Solar Energy towards Grid-Parity

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During 2009 the solar market will move from supply limited to demand limited, shrinking from 5.47 GW ($36 billion) installations in 2008 to 5.29 GW ($29 billion) in 2009. Consequently large over production of cells and modules is expected mainly due to funding difficulties and the reduction of governmental subsidies. Silicon availability which seemed as the limiting growth factor has become irrelevant as module players seek to cut inventory. And finally, modules' prices have gone down to a level that enforces the manufacturers to develop cheaper manufacturing processes at higher yields.

While this shakeout disturbs the solar community overall, and a number of companies and even some technologies will fail, these events may be used to make the critical step forward in solar to energy conversion technologies. We refer to the significant cost reductions that feed the hopes that by 2011 solar energy prices will come down into "grid-parity" range, marking a new era for the solar industry and the world.

How can solar energy reach "grid-parity"? We will present the leading solar technologies including crystalline silicon PV, high concentrating photovoltaics (HCPV), thin-film silicon (TF-Si), cadmium telluride (CdTe), copper indium (gallium) diselenide/disulfide (CIGS/CIS), dye sensitized solar cells (DSSC), organic PV (OPV) and concentrated solar thermal power (CSP). Concepts, status, challenges and new approaches will be discussed.

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Inorganic/Organic Hybrid Photovoltaics: Si / Organic Molecule / Metal Inversion Layer Solar Cells

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Si inversion layer solar cells were proposed 4 decades ago as a way to make Schottky barrier cells a practical, simple & cheap route to photovoltaics, using Metal-Insulator-Semiconductor (MIS), and Metal-Insulator-Semiconductor Inversion-Layer (MIS-IL) structures. In principle, such solar cells are constructed from a semiconductor and adjacent metal layer. By choosing a suitable metal-semiconductor combination, e.g., n-type (p-type) semiconductor with high (low) work function metal, the semiconductor surface next to the metal can become (type-)inverted, creating a p-n junction underneath the metal electrode. However, this can happen only if the interface of the semiconductor is well passivated, and direct metal / semiconductor interactions are prevented, to reduce the surface (i.e., interface) state density.
Recently we have shown that simple alkyl monolayers, self-assembled onto Si, can provide such a passivation. An additional positive surface dipole, originating from the molecular monolayer, effectively reduces the Si electron affinity and allows a Hg metal contact (with a relatively low work function of 4.5 eV) to induce inversion upon intimate contact with the n-Si.[1]
Here we build on our earlier work and use a room-temperature methanol/hydroquinone treatment, first suggested by Takato et al.,[2] to passivate the surface of 2.8 Ω.cm n-Si. Both Fermi level and band bending of the treated Si are obtained from contact potential difference (CPD) measurements with a Kelvin probe. The results indicate that this treatment is superior to the alkylation in terms of surface passivation, while, at the same time providing an even stronger surface dipole.
Dark I-V and C-V measurements were done with a Hg drop electrode. Comparing the results with numerical calculations clearly indicates that the Si interface is strongly inverted. I-V measurements under white light illumination yield an 80% Fill Factor (FF) and 0.54 V open-circuit voltage (V_{OC}). As these are the minority carrier recombination-limited values for a sample of the doping level that we used, they show the potential of this approach for metal-polycrystalline semiconductor photovoltaics.

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Can up & down conversion and multi-exciton generation improve photovoltaics?

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Repeatedly proposed directions to improve photon management in solar cells are up-conversion (UC) and down conversion of photon energy. In UC two photons with energy $h\nu<E_G$ (the band gap) create one photon with $h\nu>E_G$; in down-conversion one photon with energy $h\nu\geq 2E_G$, yields two photons with energy $h\nu \geq E_G$. Thus, for a single junction cell with E_G=1 eV, all $0.5\leq h\nu<1$ eV photons can participate in UC and all $h\nu\geq 2$ eV photons in down-conversion.

A more flexible alternative to optical down-conversion, in terms of possible efficiencies is photon-induced multiple exciton generation (MEG). In this case one photon with energy $h\nu\geq nE_G$ yields *n* electron-hole pairs. We note that MEG has a disadvantage in that MEG has to occur in the photvoltaically active material, while down conversion (and UC) can be done in optical elements that are separate from the PV cell. We showed that if we combine MEG with UC the **theoretical** efficiency of an ideal cell rises from 30% (detailed balance limit) to 49%.

HOWEVER, with what we estimate to be optimistic, maximal realistic efficiencies (25% for UC; 70% for MEG) this limit becomes slightly less than 40%, i.e., ~1.25 times the theoretical efficiency of conventional single band gap cells.

While these results do not detract from the fascinating fundamental scientific challenge to make UC and MEG simple and cheap ways to improve PV, they show that UC + MEG are unlikely to lead to the type of **radical** decrease in the **{(cost) / (efficiency × lifetime × yield)}** ratio that we need to allow large scale economic introduction of solar cells. Such **reality checks** should be considered when evaluating the short–term promises of these and other options for improved photon management. Indeed, seemingly mundane issues such as finding ways to lower the costs of multiple solar absorber arrangements and/or multi-junction systems, may well deserve attention, also at the more fundamental level.

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Preparation and Investigation of Silicon PIN Solar Cells

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Application of solar energy to generate electricity is the main issue in recent years. Direct conversion of solar energy into electricity using the photovoltaic effect seems to be successful; however, there are plural limitations to the efficiency of this process. Thus, finding ways to decrease the energetic losses and increase the efficiency conversion becomes the main goal of researchers. One of these ways is to apply intrinsic semiconductor thin film to widen the depletion region of the diode structure.

PIN based Photovoltaic structures on single-crystalline silicon were built using the sheet plasma deposition method. Thin films of intrinsic silicon and indium oxide were grown in series on the surface of conventional silicon wafers (p-type) with the surface oriented in the [111] direction. In order to remove natural silicon oxide film coating on the wafer surface, all samples were wet etched and cleaned before deposition. Then, silicon thin film was deposited using DC sputtering from a silicon target in argon atmosphere. After that, indium oxide thin film was grown on top of the previous film by sputtering of pure In_2O_3 also at an atmosphere of pure argon.

Optical and electrical properties of the deposited films were investigated using laboratory equipment. It was found that the bandgap of the intrinsic silicon layer is equal to 1.3 eV and bandgap of the emitter layer (In_2O_3) equals to 3.04 eV. Resistivity of the obtained emitter layer was equal to $5.24 \cdot 10^{-3}$ Ω·cm. Efficiency of the photovoltaic structures was no more 0.2 %. This may be explained by non-clean conditions during the thin films preparation. The prepared samples show feasibility to grow photovoltaic devices using the sheet plasma sputtering method.

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Sb_2S_3-Sensitized Nanoporous TiO_2 Solar Cells

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One of the challenges for alternative energy is to produce photovoltaic (PV) cells that are cheap, efficient and reliable over a reasonable lifespan. A fairly new concept is the ETA (Extremely Thin Absorber) cell: A thin layer of an absorbing material is deposited on a porous, transparent n-type semiconductor with a high internal surface area, while the pore volume is filled with a transparent p-type semiconductor. This concept is similar to a solid-state dye-sensitized solar cell, but with a semiconductor as the light absorber instead of the molecular dye.

We found that chemically deposited Sb_2S_3 shows promising photovoltaic behavior as the light absorbing material in an ETA cell, with TiO_2 nanoparticles as the electron conducting mesoporous film, and CuSCN as the pore-filling hole conductor. A thin layer of $In_x(OH)_yS_z$ – chemically deposited between TiO_2 nanoparticles and Sb_2S_3 – promotes the nucleation of Sb_2S_3 on TiO_2.

A SCN^- solution treatment of the cell before the CuSCN decreases its resistivity, thus improving cell performance. Cell aging also decreases cell resistance, resulting in an increase in the short-circuit current (J_{SC}) and fill factor (FF).

We achieved solar conversion efficiencies up to 3.4% from these cells. We also carried out some preliminary operational stability measurements and found the cells to be reasonably stable over 3 days of operation under load.

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Progress in commercialization of Dye Solar Cells at 3GSolar

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Dye solar cells (DSCs) offer a low cost alternative to conventional photovoltaic silicon cells on the basis of materials (bulk titania powder in place of high purity silicon) and process costs (simple screen printing and oven treatment in air in place of vacuum deposition in a clean room facility). Dye cells are based on a thin (typically 15 micron) porous layer of nanocrystalline titanium dioxide, coated with dye and impregnated with an iodine-based redox electrolyte Projected dye cell materials costs and capital costs for economic production are a fraction of those typically associated with silicon and thin film cell production lines. Furthermore, small research dye cells have been reported as having a promising >12% conversion efficiency under one sun illumination. Many developmental dye cells, however, have scale up, efficiency and stability limitations that have hindered the move to production. An in-house silver-free, robust, corrosion-resistant current collecting grid has been developed by 3GSolar that allows scale-up to large area cells having increased stability and with reduced wastage of active area. The primary product is to be a 55W, 32 cell module for solar home systems in developing countries. Full commercial size, prototype glass-based cells of area 225 sq cm have been built and assembled into multicell prototype PV modules. Performance data including recent endurance runs of cells at 85 degrees C will be presented.

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Hybrid operation of OST3 gas turbine with concentrated solar radiation and bio-fuel

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The operation of a modified helicopter gas turbine engine with concentrated solar radiation was successfully demonstrated in the Solgate project [1], [2], [3]. The system consisted of a 250 kW gas turbine, two volumetric and one tube receiver with a thermal power of 350 kW each, and a turbine driven generator connected to the public electric grid. For start-up and control reasons, this system always operated in hybrid mode with kerosene.

As the Spanish legislation applies only for power generation systems operating with nearly 100% renewable "fuel", the Solgate concept had no prospects for commercial application. To overcome this problem, the turbine fuel system was modified to operate with bio- diesel instead of kerosene. This was successfully demonstrated in 2008/9 at the Plataforma Solar de Almería in Spain.

Due to the delicacy of a gas turbine fuel system and the unique characteristics of the bio-diesel, the turbine is usually started with kerosene and later is changed over to bio-diesel. The procedure is reversed before the engine is shut down. This was the first time ever a gas turbine operated in a hybrid solar bio-fuel mode. No influence on the turbine operation has been detected while inspecting the turbine operation curves. Pressurized air, exiting the gas turbine compressor and entering the combustor, was heated by the receivers to 840C, as obtained power reached 225kW, of which about 195kWe is due to solar heat and 30kWe to bio-diesel combustion.

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Spatial Solar Flux Measurement on a CSP Tower Receiver

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The LUZ Power Tower (LPT) Solar Receiver Steam Generator (SRSG) system is a customized solar boiler based upon conventional power-plant boiler technology. The most significant difference is that the SRSG is designed in an "inside-out" configuration – conventional boilers receive their energy from an internal heat source via convection and radiation; the LPT SRSG receives its energy from the solar flux projected from the solar field. This configuration exposes the SRSG panels externally, enabling BrightSource to have an unobstructed view of the irradiated boiler panels (both Evaporator and SuperHeater) surfaces. By integrating multiple measurement technologies (cameras, sensors, etc.), with online real-time analysis and modeling algorithms, BrightSource has developed the capability of measuring a real-time 2D map of the flux incident on the receiver; a significant accomplishment for full-scale power-station boilers.

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Matching Large Solar Photovoltaic Power Plants to the Israeli Electricity Grid

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Conventional electricity grid systems employ slow-ramping turbines for base-load supply, and fast-ramping turbines for load-following purposes. In the absence of storage facilities a large PV system can provide support only for the load-following turbines, because the slow turbines cannot be ramped up and down sufficiently quickly to take advantage of fluctuating solar input. Furthermore, solar input can only save energy for the fast-ramping turbines to the extent that there is overlap between solar output and load requirements. This paper examines such overlap for an entire year of hourly IEC data and identifies the limits to solar penetration as function of the so-called grid *flexibility factor*. It quantifies the possible improvements to be expected from employing various sun-tracking technologies and from distributing PV plants around the Negev.

המשבר הכלכלי בראי הקיימות

ד"ר אברהם ארביב

סגן המדען הראשי, משרד התשתיות הלאומיות

המשבר הכלכלי העולמי הנוכחי נותח מזוויות רבות, ותחזיות שונות מתפרסמות לגבי חריפותו והתמשכותו. אולם נראה שזווית אחת נזנחה, והיא הזווית הסביבתית.

תוך הסתמכות על שתי עבודות מקיפות שהתפרסמו בשנים האחרונות, נראה שאפשר להסביר את המשבר הכלכלי הנוכחי מנקודת המבט של פיתוח בר-קיימא, על-ידי ניצול-יתר של משאבים. הניתוח מביא למסקנה הבלתי נמנעת שקצב הצריכה של המדינות המפותחות איננו בר-קיימא, ויצטרך לרדת; לכן יש לראות את המשבר הכלכלי הנוכחי כתחילתו של תיקון, שיישאר עמנו לאורך זמן.

אין זה אומר בהכרח שצפוי לנו אסון, אם נבין את המצב וניערך בהתאם, כי רמת החיים אינה קשורה באופן הדוק לקצב הצריכה. מכשירי מדיניות בתחום האנרגיה שקידומם לצערנו מתעכב עשויים לסייע לשמירה על רמת החיים למרות המשבר, עד שיוכל להתרחש שינוי פרדיגמה מוחלט ביחס למקורות האנרגיה ולטכנולוגיות להמרתה.

הערכה לפוטנציאל כושר ייצור חשמל פוטו-וולטאי מבוזר בישראל

רן ורדימון
המחלקה לחומרים ופני שטח, מכון ויצמן

מטרת המחקר

מטרת המחקר היא לבחון את הפוטנציאל של ייצור חשמל פוטו-וולטאי באופן מבוזר על שטח גג בנוי במדינת ישראל. בזמן האחרון, יש עניין ציבורי רחב ביישום טכנולוגיות בתחום האנרגיות המתחדשות לייצור נתח חשמל משמעותי מסך החשמל המיוצר כיום. ניתן לעשות זאת בשתי דרכים: על ידי הקמת תחנות כוח גדולות בשטחים לא מיושבים או על ידי שימוש בשטחי גגות פנויים לייצור חשמל סולארי באופן מבוזר. האפשרות הראשונה תגרום בהכרח לצמצום רב בשטחים טבעיים ולפגיעה קשה בסביבה. לדוגמא, כדי לייצר 10% מצריכת החשמל הפרטית של מדינת ישראל נדרשים 24 קמ"ר, זהו שטח עצום במיוחד עבור מדינה קטנה כמו ישראל, שבה שטחים הם משאב יקר.

שימוש בשטח גג לא מנוצל לייצור חשמל פוטו-וולטאי באופן מבוזר תמנע את הפגיעה בסביבה, תקטין אובדני יעילות הנגרמים כתוצאה מהסעת החשמל ואף תקטין את קליטת החום של הבניינים. עם זאת, עדיין נשאלת השאלה: האם קיים מספיק שטח גג פנוי עבור ייצור כמות חשמל משמעותית?

להלן מספר מאמרים מהעת האחרונה, הממחישים את חשיבות הנושא בסדר היום הציבורי:

- פורסם המכרז להקמת תחנת הכוח הסולארית השלישית בנגב, דה מרקר
- דו"ח: כך תיראה רשת החשמל הסולארי בנגב, ynet
- "תחנות כוח סולאריות זו הונאת הציבור", דה מרקר

שיטת המחקר המדעית

להלן מספר שלבים שבוצעו בכדי לענות על שאלת המחקר:

Fig. 2 - Orthophotos of a neighborhood in Ramat Gan. Right photo includes the buildings' polygon layer.

- ניתוח מדידות קרינה שנתיות, שהתקבלו מהשירות המטארולוגי, לקבלת ממוצעים שנתיים ולניתוח התפלגות הקרינה מבחינה גיאוגרפית.
- פנייה למאגר המידע הגיאוגרפי (GIS) של הלשכה המרכזית לסטטיסטיקה, לחישוב שטח הגגות הכולל בארץ ובמספר ערים מרכזיות.
- סקירת ספרות מקצועית ופנייה לחברות התקנת פאנלים לקבלת מידע בנוגע ליעילות טיפוסית של מודולים פוטו-וולטאים הזמינים כיום בשוק וכן להערכת שטח הגג הפנוי מתוך סך שטח הגג.

מסקנות

תוך שימוש בפאנליים סולארים בעלי יעילות של 16% ובשימוש בשטח גג פנוי בלבד ניתן לייצר באופן שנתי כמות חשמל השקולה **30%** מצריכת החשמל הכוללת של מדינת ישראל. זהו אחוז משמעותי ביותר ומעודד. לא זאת בלבד, אלא שמסתבר שאחוז זה הוא גבוה מחסם כלכלי המאפשר ייצור יעיל של עד 10-15% בלבד מכלל הצריכה של המשק באנרגיה סולארית. המסקנה הברורה היא שאין מחסור בשטח גג עבור ייצור אנרגיה סולארית בישראל.

	units	value
Rooftop area	km^2	234.3
Available rooftop area	km^2	70.3
Solar production potential	TWh	14.8
National electricity demand	TWh	50.1
Ratio of potential/demand	%	30

Table 3 – Summary of national results of rooftop area and solar production potential compared to national electricity demand

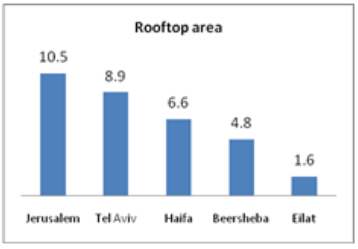

Fig. 3 – Rooftop area in major cities in Israel. Values are given in km^2.

Supplying Israel's Electric Energy Demand: a Life Cycle Analysis approach

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Israel's electric power demand has increased by more than 50% between 1997 and 2007. Though Israel Electric Company met the increase in demand by adding more turbines to an existing power plant in recent years, power production capacity today barely meets the nation's power demand. About 70% of the electricity production in Israel comes from coal combustion, and so the offered solution to the predicted increase in demand is based on expansion of the existing coal power plant in Ashkelon. In this study we chose to use a Life Cycle Analysis (LCA) approach to assess this solution along with advanced alternative solutions (i.e. wind turbine, PV cells, pumped storage). For this purpose we compared the production of 1 kWh by different solutions in three major aspects: energy return on investment (EROI), energetic cost, and environmental impact. The LCA limits included the following segments: station construction, raw materials mining and transportation, maintenance, and operation. The assessments were based on case studies of similar scenarios available at the Eco-invent database together with Eco-indicator 99 platform. The results show that in terms of EROI the coal power plant is 10 times more effective than the alternatives; on the other hand, in terms of energetic cost the alternative solutions are 10 times more efficient than the coal power plant production. The environmental costs show that power production from coal impacts human health, ecosystem quality, and mineral resources at least 8 times more than the alternatives. Although significant computation deviations might have occurred, they are unable to mask the vast difference between the options. In face of these differences, the aspects discussed should be accounted for in any future planning of electric power supply.

The First Phase of Israel's Feed-In Tariff: An Economic Evaluation and Reflections on the First Year of Operation

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Many countries have adopted various forms of subsidy for alternative energy, solar in particular, as a way to encourage them as they gradually become more competitive in price with conventional energy supplies. Recent (2008) legislation is the first to bring these kinds of broad subsidy to Israel, in the form of the Feed-In Tariffs (FIT) common in many countries in Europe and elsewhere. The first phase of these tariffs in Israel is for individual households with a maximum of 15 kWp, and for businesses, with a maximum of 50 kWp. Thirty percent of the 50,000 kWp committed in this first phase is to come from the smaller systems, the remainder from the larger ones, with much larger systems anticipated in subsequent phases.

The talk describes and extends the analysis done in a recently completed MA thesis. This consisted of a cost-benefit analysis of the economic feasibility (Pay Back Period, Net Present Value, Internal Rate of Return) of producing electricity under this new tariff arrangement for a 4 kWp private system and for commercial systems of 50 kWp with and without two-dimensional tracking. Actual costs and other typical parameters are used, and various scenarios and sensitivity tests are applied.

The economic analysis under 2008 conditions shows that the smaller private systems have a payback period of around 15 years if optimally operated. The larger commercial systems without tracking also have a payback period of about 15 years and allow some degree of profit if operated optimally and carefully (orientation, cleaning) in areas of higher insolation (southern Israel.) Two-dimensional tracking systems, however, are reported to boost productivity significantly for an additional investment of 20%. In high insolation areas, this leads to payback periods of 12-13 years and more substantial returns on investment. Here investors can profit from these government subsidies. (Overall, the first phase of the FIT will entail a subsidy of 120 million shekel.) The recent financial crisis, which has decreased the costs of solar systems by about 20-30%, significantly increases the economic viability of solar systems.

In addition to this analysis, we briefly discuss the motivations of the decision-makers sponsoring this FIT arrangement and those investing in systems under it, its contribution to preparing the legal and institutional groundwork for broader adoption of solar energy when this begins to approach grid parity, and evaluate the contribution of the FIT to the advancement of solar energy in Israel.

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פתרון רוב בעיות האנרגיה בישראל

פרופ' אמ. דן זסלבסקי

טכניון

בינואר 2009 היתפרסמה הכרזה של שר התשתיות אז בנימין אליעזר. היא דנה בהכרזת הנגב כתשתית לאנרגיה סולרית . כמו כן הייתה הכרזה על כך שהמדינה תשלם תמורת תפוקה של יחידות של אנרגיה סולרית.ההכרזה היא שעד שנת 2020 יפחיתו ב % 10 את השימוש בדלק. הכרזה הזו נלעגת, ויותר מזאת מדאיגה מאד.

1. לנגב יתרון שולי על חלקי הארץ האחרים בקרינת השמש.
2. עלות חשמל מאנרגיה סולרית בתאים פוטוווולטאים היא מעל פי 10 גבוה מעלות של מקורות אחרים. עלות של אנרגיה סולרית תרמית גדולה פי 5. שטח הקרקע הדרוש לשתיהן הוא בערך פי 40 יותר גדול ומקדם העומס לא עולה בדרך כלל על 0.2 .לפחות בשני שלישים של היממה יש צורך להשתמש בדלק או במערכת אגירה יקרה ביותר. ספק אם מותר לקרוא למקור זה אנרגיה ירוקה.
3. כבר לפני קרוב ל 3 שנים נערכה עבודה יסודית שהראתה שניתן להקטין בארץ את השימוש בדלק , ולהתחיל מייד ובטכנולוגיות ידועות ולהגיע לחיסכון של 50-60% , זאת ללא אידיאולוגיה. זה פשוט מפני שזה כדאי מבחינה כלכלית, אפילו בהשוואה לשימוש בדלק.
4. לבסוף, הפיתוח של הטכנולוגיה הנקראת "ארובות שרב" הסתיים והוא עשוי להביא כמעט ליציאה שלמה מעידן הדלק. הטכנולוגיה הזאת מנצלת מפירות השמש- אוויר חם ויבש המסופק כל ימות השנה , יומם ולילה. עלות ייצור החשמל היא בין הנמוכות ביותר הידועות כיום. החישוב של תחנת כוח ביוטבתה מצביע על עלות ייצור של 2.5 סנט לקו"ש בריבית של 5 % ו3.9 סנט לקו"ש בריבית של 10 % . בזה אומנם מצטיין הנגב ובעיקר אזור הערבה. הפוטנציאל בארץ הוא פי כמה מכל צריכת החשמל ונוסף לכך יש לטכנולוגיה 12 מוצרי לוואי. בין מוצרי הלוואי התפלת מי ים בחצי המחיר וכדי הכפלת המים בישראל, גידולים להפקת דלק לתחבורה וכן גידול דגי ים בפוטנציאל ענק. הפוטנציאל בעולם הוא 15-20 פעם כל צריכת החשמל כיום על הגלובוס וזאת במסגרת העלויות הנמוכות.

האומנם התנהגות זאת של מוסדות המדינה נובעת מבורות? קשה להאמין. מי שמטפח בכל מחיר את האנרגיה סולרית לחשמל הן חברות הנפט ואין זה מיקרה. האם גם כאן ישנו אינטרס שגובר על הכול?

מצורפת חוברת " גישה כוללת לפתרון בעיות מים ואנרגיה". ניתן יהיה להשיג אותה באתר של ISES

The main aspects of reactants selection for solar hydrogen production from water via thermal chemical redox cycles

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Potential application of concentrated solar energy is thermal chemical redox cycles for hydrogen production from water using different metals. Such cycles usually consist of two steps: metal hydrolysis followed by metal oxide reduction or thermal decomposition.
The paper describes the main aspects of reactants selection ensuring effective, reliable and safe operation of the solar and hydrolysis reactors.
Thermodynamic analysis indicates that metals with a lower molecular weight-to-valence ratio with stronger Me-O bonds demonstrate better hydrogen productivity and both higher conversion and heat releasing during the hydrolysis reaction. However they require higher temperatures or multiple steps for their oxides reduction. Experimental results presented for boron, magnesium, zinc, tin and cadmium confirm the thermodynamic prediction that the easier the oxidation (hydrolysis) step, the more difficult is the reduction step and vice versa.
An element, which can satisfy all optimal requirements for hydrolysis and reduction steps, does not exist and a compromise is inevitable.
The elements with higher heat of oxide formation, lower molecular weight (magnesium) and also higher valence (boron) demonstrate excellent hydrogen productivity per gram of reactant. However their oxides reduction is difficult and requires multi-steps. Zinc powder hydrolysis (micron size) demonstrates 90% conversion and good kinetic. Its reduction chemistry is simple and can be realized in two ways: carboreduction using bio-carbon (charcoal) at acceptable temperature level of about 1100°C with 85-90% conversion, or direct thermal splitting, which requires temperatures above 1700-1800°C, does not demonstrates high conversion but it is CO_2 free. Tin oxide splitting requires temperature above 3000°C, but carboreduction with charcoal enables full conversion with fast kinetic at temperatures of around 900°C . This can provide practical solution to the reactor with acceptable longevity. Tin hydrolysis process is less productive and significant slower than hydrolysis of boron, magnesium and zinc because of its low exothermic heat, high molecular weight and the back reaction occurs at relatively low temperature which suppresses the hydrolysis kinetic as the temperature increases. But in spite of these difficulties, tin hydrolysis can reach 90% conversion during 2 hours in batch reactor with temperature increase up to 550°C at atmospheric pressure. Comparing with other metals, CdO splitting can be realized at relatively low temperature of 1400-1500°C, its charcoal reduction is successfully performed at temperatures below 950°C and CO reduction can be completed below its melting point (321°C). The main problem of Cd based redox cycle is the hydrolysis step. Besides disadvantages inherent to tin hydrolysis, cadmium has high vapor pressure at temperature above melting point. This leads to very low productivity, low conversion and significant metal losses during the hydrolysis step. The way to suppress the vaporization and back reaction is to raise the pressure to 20-30 bar or more with significant excess of water vapor which complicates the fabrication of the hydrolysis reactor, taking also into account the operating temperature of 500-600°C. Safety issue is also associated with the cadmium cycle.

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CO_2 reforming of Methane in a directly irradiated solar reactor

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Solar energy is intermittent in nature and is not uniformly available around the globe. Therefore energy storage and transport are crucial for any wide-range application of solar energy. When carbon dioxide is catalytically reacted with methane, syngas, consisting of CO and H_2 is produced. This is an endothermic reaction with high enthalpy change (~250 KJ/mol). Syngas can be stored and transported to the user site, where the reaction is reversed in a methanation stage, generating heat to power any engine. The methane and carbon dioxide are regenerated at this stage and are returned to the solar plant to start another closed-loop cycle. A solar volumetric reactor, for CO_2 reforming of CH_4, was tested at the Solar Tower of the Weizmann Institute as part of the development of chemical storage of solar energy. The reactor was based on previous experimental work with a volumetric receiver. The main parts of the reactor were a conical quartz window and a "porcupine" base which served as the heat transfer area. Fig 1 shows a schematic representation of the "porcupine" reformer reactor.

A specially developed ruthenium catalyst was used on the "porcupine" heat transfer area. The test conditions were CO_2 to CH_4 ratio, about 1.2, and total flow rates 100-235 slpm. The maximum temperature was not allowed to exceed 1450^o K. The maximum conversion of CH_4 reached 85%. The total energy absorbed was 10.3-18.2kW. The thermal energy part was 2.3-4.5 kW and the stored chemical enrichment was 7.5-13.7kW. The results indicate that this type of volumetric reactor can be used for solar energy storage using CO_2 reforming of CH_4 and further work aimed at improving the total efficiency of the system is in progress.

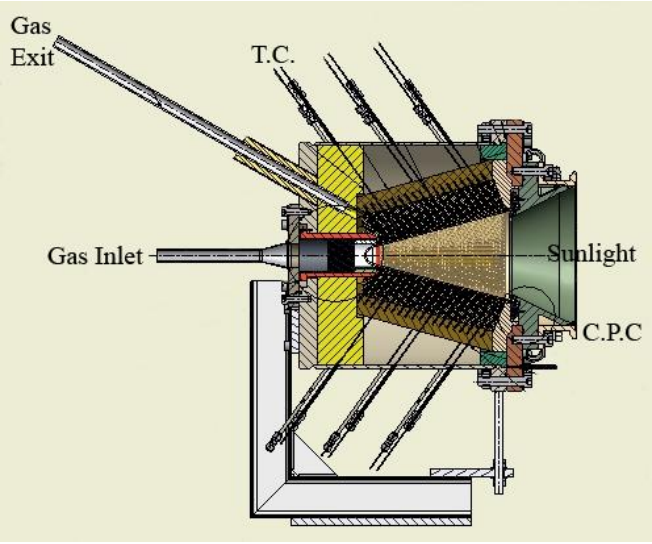

Fig 1: A schematic representation of the "porcupine" reformer reactor.

Bio-fuels from wet organic waste by solar super-critical water gasification

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Thermo-chemical gasification of biomass and other organic materials, in particular wet organic waste, is a promising direction for producing renewable fuels. Performing the gasification under conditions near the critical point of water (374°C, 221 bars) can offer several advantages, including: lower temperature relative to conventional gasification; using water as solvent and reactant in addition to its role as carrier fluid; and complete conversion of the organic matter to combustible gaseous fuel without formation of tars and other undesired products. The product fuel contains mostly hydrogen and some methane, and in addition water vapor (can be condensed and recycled) and CO_2 (can be separated and sequestrated). The fuel can be used either by combustion or by conversion to electricity in a fuel cell. The Super-Critical Water Gasification (SCWG) process requires heat input at an appropriate temperature of around 400°C or higher. The process can be 100% renewable if the source of this heat is a solar collector field, using trough or tower technologies that are capable of achieving the needed temperatures.

We have developed a thermodynamic simulation to model different configurations of solar SCWG fuel production and power generation cycles. The simulation has been validated against known results from the literature. The goal of the simulation is to optimize the performance of SCWG cycles, and to determine the cycle thermodynamic conditions such as pressures, temperatures, flow rates, and biomass loading for optimal operation. The simulation shows that this solar-assisted renewable fuel production combined with power generation can lead to high overall efficiency. Conversion from the heat input (caloric value of the biomass and solar-derived heat) to electricity can be in the range of 40—60%. The performance is sensitive to several operational parameters, including the temperatures, pressures, and configurations of process equipment.

In parallel, we are developing an experimental reactor system to validate the gasification process performance for different kinds of organic feedstock under supercritical water conditions, with and without a catalyst, and as a function of reactor operation conditions (temperature, pressure, residence time, and biomass loading).

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High Temperature Electrolysis of CO_2

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Substitution of energy produced from fossil fuel by renewable alternatives has becomes more and more important issue. Unfortunately, the most of technologies produce energy in form of electricity. Although easy for direct use and immediate transportation, electricity almost inappropriate for even short term storage on industrial scale. Therefore development of effective method for renewable energy storage becomes more and more important.
The storage of energy in form of chemical bonding or, by other words, in form of fuel is most promising method for our opinion.

The high temperature electrolysis of CO_2 could be solution for solar energy storage. Increasing of electrolysis temperature lead to substitution of required electric energy by heat. The solar-to-heat efficiency of solar installations significantly higher than solar-to-electric efficiency. Therefore higher overall efficiency of solar-to-fuel conversion could be reached. Unfortunately, up today electrolysis CO_2 was performed only up to 950C
In this work we test possibility to perform electrolysis of CO_2 to CO at temperatures up to 1400C

A furnace-based apparatus for the measurements of high temperature electrolysis of CO_2 was designed and built and is presently used for the experiments. Schematic of the test apparatus is shown in figure 1.

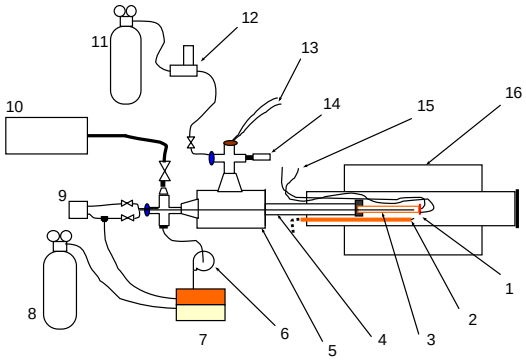

Figure 1. Schematic drawing of experimental apparatus.

As shown in the figure 1, the tested membrane (1) is stuck on the end of Alumina (Alsint) extension tube (3) and placed in the hot zone of furnace (16). The metallic extension tube (4) connects the Alumina tube to chamber (5). This chamber could be ev2-acuated by vacuum pump (10) and filled by a selected gas from cylinder (11). Pressure controller (12) is used to maintain constant pressure in chamber (5) and on the inner surface of membrane. Independent pressure measurement is performed by gage 14. A four-wire method is used to perform electric measurements. Power and sensing wires from the outer surface of membrane (15) are stretched out between the furnace's and extension tube. Power and sensing wires from the inner surface of membrane (13) go through an electric feed-through. Micro-compressor (9) is used to mix and circulate the working gas and prevent uneven concentration build up near membrane during the experiments. Gas composition measurements are performed by a Gas Chromatograph (7).

Automatic sampling is performed with the GC pump (6). Temperature measurements are performed by LJ-type thermocouples (2) attached to the main oven extension tube (made of Alumina/Alsint) and to the membrane (1). Electric measurements are performed either by a Novocontrol electrochemical impedance analyzer, for AC methods, or by a Keithley power-source meter 2611 for DC methods. Both units utilize the four-wire scheme.

Results

During experiments following measurement were performed: I-V characteristic of electrolytic cell at different temperatures and CO concentrations; Impedance spectrometry at at different temperatures and CO concentrations; actual electrolysis of CO_2 at different temperatures and current densities.

The overall cell resistance was calculated on base of I-V characteristic, distinguishing between resistance of Anode, Membrane and Cathode resistance was performed on base of impedance spectrometry. Electrolysis efficiency was calculated from data on I-V during electrolysis and from direct measurement of CO concentration as function of time.

Evaluation of electrolysis efficiency could be given on example of data from experiment at 1250C. The value of above 80% in wide range of CO concentration and current density of 50mA/cm^2 was observed, see figure 2.

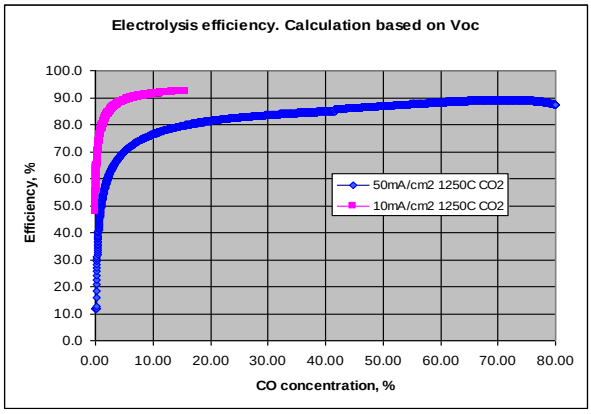

Figure 2. Electrolysis efficiency. Calculated on base of open circle voltage (Voc) and overall voltage measurement.

If solar-to-electricity efficiency is 20% and solar-to-heat efficiency is 70% then overall solar-to-fuel efficiency appears 24%. For comparison the efficiency of water electrolysis at ambient temperature with industrial electrolyser (75% efficiency) under same conditions appears 15%.

Intermediate Conclusions

1 Electrolysis of CO_2 at least up to 1400C is possible

2 High electrolysis efficiency could be reached at high temperatures.

3 Significant improvement in solar-to-fuel efficiency could be achieved by using proposed technology.

4 Analysis of materials currently used for membrane and electrodes suggests room for efficiency enhancement.

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PCM–based Storage System for Solar Energy Plants

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Thermal Energy Storage (TES) technologies are required for efficient, cost effective solutions in various heat process industries and especially for solar power plants. Common TES technologies that are developed nowadays might be classified to either sensible heat, latent heat or thermo-chemical storage. The present study provides an efficient latent heat storage system based on a phase change material.

Phase change thermal energy storage is based on the large heat of fusion of some Phase Change Materials (PCM, e.g., paraffin waxes, inorganic salts). Typically, in this type of energy storage applications the phase of the PCM changes from solid phase into liquid phase during charging of thermal energy, and from liquid back to solid phase while discharging the stored thermal energy. The major obstacle that impedes efficient discharge of the energy is the very low heat conductivity of all relevant PCMs, the rate of energy release becomes very low as the thickness of the solid phase increases.

A unique approach of using an appropriate insert (Patent pending) within "storage pipes" is presented. The heat conductivity through the solid PCM is improved approximately by 10 fold. These "storage pipes" may be applied in the typical tubes and shell, very effective heat exchanger concept of structure.

The heat conducting paths, obtained by the insert, maintain good heat conductivity despite the rapid solidification of the PCM at the periphery near the walls of the pipe. Consequently, the stored thermal energy is rapidly delivered and the freezing and melting cycles are substantially shortened. This will allow the use of well known PCMs as Sodium Nitrate for commercial applications like solar power plants.

The concept and results of simulations for melting and solidification of PCM with the assistance of several inserts would be presented. The rate of heat transfer would be compared to the classical capsule design.

30kW_{th}h pilot plant design and major characteristics would be presented as well as the concept of a commercial module.

Other advanced thermal storage technologies would be compared to the proposed approach with a prospective on their chance to become commercial

* At present on Partial Sabbatical leave at Solel Solar systems

Solar-powered systems for cooling, dehumidification and air-conditioning

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The possibility of providing cooling and air conditioning by means of energy from the sun has attracted Man's attention since the early development of solar technology. The greatest demand for cooling occurs when the solar radiation is most intense, thus making its use all the more attractive. Growing demand for air conditioning in recent years, particularly in hot and humid climates, has imposed a significant increase in demand for primary energy resources. With suitable technology, solar cooling can help alleviate, if not eliminate the problem.

The existing methods may be divided into two categories: Closed-cycle and open-cycle systems. The former include mainly absorption systems; the latter include both solid and desiccant systems.

Absorption systems are currently available commercially in different sizes and capacities. The most common are single-effect systems used mainly to provide cooling using waste heat or another form of low grade heat at about 85^{o}C. These systems can be applied directly for solar cooling, by combining them with an array of flat-plate collectors to supply the heat. Such a project was implemented already in the early 1980's at the Tel Hashomer hospital, supplying 200 TR (700 kW).

Desiccant systems are essentially absorption systems operating in an open cycle, where the humidity contained in the air serves as the refrigerant. A system of this type using LiCl-water is currently operating at the Technion.

The seminar will describe current trends in solar cooling, dehumidification and air conditioning, and will consider the closed-cycle and open-cycle alternatives.

The Analysis of UVB radiation at the Dead Sea and Its Application in the Treatment of Psoriasis

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Abstract

The Dead Sea basin offers a unique site to study the attenuation of the solar ultraviolet radiation, as it is situated at the lowest terrestrial point on the earth, about 400 m below sea level. In view of it being an internationally recognized center for photoclimatherapy of various skin diseases, it is of interest to study its UV intensity and attenuation as a function of wavelength relative to other sites. In order to provide a basis for inter-comparison of the solar radiation intensity parameters measured at the Dead Sea, a second set of identical parameters are measured simultaneously at a second site (Beer Sheva), located at a distance of ca., 65 km to the west and situated above sea level (the difference in altitude is approximately 700 m). The existing database, containing solar global, UVB and UVA at both sites, is composed of measurements from January 1995 to the present. In May 2009 the meteorological station at Neve Zohar (Dead Sea basin) was upgraded with the addition of a tracking UVB meter, viz., the measurement of normal incidence UVB. The results of this on-going research project will be discussed on two levels: (1) the analysis/inter-comparison of the solar global, UVB and UVA radiation at the two sites; (2) the relevance of these findings with regard to the success of photoclimatherapy at the Dead Sea medical spas.

The manuscript on which this abstract is based can be accessed from the on-line journal at the following website: http://deadseaarava-rd.co/il/

Solar-Driven CO_2 Reduction Using Conjugated Photo-Thermal-Electro-Chemical (PTEC) Process

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One of the most important and challenging problems facing humankind is the abundant, low-cost production of potent fuels, which can be used in intrinsically clean energy processes, that is, in processes whose net discharge has zero emission of green house gases and other pollutants.
The general goal of the proposed study is to combine photo, thermal, electric and chemical (PTEC) processes to develop a new method that would maximize the efficiency and conversion rate of solar radiation to chemical potential in the form of CO_2 reduction to CO and O_2. The carbon monoxide can then be used directly as a gaseous fuel (e.g. in power plants) or converted to methanol or hydrocarbons. The CO_2 generated during the burning of these fuels is trapped, returned to the solar power plant and reduced again.

The proposed process uses concentrated solar radiation for reducing CO_2 to CO in a series of coupled energy conversion steps, at temperatures of 800°C – 1400°C:

Step 1. Concentrated sunlight heats the electron source – a Thermionic cathode causing it to release electrons.

Step 2. Electric field is generated from the heat supplied by the concentrated sunlight to provide the electrons with the right energy for dissociating CO_2 molecules via dissociative attachment.

Step 3. The electrons and preheated CO_2 gas enter the main chamber where the Dissociative Electron Attachment (DEA) reaction

$$CO_2 + e^- \Rightarrow CO_2^- \Rightarrow CO + O^-$$

takes place, producing CO and O^-.

Step 4. Additional CO_2 is dissociated by high-temperature electrolysis as it reaches an electrode which is in contact with an oxygen conducting membrane

Step 5. The CO molecules exit the system, while the negative oxygen ions are drawn to the anode and reach it by traveling through a ceramic membrane. Upon reaching the anode the oxygen ions release their excess electrons, combine to form O_2 molecules and exit the system, while the electrons are recycled back to the cathode.

The present, ongoing project has two main objectives:

(i) Derive the relations and calculate the theoretical and achievable efficiency of a system, which uses the PTEC process to produce CO.

To investigate experimentally a high efficiency electron source which uses the thermionic effect, operating in a $CO_2/CO/O_2/O^-$ gas surrounding.

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