for covering > 30% global energy needs and that only Silicon (Si) can clear this hurdle. The serious disadvantage in PV output power fluctuation depending on the time, climate, and location, could be overcome by global PV networking with the super grid using HT_cSC cables. In addition to the well-recognised two values of vast land and sunshine, the desert has the third value, sand, for its main component, SiO_2. Sustainable energy is the key issue for developed OECD countries while the development accompanying more energy consumption is for developing countries in Asia and Africa. Our SSB project started in 2010 by the cooperation between Japan and Algeria according to the SATREPS program supported by JST and JICA in Japan [1]. The SSB plan was designed and proposed, as the most promising concrete solution for global energy and ecological issues, to the world from the Science Council of Japan (SCJ) in 2009, at the G8+5 Academies' meeting in Rome in 2009, and initiated with Algerian partners in 2010. The SSB plan [2] starts from basic material research on innovative solar Si technology and HT_cSC DC transmission. SSB may be presumed to be a quixotic dream, but the first technology for converting desert sands to solar grade Si has been verified already, for instance by the Japan-Algeria joint project (2010-2015) and the second technology of liquid nitrogen cooled superconducting dc power transmission has been going on by Chubu University group in Japan. We will make our SSB dream come true by extending our collaboration from Algeria to North Africa, Europe and Asia where Turkmenistan is particularly eager to join us. Hopefully Jordan will do so in the near future.

Research objective are summarised as follow:

1. Look forward to stem energy and material technology for sustainable development;
2. Vitalisation of oxides (CO_2, H_2O, SiO_2, etc.) as stem materials for recycling energy resources and bio-mass based on the theory of chemical

thermodynamics and new concept of artificial photosynthetic. Specific challenges will include chemical and photochemical fixation of CO_2 and H_2O photo-catalysis as well as innovative Si technology directed towards global energy future by converting desert sand into Si for electronics and solar cell;
3. Reactor and process design of micro-wave and SPS (spark plasma sintering) induced chemistry as new technology for clean energy materials;
4. High throughput screening of the above objectives using the combinatorial technology.

Questions to be asked:
1. Has PV reached a grid-parity level of energy generator?
2. What, why, and how is the key technology to shift the global system into new paradigm?

Answers to the above questions:
1. Stem concept and technology initiative for sustainable development;
2. SSB Plan for global energy and environment future. cf. Desertec?
3. Design strategy and assemble Backgrounds potentials.

2. BEYOND SIEMENS PROCESS: DIRECT CARBOTHERMIC REDUCTION OF PURIFIED SIO2

With the spread of solar cells, the silicon for the solar cells class has come to be manufactured in large quantities. 80% of solar cells are crystal and related silicon. A new silicon production process is required. Our strategy is to make the new energy supply chain from the desert as the infinite energy reserve. The SSB plan was designed and proposed to the world from the Science Council of Japan in 2009, and initiated with Algerian partners in 2010. SSB has two core technologies to develop:
1. Converting the desert sands into reasonably efficient solar PV material or new material to replace the conventionally used fossil fuels with the aid of solar energy and
2. Transmitting the PV electricity globally by using high-Tc superconducting network [3]

The Sahara Solar Energy Research Centre (SSEC) [4] has been pursued for 5 years as SSB initiative: by those who have been devoting to innovative research on clean energy materials, devices, systems, and applications, with focuses on new silicon technology to enable large scale and low cost PV system and on preliminary data collection for PV operation in the desert and super grid: global scale electric power transmission network.

Beyond Siemens process is aimed at converting SiO_2 directly into Si by carbothermic reductions. Carbothermic reduction process for purified silica has potential to decrease energy-cost drastically and innovatively. However, the control of total reactions is not easy, because this reduction reaction consists of a lot of complicated reaction paths. For the optimization of the sub processes such as SiO and SiC formation, the control of many parameters such as reaction temperature, partial pressure and composition is required. We developed a new concept reduction furnace using the combinatorial method in order to investigate the carbothermic process for silicon reduction [5]. The combinatorial methods are powerful tools to optimise a complicated chemical reaction. Here, we demonstrate reduction furnace using the combinatorial method for reduction of silica process as shown in figure 1 [6].

PV has energy conversion efficiency 10 times higher than photosynthesis as depicted in figure 2 [7]. Global energy problem looks to be a matter of zero exergy oxides that is, no energy available for conversion to useful work. For the further spread of prospective PV cell, we need:
1. Lower cost;
2. Improved energy efficiency
3. Suppression of CO2 emission (When making Si, a lot of CO2 is emitted as shown in figure 3) [8]

A new silicon production process is therefore required.

3. TOTAL SIEMENS PROCESS AND DIRECT CARBOTHERMIC REDUCTION

Conventional Siemens Si process starts from silica rock that is reduced with charcoal into 98 % pure metallurgical Si by applying 11 kWh electric energy for 1kg-Si production. To improve the purity of Si to semiconductor-grade (> 10 nines), about 100 kWh/kg-Si energy must be consumed. By starting from silica sands, we can expect to produce solar grade–Si (6 nine purity) at a reduced production energy to 20-40 kWh/kg-Si. Since 10,000 t (10 kt) solar silicon can afford 1 GW solar PV panels, which is equivalent to a nuclear power station, there are a lot of deserts, silica mines and seashores in the world to supply sufficient amounts of SiO_2 for producing as much solar silicon and Si-PV power station as 1 Mt/y and 100 GW/y, respectively. With the spread of solar cells, the silicon for the solar cells class has come to be manufactured in large quantities. 80% of solar cells are crystal and related silicon. SSB project is proposing an innovative breeding research on the silicon industry for the solar cells from desert silica resources: Reduction Process of SiO_2 by Carbon. The total reaction is simple presented as follows [9]:

$SiO_2 + 4C \rightarrow Si + 4CO\uparrow$

But, thermodynamically the reaction splits to...

$SiO_2 + C \rightarrow SiO\uparrow + CO\uparrow$ ⇒ Generation of SiO

$2SiO_2 + SiC \rightarrow 3SiO\uparrow + CO\uparrow$ ⇒ Generation of SiO

$SiO + 2C \rightarrow SiC + CO\uparrow$ ⇒ Generation of SiC

$SiO + SiC \rightarrow 2Si + CO\uparrow$ ⇒ Generation of Si

$2SiO \rightarrow SiO_2 + Si$ ⇒ SiO disproportionation

SiO [*Gas phase Dimer ～ hexamer*
Solid phase: nano-level disproportionation

The H-radical effect, after experimentation, between the current Siemens and our new approach is depicted in figures 4 and 5.

3.1 Innovative breeding research on the Silicon Industry for the solar cells from desert silica resources

A Sahara Solar Energy Research Centre (SSERC) project has been pursued for 5 years as SSB initiative: by those who have been devoting to innovative research on clean energy materials, devices, systems, and applications, with focuses on new silicon technology to enable large scale and low cost PV system and on preliminary data collection for PV operation in the desert and super grid: global scale electric power transmission network. Total Siemens process and direct carbothermic reduction process are shown in figure 6 [10]. B, P-free Si can be made from high-purity Silica by Carbon using this new proposed process.

The reduction equipment, now available at the University of Sciences and Technology of Oran (USTO-MB), is shown in figure 7. The design has been made in Japan with the collaboration of PhD students from USTO-MB (A. Boucetta and R. Benioub) [11].

3.2 Direct deduction of high purity silica by microwave heating

Innovative manufacturing process technology for SOG-Si loom up recently, that is highly purified Desert Sand deducted in one time by microwave heating System, consumption of thermal energy is relatively low 20kWh/kg (Targeted). But products of silica's deduction are required extremely high temperature reduction process about 2000°C by conventional heating system. Therefor thermal source of heating system, the refractory and crucible will be exceed 1650°C then the molten silicon absorb impurity from refractory and crucible. Also the crucibles loose durability.

An attempt on one time deduction experiment, which is heating up by microwave heating system, has been carried out at the SEAVAC Company in Kyoto (Japan) [12]. The microwave available to heat up Silica and carbon black on an elective basis like the material of high dielectric constant and or high conductivity, less to heat refractory and crucible, ergo microwave heating system accomplish high speed and high efficiency heating without heat up refractory and crucible, just focus on the specimen (see figure 8).

A Comparison of the energy consumption in different production processes for solar grade silicon is depicted in table 1 [13].

Goal of SOG-Si manufacturing by Microwave Heating Reduction:

1. Developing High Trough put SOG Si manufacturing system→ 1Ton/ Year
2. Purity: SOG Si, >6N (Si Purity <99.9999%) B,P <1ppm
3. Performance, Efficiency >16%
4. Thermal energy consumption < 10KWh/Kg (SOG-Si)

4. CONCLUSION OF ULTIMATE SUSTAINABLE RENEWABLE ENERGY WITH SOG SILICON WAFER

Innovative breeding research on the Silicon Industry for the solar cells from desert silica resources has been presented. Bore and Phosphor free Si can be made from high-purity Silica by Carbon and the reactions are explained by thermodynamic diagrams and reactions. Goal of SOG-Si manufacturing by Heating Reduction is:

A. Cost: < $10.00/Kg
   1. Thermal energy consumption at Reduction of Silica, without Crucible
   2. SOG-Si Wafer be in economical production
      a) Trina Solar: Spin coating no vacuum
      b) 1366 Technologies Inc.: Lean manufacturing just cell itself, no cutting loss
B. Efficiency : >16% mean
C. Lifetime: > 20 years
D. Location of Installation: Desert area
E. Environment: Fewer emission and Clean Manufacturing Operation

China SOG Si price transition is depicted in figure 9 [14]. Socio-Economic and Technological Analysis of our new proposed technology shows how it is efficient and useful for a sustainable world.

References

[1] A. Boudghene Stambouli and H. Koinuma, A primary study on a long-term vision and strategy for the realisation and the development of the Sahara Solar Breeder project in Algeria. Renewable and Sustainable Energy Reviews 16 (2012) 591– 598.

[2] http://www.ssb-foundation.com

[3] S. Yamaguchi, A. Iiyoshi and H. Koinuma, DC Superconducting Power Transmission Line as the most Efficient Energy Transport & A Proposal of Electric Transmission from Algeria to Europe. The 5th Asia-Africa Sustainable Energy Forum Jointly with7th International Workshop on Sahara Solar Breeder. May 11th– 13th, 2015, University of Tsukuba, Japan.

[4] A. Boudghene Stambouli, S. Flazi and H. Koinuma, Renewables within the Algerian Energy System: Status, Experiences, Challenges and Opportunities in the Framework of the Sahara Solar Breeder Project. EFEA 2014: 3rd International Symposium on Environment-Friendly Energies and Applications, 19-21 November 2014, Supmeca, Saint-Ouen, Paris, France.

[5] H. Koinuma, K. Tsubouchi, H. Fujioka, K. Morita, A. Stambouli, M. Sumiya, K. Itaka, Y. Furuya, K. Miura, S-Y. Jeong, Feasibility study of Beyond Siemens process for solar silicon from desert sands. Material Research Society MRS 2011 Fall Meeting Symposium Africa (Zimbabwe, 06-10/12/ 2011)

[6] H. Koinuma and A. Boudghene Stambouli, Science and Technology Cooperation between Japan and Algeria Initiated from University of Science and

Technology of Oran-Strategy and Current Status of Sahara Solar Breeder (SSB) Plan-. Book of Sustainable North African Society, Exploring Seeds and Resources for Innovation. Editors: H. Isoda, M. Neves and A. Kawachi. Published by Nova Sciences Publishers, Inc. New York (2014).

[7] H. Koinuma K. Tsubouchi, K. Itaka, A. Stambouli."Sahara Solar Breeder project", McGraw-Hill 2013 Yearbook of Science and Technology, pp.325-330 (2013)

[8] A. Boudghene Stambouli, S. Flazi and H. Koinuma, Sustainable development by Sahara Solar Breeder plan: Energy from the desert of Algeria, a Green Energy Dream grows in the Sahara. SolarTR-2 Solar Electricity Conference and Exhibition November 7-9th , 2012, Antalya, Turkey

[9] K. Itaka, High-purity Carbothermic Silica Reduction for Solar-Grade Silicon. The 5th Asia-Africa Sustainable Energy Forum Jointly with7th International Workshop on Sahara Solar Breeder. May 11th – 13th, 2015, University of Tsukuba, Japan.

[10] H. Koinuma, Progress and potential of SSB project for sustainable energy future. The 5th Asia-Africa Sustainable Energy Forum Jointly with7th International Workshop on Sahara Solar Breeder. May 11th – 13th, 2015, University of Tsukuba, Japan.

[11] A. Boucetta and R. Benioub, Innovative breeding research on the Silicon Industry for the solar cells from desert silica resources. The 5th Asia-Africa Sustainable Energy Forum Jointly with7th International Workshop on Sahara Solar Breeder. May 11th – 13th, 2015, University of Tsukuba, Japan.

[12] Masayoshi Shimizu, Direct deduction of high purity silica by microwave heating. Shimizu Densetsu Kogyo Co., Ltd.

[13] Reference from Silicon for the Chemical and Solar Industry IX Oslo, Norway, June 23-26, 2008

[14] Tokuyama Corporation 2013 annual report

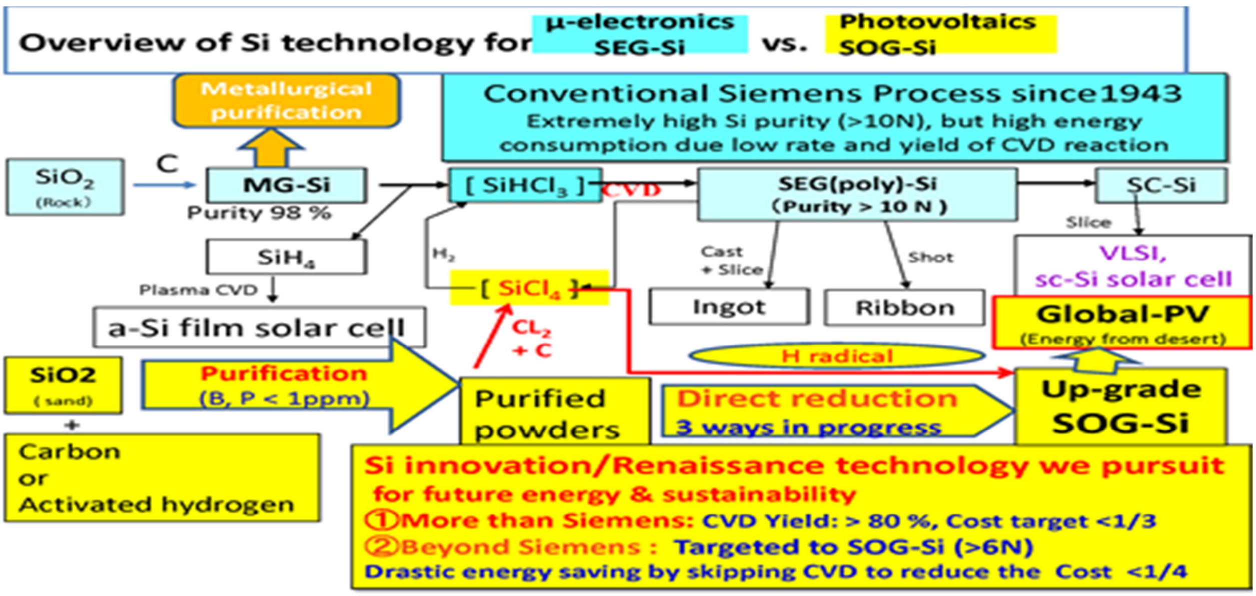

Figure 1: Si innovation/Renaissance technology we pursuit for future energy & sustainability

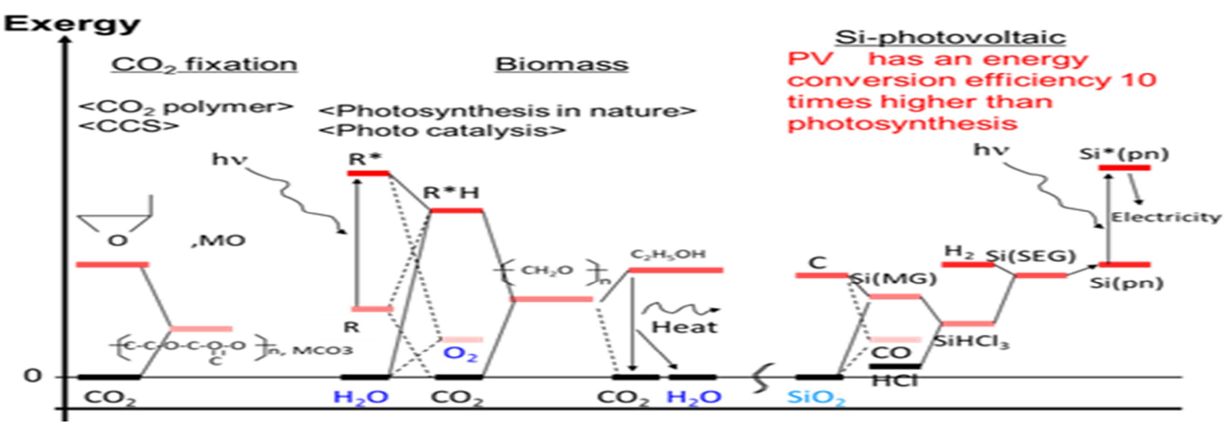

Figure 2: Life cycle of materials driven by solar energy

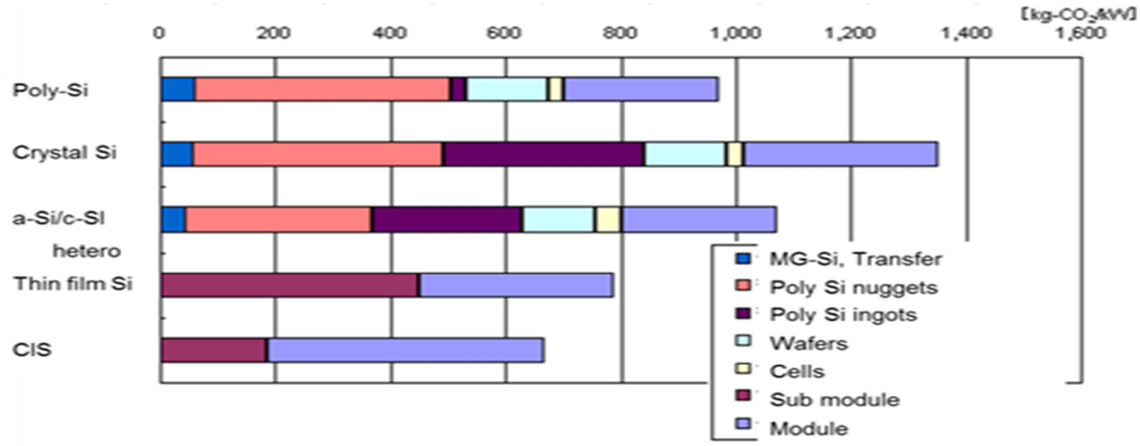

Figure 3: CO_2 emissions by solar cell module manufacture

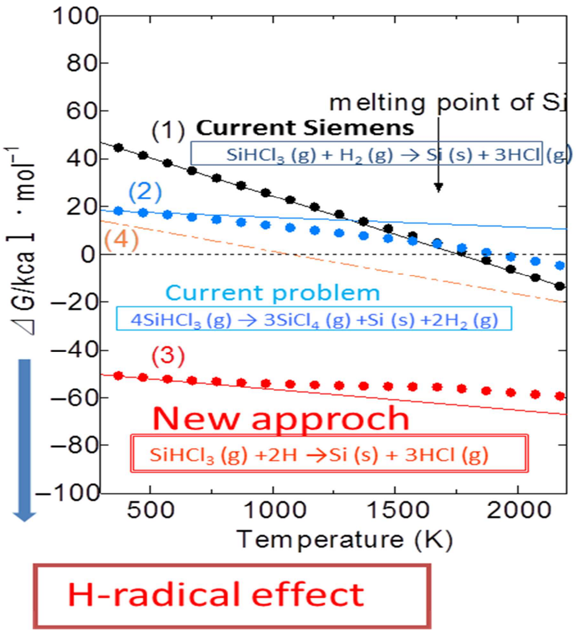

Figure 4: H-radical to fabricate SOG-Si in high yield

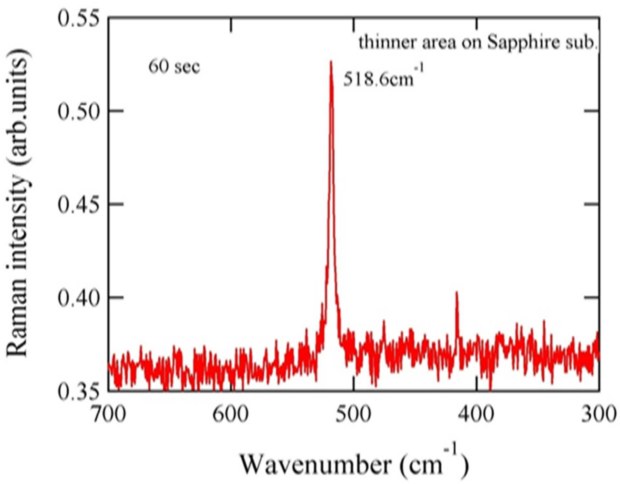

Figure 5: Results from Raman experimental technique

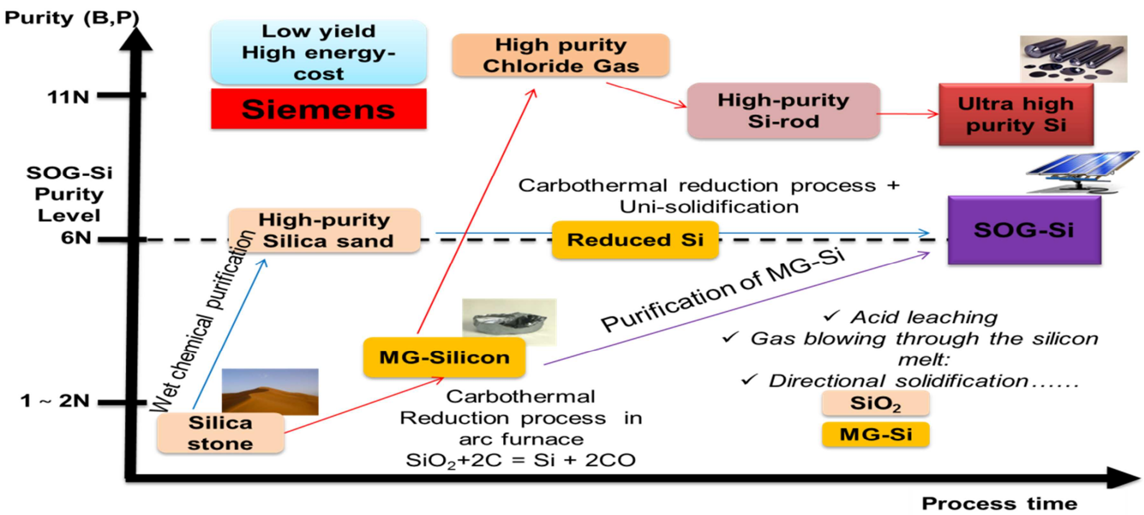

Figure 6: Total Siemens Process and direct carbothermic reduction process

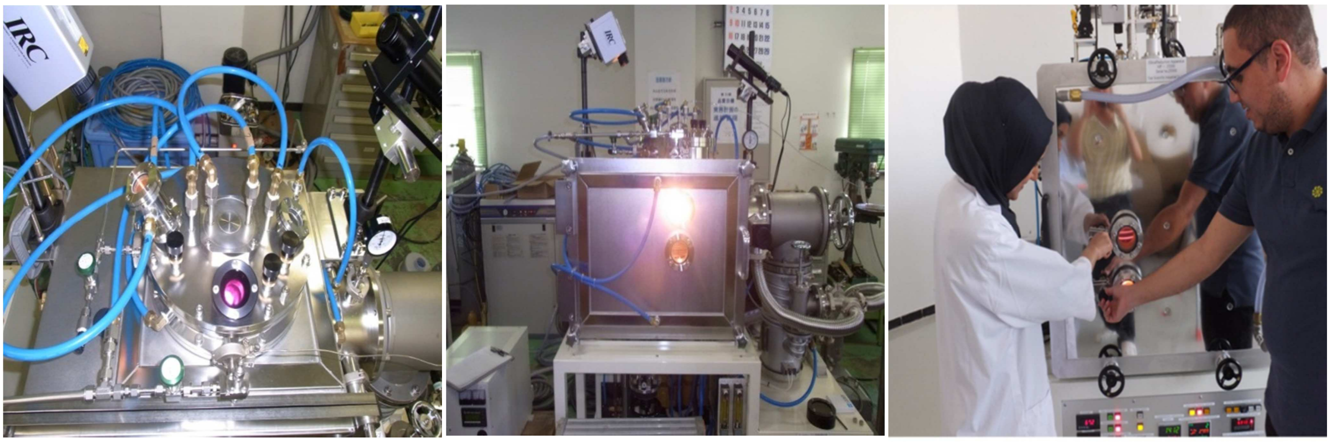

Figure 7: Silica Reduction Furnace (Collaboration between Hirosaki University and USTO-MB)

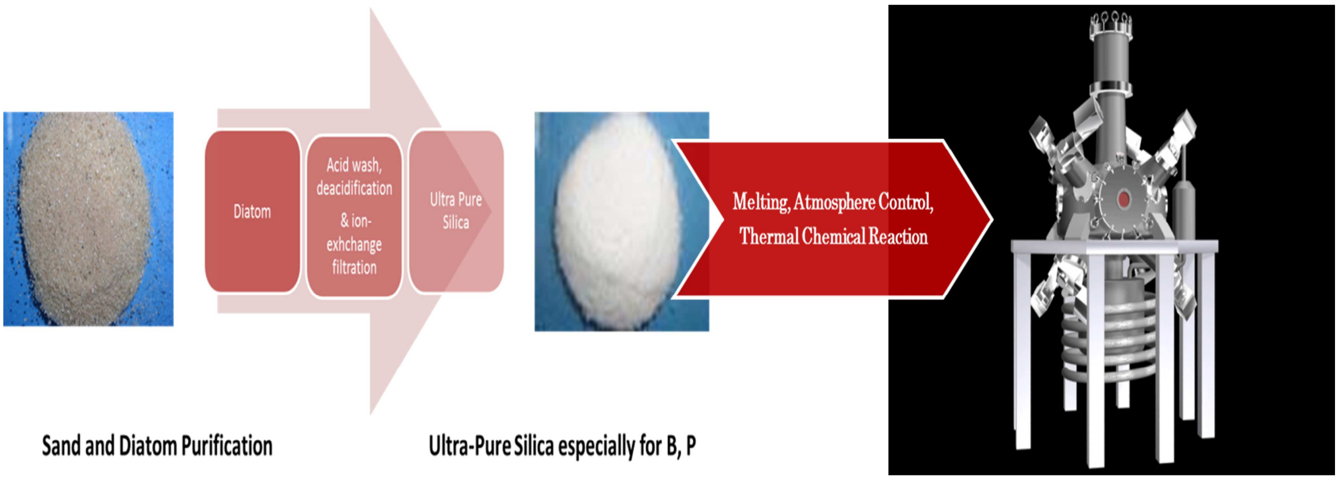

Figure 8: Silica Reduction Concept using microwave heating (One time Reduction by Microwave Heating)

Table 1: Comparison of SOG Si manufacturing Thermal Energy Consumption

Process		SIEMENS Process	Elkem Process	Microwave Heating System
Metal Grade Si	Feed Stock	Crystal Silica Graphite	Crystal Silica (Rock, Graphite	
	Manfctring Equipment	Electric Arc Furnace	Electric Arc Furnace	
Chrolide Silane（SiHCl3,SiCl4) Gas Mfg.	Feed Stock	Metal Grad Silicon	Metal Grade Silicon	
	Purification Process	Chlorosilane		
High Purity (Single, Poly) Crystal Silicon Purification	Feed Stock	Silane Gas	Slag Treatment	High Purified Amorphas Silica, Diatom
		Hydrogen Gas	Leaching	Graphite
	Manfctring Equipment	CVD Bell-jar Reacor	Solidification	Microwave Heating Reduction
Purification				One way cooling Segregation Method
Purified Silicon		(High Purity Crystal Silicon Semi Conductor, High Purity SOG-Si)	SOG-Si	SOG-Si
Quality of Purified Silicon		12N, 9N	>6-8N	>6-8N
Electricity Consumption [kWh/kg(SOG-Si)		120	30	10
CO_2 Gas Emission（ton/5000ton SOG-Si)		500,000	50,000	6,000
Cost of SOG-Si (at $0.1/kWh)		$27/Kg	$9/Kg	$4/kg
Presumed Net Price		$30/Kg,	$18/Kg	$10/kg

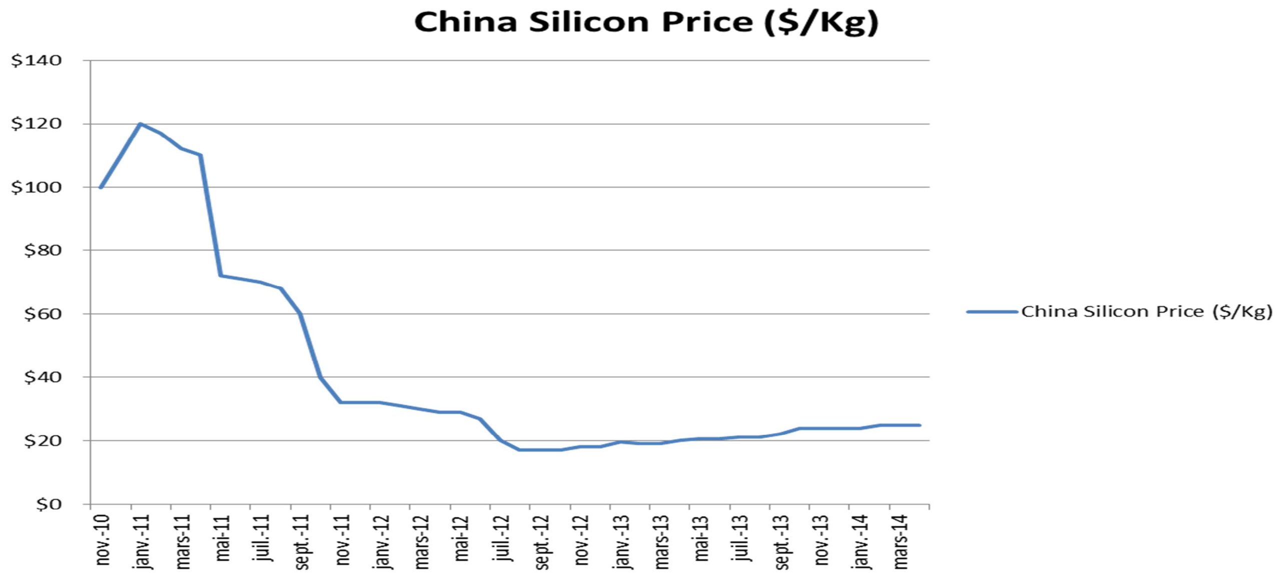

Figure 9: China SOG Si Price transition