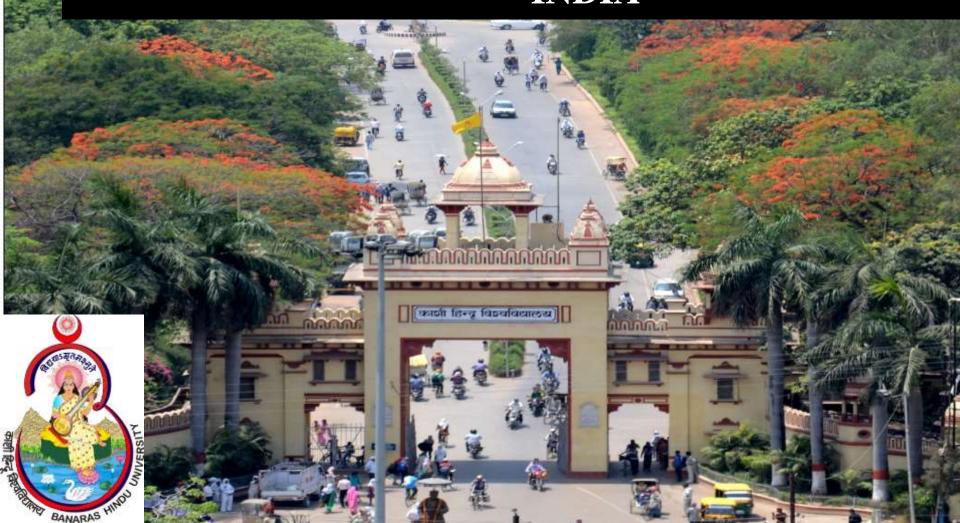
BRICS... ENERGY c/o Dr. S.V. Shirinskii MPEI Russia (25 JUNE 2020) Banaras Hindu University INDIA







- Banaras Hindu University is situated in the holy city of Varanasi
- Founded: in 1916 ,by the great visionary, Pandit Madan Mohan Malviya,.
- Area of the main campus is about 1400 acres
- A satellite campus of the university area of 2700 acres.
- The university comprises:
- 5 Institutes
- 16 Faculties
- 150 Departments, spanning a vast range of subjects pertaining to most of the branches of humanities, social science, technology, medicine, science, fine arts and performing arts.

- It has 6 centres of Advanced Studies, 10 Departments under Special Assistance Programme and a large number of specialized Research Centers.
- BHU houses the largest museum among the Indian universities, which is a treasure trove of exhibits
- The Institute of Medical Sciences of the University houses the largest trauma centre of the country and an additiona ¬ 1000 bed hospital.
- The University family consists of about 32000 students, (including students from developed countries)
- About 2000 teachers.
- A large number of students from about 60 countries all over the world come to study



Number of students:
Undergraduates:

- Postgraduates:M.Phil:
- Ph.D.:
- Diploma:
- Certificate:

41 3,497 2,998 362

14,649

9,120

• Total:

- Students (Male); 19,392
- Students (Female): 11,275
- Total no. Of students: 30,667





- International Students:
- Male: 417
- Female: 186
- Total: 603 (from 54 countries)
- url of the Web page of the University: http://www.bhu.ac.in/

- Theme: ENERGY
- Banaras Hindu University(INDIA)

• Summary:

- The details about BHU have been uploaded to the BRICS NU website and are now accessible
- BHU has floated 4 courses on Energy for BRICS NU partners:
- **1.** Post Graduate Diploma in Non Conventional Energy sources
- 2. Certificate Course on Clean Coal Technology
- **3. Energy Resource Management**
- 4. Post Graduate Course in Energy Economics
- 5.RESEARCH.....including collaborative efforts with BRICS 15 PROJECTS

The progress of project proposals on Energy is summarized below

Total projects Prepared:08Projects Agreed upon by BRICS partners:05Projects under Consideration/:03Being Explored:03

- The BHU Energy Group attended the various web conference hosted by BRICS NU
- BHU will be solar energy driven campus/ zero energy campus shortly and this project is already in place
- In addition numerous emails have been sent by the interested BHU faculty to potential BRICS NU partners abroad but most of them have not been responded to. It is requested to develop structures to facilitate the collaborations among BRICS nations.



Points of Discussions

- To find interested potential universities for the courses we have floated
- To explore the possibility of making our courses more meaningful of attractive
- To find potential collaborators among the BRICS NU programme in the various fields of energy that we have competence and we also have interested faculty for joint bilateral and multilateral projects
- To explore possibility for student and faculty exchange. Possibility of student exchange at various levels, viz. undergraduate, post graduate and research levels to be explored
- To explore possibilities of joint research supervision among the partners of BRICS NU





Collaborative projects proposed: Eight Projects



EightProjects EightProjects 1st Project: Hydrogen Energy: Production ,Storage and Applications



1.Collaborative project proposed: HYDROGEN AS A NEW RENEWABLE, CLEAN AND CLIMATE FRIENDLY FUEL;ITS PRODUCTION;STORAGE; AND APPLICATIONS. PI:Prof ONSrivastava BHU..Varanasi INDIA Collaborating Institution:Prof 1AlexenderY.Ramenskiy Moscow ..Russia 2.Prof.Helton Jose Alves..Universida Federal do Parana Brazil.



Effects of nano size mischmetal and its oxide on improving the hydrogen sorption behaviour of MgH₂

T. Sadhasiyam 43, M. Sterlin Leo Hudson 47, Sunita K. Pandey*, Ashish Bhatnagar⁴, Milind K. Singh⁴, K. Gurunathan⁴, O.N. Srivestave^{4,4}

* Nydrogen Storoge Millisien Model MPARE Project Unit, Rodrogen Zoarge Canter, Department of Provids, Newards Hinds Orisersity, Varunasi 211005, India Department of Nonzience and Technology, Alapapor University, Kanalhald 62000, India

Department of Physics, General University of Tamil Nath, Thinssene 40004, India

PHYSICAL CHEMISTRY

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Excellent Catalytic Effects of Graphene Nanofibers on Hydrogen Release of Sodium alanate

Zhao Qan^{6,12} M. Stoble Lee Baalan⁴ Humanlas Bagbahanik³ Bidyi H. Schenhar,² Becomp Pathal⁴ C. Necota Analas⁴ Anders Riempin¹²⁴ Nitre Johansen^{2,2} D.N. Stronberg^{4,0} and Raper Alage^{4,12}

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Structural and hydrogenation studies of ZnO and Mg doped **ZnO** nanowires

Jai Singh, M.S.L. Hudson, S.K. Pandey, R.S. Tiwari, O.N. Srivastava"

Hadrogen Energy Centre, Ont or Hassacheren & Technology, Department of Plance, Reserve Study University, Veterand 211005, India

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M. Sterlin Leo Hudson, Himanshu Raghubanshi, D. Puhazhaelvan, O.N. Srivastava" rescience and furbrategy (vist, Department of Physics, Inverse Hindu Deterryity, Venenael 201010, India

ABSTRACT

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Synthesis, characterization and hydrogen storage behaviour of AB₂ (ZrFe₂, Zr(Fe_{0.75}V_{0.25})₂, Zr(Fe_{0.5}V_{0.5})₂ type materials

T.P. Yadav', Sobit R. Shahi, O.N. Sriuzatawa

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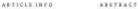
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Studies on the de/re-hydrogenation characteristic of Mg(NH2)2/LiH mixture admixed with carbon nanofibres

Rohit R. Shahi, Himanshu Raghubanshi, M.A. Shaz, O.N. Srivastava'

Department of Physics, Hydrogen Durge Centre, Sienaran Hinda University, Vatarani 221005, Judie

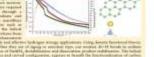


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The effect of cortion ranofflives (2070) on the doine-badrogenation characteristics of 12 magnetism attaide (MgNH4.2) and Ethium hydride (LH) mintare is insurigated. It is found that the description as well as absorption characteristic of the 1.2 high/HA_/LIN minture is improved with admining of different shaped iplanar and bulkalt (DITe separately. The different shaped QSTs were emthesized through catalytic decomposition of sortylene gas over latti, allow the synthesized ON's metals Mirmetal mana particles. Among two different types of suscellares namely planar rathen nanothers (POWM and halical rather successore didn's, the later was found to art as a better catalyst. The decomposition sumpensium of the printine Mg966;1,/UH minture is - SH11C, reduced to SH1 and H411C for the PCNF and NCNF admined MgNH (1, CH mixtum respectively. The activation energy for debackogenation reaction was found to - 97.210/mck, which is further reduced to -47 and - 65 lithol for the PDP and HDV admined Mg0012/AH minture respectively. The lowering of decomposition temperature and enhancement in description kinetica, with aimizing of different shoped CNPs are described and discossed.

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One step high pressure mechanochemical synthesis of reversible alanates NaAlH4 and KAlH4

D. Pukazhselvan "", Duncan Paul Fagg ", O.N. Srivastava "

* Nonmethnalogy Research Distainer, Centry for Machanical Technology and Automation, Department of Mechanical Regimenting, Deleverity of Aprico, \$835-350 Aprico, Pertugui 10 Hydrogen Energy Cartier, Department of Physics, Banarias Hinda University, Varianasi, UP 222 005, India

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The present study suggests high pressure succharacheraical trastment is a better strategy be the synthesis of partnersport solvared revenible slangers. The reactions MatODH - Alstarty with catalysis (TiCl., T.F., and TiC.) milled under 100 for hydrogen pressure for 30 h. effectively trencforms to products (NaAH4 and KAH4) in a single step. The so-synthesized Haddil, and KAH, samples release hydroges at the temperatures of -100 °C and 215 °C. respectively. The stability of the RAH4 phase can be further reduced by extending the high pressure mechanochemical reaction time to 86 h. The BRD and TEM analysis of the realdues observed after extracting the baskle, from the THD, catalysied material confirms the prosence of Ti-Al ality and highly dispensed NaCl nanoperticles. Catalytic ectivity is therefore attributed to mechanic-chemical activation which tonolves catalptically active species fler u.g. TI-All and delects/vacuescies/strain in the prefere.

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MgH2-ZrFe2Hx nanocomposites for improved hydrogen storage characteristics of MgH₂

Rohit R. Shahi ", Ashish Bhatanagar , Sunita K. Pandey , Vivek Shukla , T.P. Yaday , M.A. Shaz , O.N. Srivastava

ent of Physics, Motial MAVs Netwool Institute of Technology Allahabad, 2110(4, Julia * Hydrogen Diergy Center, Department of Physics, Ramona Moda University Varanasi, 221005, Joka

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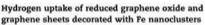
HYDROGEN STORAGE IN CARBON DERIVED FROM SOLID ENDOSPERM OF COCONUT

Viney Dixit, Ashish Bhatnagar, R. R. Shahi, T. P. Yadav, O. N. Srivastava* Hydrogen Energy Center, Department of Physics, Banaras Hinda University, Varanasi-221005, India * Corresponding author: E-mail: hepomphy@gmail.com; Tel: 00915422368468

Abstract

Carborn are being widely investigated as hydrogen storage material owing to their light weight, fast hydrogen adsorption kinetics and cost effectiveness. However, these materials suffer from low hydrogen storage capacity, particularly at room temperature. The aim of the present study is to develop carbon-based material from natural bio-precursor which shows at least moderate hydrogen storage at room temperature. For this purpose, hydrogenation characteristics of carbon derived from solid endosperm of ecconut is studied. Solid endosperm and its carbonized version have a native grown distribution of light elements like K (from KCl), Na, Mg, etc. The hydrogen storage measurements reveal that the as synthesized materials have good hydrogen adsorption and desorption capacity with fast kinetics. The synthesized material adsorbs 2.30 wt. % at room temperature and 8.00 wt.% at liquid nitrogen temperature under 70 atm pressure. The present work is likely to initiate research on native light metal bearing carbon derived from natural precursors

Keywerds: Coconut endosperm: Carbonization: Hydrogenation; KCI; Mg.



M. Sterlin Leo Hudson "", Himanshu Raghubanshi", Seema Awasthi', T. Sadhasivam⁴, Ashish Bhatnager⁴, Satoru Simizu¹, S.G. Sankar⁴, O.N. Srivastava

*Department of Physica, Central University of Tamii Nada, Thiravatar 620004, India *Nanotechnology Application Centre, University of Allababad, Allababad 911002, India *School of Physics, Hyderschad Central University, Hyderschad 500046, India nent of Nanoncience and Technology, Alayappa University, Keenikuli 630003, India ADVIRE Mission Mede Prosett Unit, Department of Physics, Banaras Hindia University, Varanasi 221001, Judia Advanced Materials Corporation, Fillsburgh, PA 15220, 101A

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Effects of Ti-based catalysts and synergistic effect of SWCNTs-TiF3 on hydrogen uptake and release from MgH₂

Rohit R. Shahi "", Ashish Bhatnagar", Sunita K. Pandey", Viney Dixit", O.N. Srivastava*

*Nanopeierus and Nanotechnilogi Unit, Department of Physics, Baners Works University, Varunani 221005, India *Department of Physics, Matilal Nelvus National Institute of Technology, Alabahad 211004, India

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ABSTRACT The present investigations are forward on the effect of Athener Ti-based patalysis (Ti, TiCs, TIC), and TU-2 on dolve hydrogenetics characteristics of assocryptuline MgH, Description inequalities of rolling MgH, lowers from 368 to 350, 560, 718 and 260 °C with the addition of Ti, Titi, Titi, and TiF, respectively. The rehadingenation characteristics are also an through the depletreness of Ti-based natalysts: Arosing all Ti based additions, TW, is found to be the must effective catalpat he hydrages serption from nano MgR. The better cala lytic offset of TO's over other To-based catalysic can be explained on the basis of temps programmed reduction (TPM) studies. TPE experiments performed for different TI additions, reveals that flame is no coldstant/ordustant markum below 400 *C sociest for TSF, The 19th profile of Tilly shows assess coolation/veiluction reaction exhibits at 200 °C. is order to further reprove the surgion characteristics and cyclability of TiP, catching name MgH, we have investigated the effect of SHEMTs in Migh, vYiF, sample. Detrebuiltngenation characteristics several the synergistic effect of SMORTs and TP₂ in MgR₂+TP₂ sample. The details of the improvement in complian behavior of MpH .- TOP, impresence of SWCHTs are investighed and damaged.

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On the synthesis, characterization and hydrogen storage behavior of ZrFe2 catalyzed Li-Mg-N-H hydrogen storage material

Vivek Shukla ", Ashish Bhatnagar ", Sunita K. Pandey ", Rohit R. Shahi ", T.P. Yadav , M.A. Shaz , O.N. Srivastava

* Hadrogen Energy Centre, Department of Physics, Banarus Hindu University, Varanusi 221005, Initia * Department of Physics, Motilal Nebra National Institute of Technology, Allahahad 211004, Isala

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Krywerds: Li-Mg-5i-fi Nydrogen: ntorage 221%; Cabdym:	In better than several other reported studies using different catalyses. Based on experi- mental results, a studie mechanism for detpelongeration of Mg2H1 ₆ /s in the presence of Diffe, has also been prepared. Copyright 6 2005, Hydrogen Storryg Hubbrahom, LLC, Published by Elsevier 101. All rights preserved.		



(Continue)

Catalytic effect of carbon nanostructures on the hydrogen storage properties of MgH2-NaAlH4 composite

Ashish Bhatnagar", Sunita K. Pandey", Viney Dixit", Vivek Shukla", Rohit R. Shahi", M.A. Shaz", O.N. Srivestava ""

Walnum Energy Centre, Department of Physics, Bonarus Hindu University, Varianiai 221525, Judia Department of Physics, MOVET, Allahabad 211004, India

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pressed investigation describes the hydrogen stronge properties or a 1 years rates of -MuANI, compositie Delvelophingenation study severals that MpH,-HuAN, composibenaficial hydrogen storage characteristics as compared to printing MaXM, and To investigate the effect of carbon numericatures (CNS) on the derivity/suger nim of MgE_obiadily, remposite, we have employed 2 wt 5. ON costally, single well in manufales (NPOT) and graphere same sheets (DHD. It is found that the hydrogen up behavior of composite gets improved by the addition of 2 with CMS. In particula ptic effect of CME - 29/CHT improves the lipitingen manage beliance and cyclability of imposite. Switchedingeniation experiments performed up to six cycles show lose of ort % and 0.04 ort % indicates repairly to MgR, -NuAN, caratyout with 2 with 2007 and 3 with OM respectively. On the other hand, the lose of hydrogen capacity after siz subplyingenation cycles in GHS + SWIDHT (L1 = 0.5) with catalysed MpL--HaADL is distantial to 5.41 with.

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Effects of Ti-based catalysts and synergistic effect of SWCNTs-TiF₃ on hydrogen uptake and release from MgH₂

Rohit R. Shahi 📥 , Ashish Bhatnagar , Sunita K. Pandey , Viney Dixit , O.N. Sripastaug

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The present investigations are forward on the effect of different Ti-based totalyity (Ti, TiCo TiCl, and TiF 2 on do/se fordregeration characteristics of noncerpotation MpH, Description inequations of collied MgH, inwere from 360 to 360, 560, 310 and 200 °C with the addition of Ti, Titl,, Titl, and Titl, respectively. The relatingenation characteristics are also segrethrough the deplectment of Ti-based catalyms: Avening all Ti based additions, TW, is found to be the most effective catalyst he hydrages serption from name MgH, The better catalatic effect of TUP, over other Ti-based catalysi can be explained on the basis of temperature programmed reduction (1996) studies. THE experiments performed for different TI additions, reveals that fairs is no coldation/behattion martum below 400 *Caucept for TJP, The 1991 proble of 70%, shows assos ossidation/verticition reaction ashibits at 200 °C. is order to further reprove the surprise characteristics and syclability of TiP, consisted name MgR, we have investigated the effect of DECMTs in MgR, «Tills sample. Deterhologen characteristics several the synergistic effect of SWORTs and TP₂ in MgR₂+TP₃ sample. The details of the improvement in sception behavior of MpH,-TIF, in presence of SWICH's are inwrited and damaged

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Hydrogen storage by reduced graphene oxide and graphene-like nanosheets decorated with Fe nanoclusters

Autrors W.S.L. Hudson, D.N. Srivastava, S. Simita, S.G. Sankar

Afflation: Central University of Tamil Nady, IV

Pages: 423-427

Keywords: helium isotherm, nitrogen isotherm, thermal reduction, chemical reduction, pore size analysis

Abstract. Here, we present the high pressure hydrogen scription isofrem up to 50 bar of graphene oxide IGD) reduced by Thermal reduction (TR-GO), chemical reduction (CR-GO) and creathene like nanosheets decorated with Fe nanoclusters (Fe-GS), GO was first derived by themal extrilation of graphile suide, prepared by modified Standemiur method; further reduction at 623X under high vectum yields TR-GO. CR-GO has been produced by reduction of GO using hydrazine. Fe-GS has been synthesized through arc discharge between the ends of two graphile rods with one not carrying Fe nanoparticles. The surface area calculated from nitrogen adsorption isotherm at 7T K using BET method for GO, TR-GO, CR-GO and Fe-GS are 304, 357, 90 and 165 m2p-1, respectively. The skeletal density of TR-GO, CR-GO and Fe-GS determined through He gas probing are 1.8, 2.0 and 1.05 gon-3, respectively. High pressure hydrogen PCT isotherm of TR-GO, CR-GO and Fe-GS has been determined at 300 K and 77 K. The volume of hydroen aborted by TR-GO, CR-GO and Fe-GS at TT K and SO bar is 230 costplorem (2.07 visuitherase (CH # to R) Constriction (MC has (CH # to 12 (i) metricition (R with the





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A dual borohydride (Li and Na borohydride) catalyst/additive together with intermetallic FeTi for the optimization of the hydrogen sorption characteristics of Mg(NH₂)₂/2LiH†

Vivek Shukla," Ashish Bhatnagar," Sweta Singh, ** Pawan K. Soni, " Satish K. Verma," T. P. Yadav," M. A. Shaz" and O. N. Srivastava **

The present study deals with the instantial takoning of Mg/NH₂I₂-2LH through dual borshydrides: the inactive LBH₄ and the non-reactive NaBH₄. Furthermore, a pulveriter, as well as a catalyst FET. In as been added in order to facilitate hydrogen sorption. Addition of LBH₄ to LNH₄ in a 1.3 molar ratio leads to the formation of LBH₄(I)[MH₂]₂ which also acts as a catalyst. However, the addition of NaBH₄ doesn't lead to any composing formation of LBH₄ (I)[MH₂]₂-2LH/O₄(I][MH₂]₂ which also acts as a catalyst. However, the addition to Inself4, doesn't lead to any composing formation of LBH₄(I)[MH₂]₂-2LH/O₄(I][HH₂]₂(I)[HH₂]₂(I][HH₂]₂(I]][HH₂]₂[I]][HH₂]_2 [I]][HH₂]_2 [I]

Received 29th May 2019, Accepted 27th June 2029 DOI: 10.1039/c9dt02270h nr 6/debre

1. Introduction

The increase in the demand for energy and use of fossil fuels to fulfill this demand has now become a potential threat to the society. Hydrogen is a promising energy vector,¹ has the highest energy density (142 MJ kg⁻²) and is clean, renewable & environmentally friendly.²⁴ Devices based on H₂ fael could not be readily developed due to technical challenges in areas such as hydrogen production, storage, and application. Among these three issues, storage of hydrogen in a safe, efficient and economical manner is a huge challenge.^{4,3} The US: DOE 2020 has set the target (gravimetric capacity: 4.5 wt%, volumetric capacity: 30 g per H₃) which has to be satisfied by the hydrogen storage material for application in whicular transportation.³ As a result of tremendous IRD efforts an hydrogen

storage materials, it is expected that light weight hydrides will emerge as a potential consiliate capable of falfilling the abovesaid criteria.³ Recently, special attention has been paid to such hydrides which are composed of light metal elements and have a high hydrogen content such as unides,^{4,8} alanates,^{60,11} and borohydrides.¹⁰ One category of these materials which seems very promising is the combination of amide/hydride composites, which show a relatively high hydrogen content and also possess good reversibility.^{13,14} However, some issues need to be addressed before it can be used for practical application. These include: [1] a higher desorption temperature to refease hydrogen (-250 °C). (ii) Slow hydrogen sorption kineties [<1] wt95 min⁻¹). (iii) Limitations of high emhalpy (-45 k [mt0⁻¹] and lack of good cetability.^{13,14}]

Out of the various amide/hydride composites, Mg[NH₂]₃: 2LiH (molar ratio 1:2), which has a hydrogen storage capacity of 5.5 wt% and a working temperature of ~220 °C, is an optimum material.²¹⁻⁴⁴ For brevity, this will henceforth be written as 1:2 Mg[NH₂]₂-LiH. To improve the hydrogen storage characteristics of this material, various catalysts/additive^{35,56} have been employed. For example, Yang et al.²⁶ first introduced LiBH, in the Li-Mg-N-fil system where

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Cite this: Phys Chem Chem Phys. 2017, 19, 9444

Enhanced hydrogen sorption in a Li-Mg-N-H system by the synergistic role of $\rm Li_4(NH_2)_3BH_4$ and $\rm ZrFe_2^{\dagger}$

Vivek Shukla, Ashish Bhatnagar, Pawan K. Soni, Alok K. Vishwakarma, M. A. Shaz, T. P. Yadav and O. N. Srivastava 💁 *

Received 6th December 2016 Accepted 7th March 2017 OCR 10.1039/c6cp08133a

mc.3/pccp

1. Introduction

Recause of the enhanced emphasis on the detrimental effects of global warming, the worldwide demand for renewable energy is quickly increasing.¹ Hydrogen may be an ideal renewable energy currier if it can be safely and efficiently stored. Hydrogen is a totally carbon-free fuel and it has the highest energy density of 142 MJ kg⁻¹ compared to other fossil fuels.¹ Thus, when used as a fuel, it can mitigate global warming. Many efforts have been made in the development of new hydrogen storage materials worldwide. After these extensive efforts, it has been found that solid state storage of hydrogen in the form of hydride is one of the best options for storing hydrogen.²⁻⁴ However, after decades of research, no hydride has been found

Hydrogen Dengy Centre, Department of Physics, Esseana Histoh Uwiersaly, Yanzana's 210005, Jodie, Jenezi: Inspensphysicanitame, Tel. 101.6522 (20080).
Henromin suppresentatio information (2018). The Contentional graphy (5K) measurements using Carbosphere and Correseoanth columns (1 and i1) alumitation of pure H₀ in Chromosuch solarum (1ii and 11) detartions of evolved gases on the delydrogenetics of the TL-IM-R-2 sample in a Chromosoth column. Fig. 52: Storage capacity sport-specing (100 °C) of the ratio/sed TL-IM-R-2 composite. Tig. 55: (1) 3001 of the 12-M-Q and TL-IM-Q sample and (1i) 1000 of the 'TL-IM-Q sample, Fig. 51: Transmission Content meleroscopy images (0) the 1-M-R-2 sample, [16] selected area diffraction pattern (50020) of the L-M-R-2 sample, (1) storage TL-IM-R-2, and (2) solvent area diffraction pattern (50020).

that satisfies all the requirements for H₃ storage (United States Department of Energy (US DOE) target-2015),6 in the last few years, complex hydrides such as alanates, amide-hydrides, and borobydrides have been considered as promising materials for safe and efficient hydrogen storage. The Li-Mg-N-H system is the one of most propitious candidates for hydrogen storage because of its favorable thermodynamics, high hydrogen content, and good reversibility at moderate operating temperatures.^{2,0} Out of various metal N-H systems, 1:2 Mg(NH₂)₂/LiH has a theoretical storage capacity of 5.5 we% in the mild temperature range of sorption (>200 'C). The metal-NH system can be a storage material of great interest if its unfavorable thermodynamics, slow kinetics, and inability to rehydrogenate or comparatively low hydrogen storage capacity can be resolved.⁹⁻¹² Thus, it is necessary to improve the thermodynamics and kinetics of the Li-Mg-N-H system. In this regard, V. V2O5, VCl3, TiCl5, Ph.PO40 TiN, KF, RbF, NaH, and KH have been used as catalysts to improve the thermodynamics and kinetics of the Li-Mg-N-H system. 13-28 However, it is still not good for practical purposes, which restricts its application. It has been found that metal borohydrides such as LiBHa, NaBHa, Ca(BHa), and Mg(BHa); are also effective dopants for improving the hydrogen sorption. (de/rehydrogenation) reaction kinetics of the Li-Mg-N-H system.21-27 Yang et al.21 observed a ternary composite system LiNH₂/MgH₂/LiBH₂ and explained that in this system, LiNH₂

¹Halingen Europy Genter, Jugartmenn of Physics, Basarias Hinda Generally, Vancauri 221005, India: Annali: Improved/AnalypeutLove: Tel: 90.0562 2386488 ¹Department of Physics, Tobaci of Physical and Blaterial Sciences, Mahalma Gandhi Gantal Toherney, Bhar, 46140, India.

^{*}Electronic supplementary information (ESI) available: Fig. 81-80, See EOG patrons/ved/02270k

Publication of hydrogen energy 2019-20



Multiple improvements of hydrogen sorption and their mechanism for MgH₂ catalyzed through TiH2@Gr

Satish Kumar Verma ", Ashish Bhatnagar ", Vivek Shukla ", Pawan Kumar Soni ", Anant Prakash Pandey ", Thakur Prasad Yadav ", Onkar Nath Srivastava **

* Hydrogen Energy Centre, Department of Physics, Institute of Science, Bonaros Hindu University, Varanasi, 221005, Inidia

^b Department of Physics and Materials Science and Engineering, Jaypee Institute of Information Technology, Noida, 201309, India

HIGHLIGHTS

- · Ooset dehydrogenation temperature of 204 °C for MgH₂ catalyzed by TiH-ØGr.
- · Good cyclic stability and improved thermodynamics for MgH₂ catahyzed by TiH-@Gr.
- · Mechanism for cutalytic action of TiH-OGr on MgH:
- . Comparison of catalytic effect of Ti@Gr, TiOy@Gr and TiH,@Gr on MgH₂.

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Keywords: Hydrogen storage Magnesium hydride Graphene templated Ti-based

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E-mail addresses: heponyphy@gmail.com, heponyphy.bhu@gmail.com (O.N. Srivastava). https://doi.org/10.3016/j.ijhydene.2020.05.001

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Ternary transition metal alloy FeCoNi nanoparticles on graphene as new catalyst for hydrogen sorption in MgH₂

Sweta Singh ¹, Ashish Bhatnagar ⁴, Vivek Shukla ⁴, Alok K. Vishwakarma ", Pawan K. Soni ", Satish K. Verma ", M.A. Shaz ", A.S.K. Sinha⁴, O.N. Srivastava⁴

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* Department of Physics and Materials Science and Engineering, Jaypee Institute of Information Technology, Noida, 201309. India

4 Department of Chemical Engineering and Technology, Indian Institute of Technology, Banaras Hindu University, Varangoi, 221005, India

HIGHLIGHTS

· Synthesis of PeCoNi0GS by one pot method. .FeGoNi@G5 has been used as

- catalyst for MgH₂ · MgH₁ catalyzed by FeCoNi@GS
- show excellent cyclability.
- · Formation enthalpy of MgH2: FeCoNi@GS is reduced by 19.26 kJ/ mol of H₂ as compared to ball milled MgH2.

ARTICLE INFO

Article history Received 25 June 2015 Received in revised form 22 September 2019 Accepted 25 October 2019 Available online xxx

Krywords: Ternary alloy FeCoNi Graphene templated FeCoNi MgH: Hydrogen storage

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GRAPHICAL ABSTRACT



ABSTRACT

The present investigation deals with the synthesis of ternary transition metal alloy nanoparticles of FeCoNi and graphene templated FeCoNi (FeCoNi@GS) by one-pot reflux method and there use as a catalyst for hydrogen sorption in MgH₂. It has been found that the MgH₂ catalyzed by FeCoNi@GS (MgH₂: FeCoNi@GS) has the onset desorption temperature of ~255 °C which is 25 °C and 200 °C lower than MgHg catalyzed by FeCobii (MgHg FeGoNI) (onset desorption temperature 280 °C) and the ball-milled (B.M) MgH₂ (onset desorption temperature 355 'C) respectively. Also MgH₂: FeGoNi@G5 shows enhanced kinetics by absorbing 6.01 wt% within just 1.65 min at 290 °C under 15 atm of hydrogen pressure. This is much-improved sorption as compared to MgH2: FeCoNi and B.M MgH2 for which hydrogen absorption is 4.41 wt% and 1.45 wt% respectively, under the similar condition of temperature, pressure and time. More importantly, the formation enthalpy of MgH2: PeCoNi@GS is S8.86 kJ/mol which is 19.26 kJ/mnl lower than B.M: MgH2 (78.12 kJ/mnl).



ABSTRACT

The present investigation reports the effect of TiH2 templated over graphene (TiH2@Gr) on the hydrogen sorption characteristics of MgH2/Mg. The as synthesized TiH20Gr leads to significant effect on sorption in MgH₂ by the following effects: the first is dehydrogenation of MeH--TiH-OGr, which leads to the conversion of some part of TiH- into TiH- ma, TiHtogether with TiH1200 works as a better catalyst than TiH2 alone. The second is ball-milling of TiH₂@Gr, which produces defective graphene, which also works as co-catalyst. The third is anchoring of TiH2 on graphene, which does not allow the catalyst to agglomerate. The catalytic effect of TiH₂@Gr on MgH2 is found to be better than Ti@Gr and TiO2@Gr. The onset desorption temperature for MgH2-TiH2@Gr is -204 °C, which is 31 °C and 36 °C lower than MgH2-TiOGr, MgH2-TiO20Gr respectively. The better catalytic behavior of TiH20Gr

GRAPHICAL ABSTRACT

.2nd Project :.<u>BIOFUEL FROM MICROALGAE</u>

Status: Collaborator: Prof. Dr. Eduard Jacob-Lopes, Univeridade Federal de Santa Maria, Centro de Ciencias Rurais Av. Roraima 1000, Camboi Santa Maria, Brazil

• Prof. R.K. Asthana, Dept. of Botany

TiO2 thin film photoanode based dye-sensitized solar cells (DSSCs) for harvesting solar radiation (light energy)

Status: Collaborators being explored

 Dr. Pankaj Srivastava, Assistant Professor, Department of Chemistry, Institute of Science, BHU Varanasi 221005 ^{3rd} Project New materials for fuel cells, super capacitors, electrochemical sensor and for the removal of organic/inorganic contaminants from natural water sources

- Status: Collaborators being explored
 Dr. V. Ganesan
- •Assistant Professor, Department of Chemistry, Institute of Science6



5.4th Project. TiO2 thin film photoanode based dyesensitized solar cells (DSSCs) for harvesting solar radiation (light energy)

• Status: Collaborators being explored

 Dr. Pankaj Srivastava, Assistant Professor, Department of Chemistry, Institute of Science, BHU Varanasi 221005 Uttar Pradesh, India

Collaborators being explored





- .5 th Project:.Title of the Project: "Graphene Based Hierarchically Nanostructured Composites as Multi-Functional Materials for Energy Storage, Actuator and Sensing Applications"
- Proposal submitted by us under the project BRICS PILOT Call 2016Collaborators:
- From India: Dr. Anchal Srivastava, BHU
- From China: Prof. Li Song, Synchrotron Radiation National Lab, University of Science and Technology of China.
- From South Africa: Dr. Patric Ndungu, Department of Applied Chemistry, University of Johannesburg.

6TH PROJECT:. DEVELOPMENT OF NEW GENERATION - BIOFERTILIZERS/BIOPESTICIDES FOR CLIMATE RESILIENT AGRICULTURE

- Collaborators: Prof. Leonardo F. Fraceto Institute of Science and Technology - São Paulo State University, Brazil) and Prof. Renata de Lima (University of Sorocaba, Brazil).
- Collaborators from India:
- Prof. H. B. Singh and Prof. B K Sarma
- Department of Mycology & Plant Pathology, I.Ag.Sci., BHU, Varanasi
- Prof. Bandana Bose and Prof. PadmanabhDwivedi
- Department of Plant Physiology, I.Ag.Sci., BHU, Varanasi
- Dr. AmitavRakshit, Sr. Asstt. Professor
- Department of Soil Science & Agric. Chemistry, I.Ag.Sci., BHU, Varanasi

- 7th Project: Project Details:
- **1. Development of thin film Solar cell using thermal/e-beam evaporation technique**
- Status: Agreed upon by BRICS partner
- Participating Faculty: Prof B.K. Singh, Department of Physics
- Theme: Energy (Sub theme: Solar Cell)
- The group has agreement with a Russian group headed by Prof. V. F. Markov of Ural Federal University (Russia) under BRICS Network.

- 8th Project :. A Project proposal on Energetic materials for submission to BRICS Network University (consideration under "Nanomaterials and meta materials for energetics for MISIS, Moscow)
- Status: Collaborators being explored
- Dr. Satyen Saha, Assistant Professor, Department of Chemistry, Banaras Hindu
- University, Varanasi 221005, India.





COURSES FLOATED (four courses)
BY ...BHU (INDIA) UNDER BRICS

FOR BRICGS NU ENERGY ITG

Course flotted

Course name: M A (Masters) in Energy Economics

Basic university: Banaras Hindu University, A Comprehensive University, as Institute

of Eminence, of International Repute and of more than Hundred Years Old.

URL of the University: www.bhu.ac.in

Educational program / degree: Master's Degree in Energy Economics (M. A in Energy Economics).

Duration: **Two years full time duration with 4 semesters** emphasizing both on class room teaching and field work.

Eligibility: Eligibility: B.A. (Hons.) Economics/ B.Com./B.Sc./B.A. Programme with Economics or B.Tech. or MBA with minimum of 50% aggregate marks from a recognized University/Institute. The course will be taught in English Medium only.

NOTE: In addition to the above that the candidates must have minimum 50% marks at Higher and Senior Secondary level with Mathematics as one subject. However, this course requires advance knowledge of mathematics.

Responsible person (with contact details): **Prof. Mrutyunjaya Mishra, Course Coordinator**, Professor of Economics (Environmental Economics), Department of Economics, Faculty of Social Sciences, Banaras Hindu University, Varanasi-221005, Mobile No: +91 9838419845, email: <u>coordinator.energyeco@bhu.ac.in</u>; <u>mmishrabhu@gmail.com</u>.

Program description: Background to the Course:

This course owes its Origin to the BRICS-NU programme to which Banaras Hindu University is an International Partner. Of few selected Core Areas of Research and Higher Study Energy is an important part and Energy Economics is one among the cores. Its our proud privilege that the Esteemed Banaras Hindu University happens to be a lead partner of this Core Area and Group. On the initiation of the Hon'ble Vice Chancellor and the guidance of the Dean of Faculty of Social Sciences, Department of Economics decided to launch this course, **Master of Arts in Energy Economics**.

Course preamble:

Efficiency and sustainability of energy system are pre-requisites for Sustainable Development and the challenges to achieve this lie at the interface of technology, innovation and human behavior. This course is tailored for the student desiring an understanding of the

relationship between the energy sector and the wider economy. It covers additional topics in related and associated fields of Management, Commerce, Engineering, Mining and Natural Resources with emphasis on tracing the national and Global impacts and implications of energy sector decisions. This course provides an overview of the economic, technological, and political forces that shape the global energy industry, the methods governments use to regulate the industry, and the business models that emerge.

The course aims at broadening the vision of students while making any energy related decision as a technology developer, energy manager, entrepreneur, policy maker, researcher in future or simply for personal energy use in day to day activities.

Topics to be covered include, resource based energy activities, depletion policy and environmental issues, pricing security and sustainability.

The course begins by framing the industry in its microeconomic context and uses that framework to explore the role of technology and innovation, global markets and geopolitics, and the regulation of externalities including climate change. The readings and coursework will use specific examples from the power, renewables, oil & gas, and environmental sectors from the both developing and developed countries and other select geographies to illustrate these forces in context. Students can tailor their final policy memo towards their topics of interest.

Objectives

The aim of the of the Masters in Energy Economics programme is to prepare the students for managerial, advisory and academic position in the energy sector. The programme aims to provide an intellectually challenging academic programme which will strengthen the ability of students to analyse, synthesise and evaluate key theoretical concepts and practical applications in energy with emphasis on the economic dimensions of the subject. Since the world's long term economic development depends on the existence of efficient, innovative and creative energy industries individuals who possesses sound knowledge on various aspects like economic, commercial, technical, management and environmental aspects will be of high demand and cater to the need of both at national and international level.

Curriculum: Course Curriculum of Energy Economics

All papers covered under the course are Core courses of 4 credits each and dissertation is 4 credits. The internship is assigned with 4 credits. So total credit score is 84 credit.

Sl.N o	Course No	Course Title	Course No	Course Title	
	SEMESTER	I	SEMESTER II		
1	MEE-101	Microeconomics	MEE -201	Macroeconomics	
2	MEE -102	Energy Economics	MEE -202	Basic and Applied Econometrics	
3	MEE -103	Environmental Economics	MEE -203	Advanced Resource Economics	
4	MEE -104	Mathematical Economics	MEE -204	Investment and Portfolio Management	
5	MEE -105	Applied Statistics	ECM-205	Advanced Mining and Evaluation	
	SEMESTER	III	SEMESTER	IV	
6	MEE-301	Operations Research	MEE -401	Economic Evaluation and Project Management	
7	MEE-302	Research Methods for Energy Analysis	MEE-402	Management of Technology for Energy	
8	MEE-303	International Trade in Energy resources	MEE -403	International Business Strategy and Energy Sector	
9	MEE -304	Energy ,Economy and Society	MEE -404	Energy, Climate Change and Global Politics	
10	MEE-305	Accounting and Finance	MEE -405	Field Work based Dissertation	

Presentation: Students are required to undergo **Summer Internship** during the summer vacation between II and III semester and prepare reports about their learning, education and training during summer internship.

Further students submit a Master Dissertation at the end of the Semester as a partial fulfillment of the course and the dissertation is of 4 credits. Other materials: Course and Source Materials provided to students by teachers and resource persons from time to time. Standard books and study materials

prescribed for reference as study and reference materials.

COURSE ON HYDROGEN ENERGY

Hydrogen Energy Centre, Department of Physics, Banaras Hindu University, Varanasi, India Academic plan showing the courses proposed: <u>Proposed Courses</u>

The PG special course will run for one year. The student to be admitted will be PG students from Science / Engineering stream. The one year course will be divided in two semesters. Also the teaching will be in research ambience. This will be achieved through a project which will be research oriented and will form essential part of the syllabus and will carry 4 credits and will be carried out in the second semester (out of total 10 credits where 6 will be from theory for each semester).

The courses will run for five years, midterm changes will be made to bring new relevant topics covering emerging areas. The five year course will be based on feedback from the first five year PG students who would have undergone the special course in Hydrogen Energy. Besides this the next five year course will bring in such new topics which will be in conformity with societal need relating to use of clean, renewable and environment friendly energy (only hydrogen fulfill all these requirements) for which the country is committed (India has signed 2015 Paris Agreement). The last five years course schedule will be based on new and innovative areas in Hydrogen Energy which would have emerged by then. It will also cover academic strategies and research perspectives for adoptability of Hydrogen Energy for the country. A tentative academic plan showing the course proposed is given in the following.

COURSE ON HYDROGEN ENERGY

1st Semester (III Semester as per present PG teaching schedule)

Course 1 (Theory) (a) Hydrogen vis-a-vis other Renewable Energies

(b) Present route of hydrogen production from Hydrocarbon and its limitations.

(c) The solar Resource

(d)Introduction to Hydrogen Production through splitting of water using solar energy various Solar Routes

Course 1 (Laboratory).

Basic experiments on Hydrogen Production.

Course 2 (Theory) (a) Why storage? The logic of storage (b) Various Techniques of Hydrogen Storage (High Pressure Gaseous, Liquid and Solid (Hydride))

(c) Advantages and preference for solid state hydrogen

storage route.

(d) The safety aspects of various storage routes.

Course 2 (Laboratory)

Basic experiments of Hydrogen Storage including known intermetallic hydrides for Hydrogen Storage.

4. Hydrogen Energy Centre, Department of Physics, Banaras Hindu University, Varanasi, India Academic plan showing the courses proposed : <u>Proposed Courses</u>

2nd Semester (IV Semester as per present PG teaching schedule) Course 1 (Theory)

Various Routes of Production of Solar Hydrogen in

(a) Solar energy driven pathways through water splitting.

(b) The role of nanomaterials in PV driven hydrogen production

(c) Hydrogen production using solar energy induced water splitting employing nanocatalyst e.g. Cds TiO_2 .

(d) Photo biological methods of renewable hydrogen production.

(e) Photoelectrochemical Electrolysis (use of Photoanodes of nanostructured oxide TiO_2 , Fe_2O_3 , WO_3 etc.

(f) Photocatalytic Electrolysis (deploying semiconductors nanoparticles e.g. nano Cds and hybrid materials).

Course 1 (Laboratory)

Hydrogen Production Experiments using nanomaterials.

Course 2 (Theory)

(a) Various types of hydrogen storage materials (hydride).

(b) Hydrogen storage modes: Physisorption and chemisorption.

(c) Mechanism of hydrogen storage.

(d) Understanding Hydrogen Storage in Hydrides in regard to optimizing.

Course 2 (Laboratory)

Synthesis and Characterization of Large Scale Hydride (Kg Level) for Hydrogen Application and Demonstration for Electricity and Automotive Power Applications.

• The University has floated the following courses Post Graduate Diploma in Non Conventional Energy sources

- Development and economic growth of societies depends on the energy inputs. Growth of energy sector is particularly critical for socioeconomic development of rural areas. Globally the need for energy is only bound to increase. Unsustainability of fossil fuels due to their limited nature leaves no option but to harness non-conventional energy to overcome the barriers to development posed by energy security in the rural areas. In view of the anthropogenic global warming threat driving climate change coupled with scarcity of fossil fuels, the Post Graduate Diploma Programme in the Non-conventional Energy Sources is timely to enable students with varied backgrounds to appreciate various aspects of the energy sources. Students will be exposed to the different kinds of non-conventional energy sources and their applications to different aspects. The course is aimed at providing an understanding of the non-conventional energy sources and their applications, Hydrogen Energy & Fuel Cells, Wind Energy and Biomass, Geothermal Energy, Batteries, Supercapacitors and Nuclear Energy. Lab training with credits would form an integral part of the course
- Duration
- Eligibility Qualifications Discipline

- : 2 Semesters
- : B.Sc. in Science



Certificate Course on Clean Coal Technology

- Clean coal technologies focus on efficient combustion of coal with reduced emissions of sulfur dioxide, nitrogen oxide, particles and mercury, and reducing carbon dioxide emissions through carbon capture and storage. Other technologies such as coal liquefaction and gasification are being pursued to produce low cost, secure alternatives to oil and natural gas for use in electricity generation and transportation. The Department of Geology, B.H.U proposes a certificate course to educate, encourage and support public/private organisations to be aware of the intricacies of coal constitution and its bearing on the clean coal technologies that ultimately can be brought to large-scale commercial deployments. The takers of this certificate course would not only be the Thermal Power Generation plants but also other coal consumers like, steel plants, cement plants and other industries including post graduate students. The course structure would include coal as rock and fuel, environmental pollution and assessment, clean coal technologies (CCT) and coal preparation. There would be credits for lab training.
- Duration
- Eligibility Qualifications Discipline

: 1 Semester : B.Sc. in Science



SOME DETAILS OF MAJOR RESEARCH 1STPROJECT Hydrogen Energy: Production ,Storage and Applications

<u>Energy (Electricity) Scenario In India</u>

WHY HYDROGEN FOR INDIA? India is 3rd largest electricity producer China 6015 (TWh) USA 4327 (TWh) India 1423 (TWh) Russia 1038 (TWh) India's electricity consumption is very low 1/3rd of world's consumption i.e. 1213 kWh per capita (This has to be increased for improving the life quality).

Various Sources of Electrica

Coal (63.90%) Hydro (13.00%) Wind (3.70%) Solar (15.30%) Biomass (1.10%) Nuclear (3.00%)



India expanded its solar-generation capacity 8 times from 2,650 MW on 26 May 2014 to over 20 GW as on 31 January 2018. Installed capacity of electricity generation in India was 344 GW on 31 may 2018

Renewable Energy Component for India ~17%. India will continue to depend on Coal for future production but the Renewable and Nuclear Energy component is planed to be increased, up to ~30% in coming~10 years



Energy (Oil) Scenario In India

Total Oil Production

India 856 Tbd (Thousand barrel daily) China 3999 Tbd Russia 11227 Tbd Brazil 2605 Tbd South Africa 169 Tbd



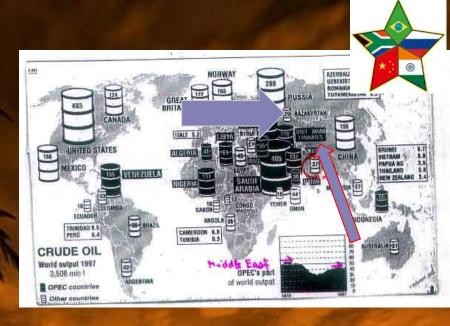
Total Oil Consumption

India 4,69,0000 Bbd (Billion barrel daily) (Per Capita one of the lowest world China 1,32,26,000 Bbd Russia 3,22,4000 Bbd Brazil 30,17,000 Bbd South Africa 5.90.900 Bbd India has therefore very precarious position in regards to

Oil. It is almost a total oil importing country and has to spent about 50% of its foreign exchange reserve on oil imports.

Therefore it is looking for a indigenous replacement of oil. It has been found that based on logistics Hydrogen is the best option. Why Hydrogen for INDIA? Indigenous oil production in 1997 India 46MT (1992) 37MT (1997) 32MT (1999) China 155MT (1999) Saudi Arabia 406MT USA 403MT Russia 298MT

Decreasing Indigenous oil supply but ever increasing demand



Large Gap between
Demand & Supply
1\$=Rs.17; 0,000CroresWorld Resources 1052.7 Billion US Baralls
Middle East
69%USAChinaIndia69%15% ?5%0.9%

India is importing about 156--180 MT Indigenous oil (30MT Indigenous)

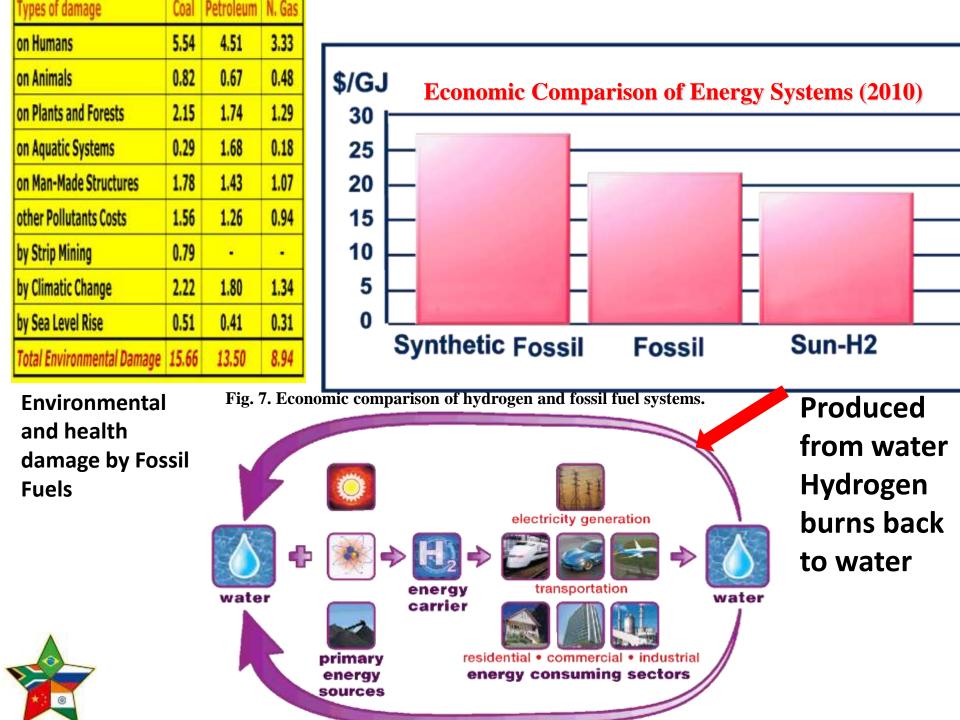
Y		Country	Production (bbl/day)	Share of World %	Date of Information
		World	84,820,000 ^[6]	100%	—
1		Russia	10,900,000	13.28%	2013 est. ^{[7][8]}
2	<u>888</u>	Saudi Arabia	9,900,000	12.65%	2013 est. ^{[7][9]}
3	655	United States	8,453,000	9.97%	2013 est.
4	2	<u>Iran</u>	4,231,000	4.77%	2013 est.
5	*3	China	4,073,000	4.56%	2013 est.
6	•	<u>Canada</u>	3,592,000	3.90%	2013 est.
7	44	Iraq	3,400,000	3.75%	2013 est.
8		United Arab Emirates	3,087,000	3.32%	2013 est.
9	0	Venezuela	3,023,000	4.74%	2013 est.
10		Mexico	2,934,000	3.56%	2013 est.
11		Kuwait	2,682,000	2.96%	2013 est.
12	\diamond	Brazil	2,633,00	3.05%	2013 est.
13		Nigeria	2,525,00	2.62%	2013 est.
14	╬	Norway	1,998,00	2.79%	2013 est.
15	e	Algeria	1,885,00L	2.52%	2013 est.
16	<u>a</u>	Angola	1,840,000	2.31%	2013 est.
17		Kazakhstan	1,635,000	1.83%	2013 est.
18		Qatar	1,631,000	1.44%	2013 est.
19		United Kingdom	1,099,000	1.78%	2011 est.
20		Colombia	1,011,992	0.97%	2013 est.
21	•	Azerbaijan	987,000	1.20%	2011 est.
22		Indonesia	982,900	1.66%	
23	0	India	897,300	1.04%	2013 est.

INDIA IS LOOKING FOR A FUEL WHICH CAN REPLACE **OIL(PETROLEUM)**, WHICH IS **INDIGENOUS, RENEWABLE, CLEAN** AND CLIMATE FRIENDLY. **VARIOUS LOGISTICS SUGGEST THAT** FOR INDIA SUCH A FUEL MAY BE **HYDROGEN....PLENTY OF WATER AROUND BAY OF BENGAL..ARABIAN** SEA ... INDIAN OCEAN~ 200 RIVERS **INCLUDING**, BRHMAPUTRA&GANGA

> PLENTY OF SOLAR INSOLATION ...NEXT ONLY TO AFRICA



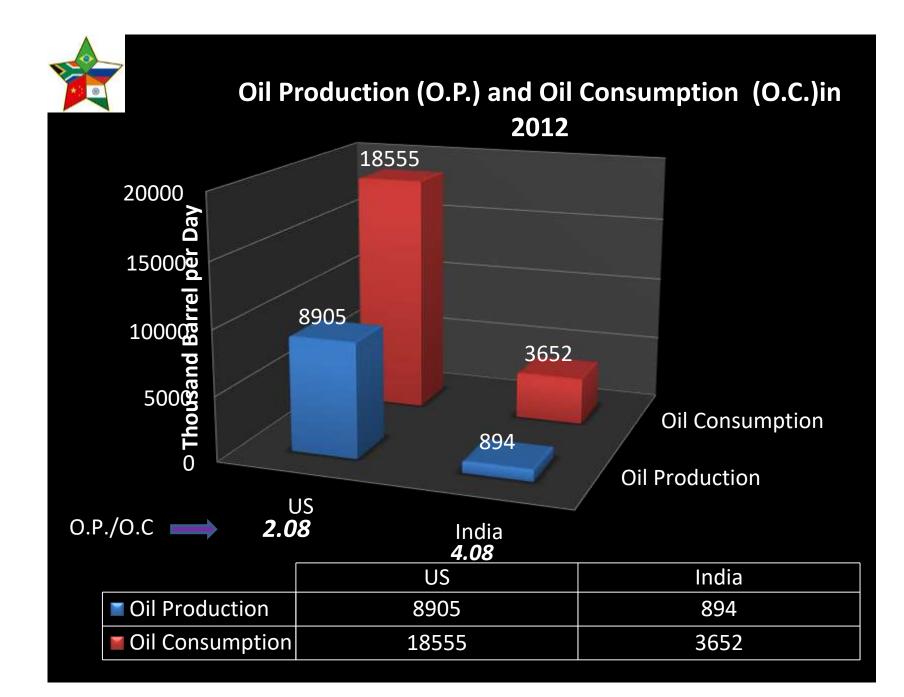
WHY HYDROGEN FOR INDIA? **1.HUGE DIFFERENCE BETWEEN OIL PRODUCTION AND** ONSUMPTION **2.CLIMATE CHANGE EFFECTS 3.Urban AIR POLLUTION**



ENERGY OPTIONS FOR INDIA



For Electricity INDIA will cotinue to depend on Coal fired Power Stations **because of Huge Coal Reserves that** it has.. INDIA..~ 60.6 Bt(Fifth biggest Coal Reserves) CHINA..~114.58Bt Russia~157.01Bt At the same time to reduce the Global Warming_as per PARIS AGREEMENT(not more than2degree C up to2050 Dec.2015..INDIA will keep on increasing the Renewable **Contribution...IT has risen from ~10%**



WHY HYDROGEN FOR INDIA? **1.HUGE DIFFERENCE BETWEEN OIL PRODUCTION AND** ONSUMPTION **2.CLIMATE CHANGE EFFECTS 3.Urban AIR POLLUTION**



Why Hydrogen for India?

Various Facets Related with Oil in India(2007)

1. EXTREMELY SCANT OIL RESOURCES Availability of oil ;Depletion Largest difference between demand & supply 2. Pollution. (Detoriating urban air quality) **3.Global Warming/Climate Change** ..(Effect on life of living beings ;Agriculture) **4.Energy Security**

Why Hydrogen for INDIA? GLOBAL WARMING /

USA	INDIA			
Global Warming (Climate Change) say rise of 2°C will help initially cold countries like USA.	 >Global warming (climate change) (say rise of 2°C) will start to cause / already causing harmful effects. > (Change in monsoon patter, lower agriculture yield etc.) right away. It has in fact already status affecting India. 			
GLOBAL WARMING / CLIMATE CHANGE				
Glacier melting will affect USA as well.	Glacier Melting will affect – India most crucially HIMALAYA			
Use of Green i.e. Bio fuels (low carbon fuels) → e.g. synthesized from corn oil) can help USA on a short / mid term basis	 >Use of Green i.e. Bio fuels (low carbon fuels) → e.g. synthesized based on jatropha after initial euphoria has run into problems and is not thought to be quite viable option. >"Fuel vs Food Crisis" population 			
Dependence of GDP on Agriculture ~0.9%	Dependence of GDP on Agriculture ~23% GB affecting Agriculture ~16%			

H₂ Production

H₂ Applications

H₂ Storage

H₂ Safety

HYDROGEN ENERGY CENTER AT B.H.U. VARANASI (INDIA) CARRIES OUT R&D AND APPLICATIONS ON ALL THESE ASPECTS 4. Hydrogen as a new renewable, clean and climate friendly fuel: Its production, storage and applications



- Status: Name of BRICS Collaborators with Institution
- 1. Prof. Helton Jose Alves (Universida de Federal do Parana, Brazil)
- 2. Prof . Alexander Yu. Ramenskiy (Vice President International Association of Hydrogen Energy, Moscow, Russia)
- 3. Hydrogen Energy Centre Group (HEC)
- Prof O.N. Srivastava, Prof R.S. Tiwari, Dr M.A. Shaz, Dr T.P. Yadava (Faculty members from Physics Dept): Professor R.K.Asthana and Professor S.P.Singh (Botany): Prof. V.B. Singh Prof. A.S.K. Sinha (Chemical Engineering)



Research Publications in 2017-2018 2017----20 Publications in Peer Reviewed Jornal; 2018-----8+2

Hydrogen production

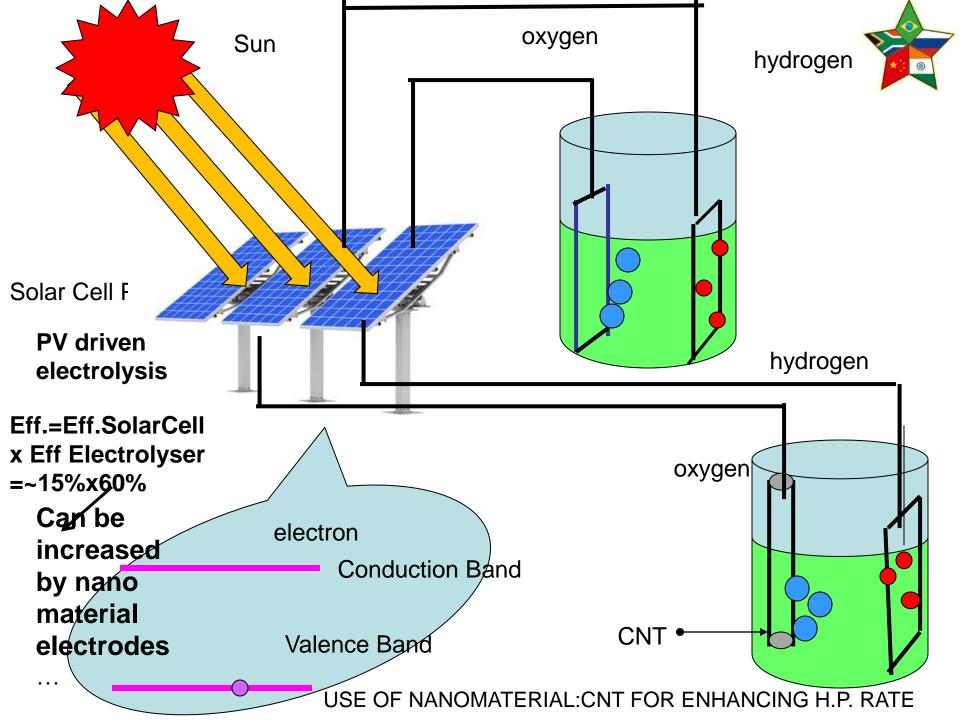


CO.7

Steam reformation of hydrocarbons

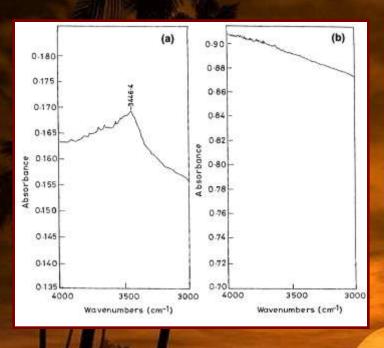
SOLAR HYDROGEN

1.PV driven electrolysis
2.Photoelectro chemical electrolysis
3.Photocatylytic electrlysis
4.Phtobiological route



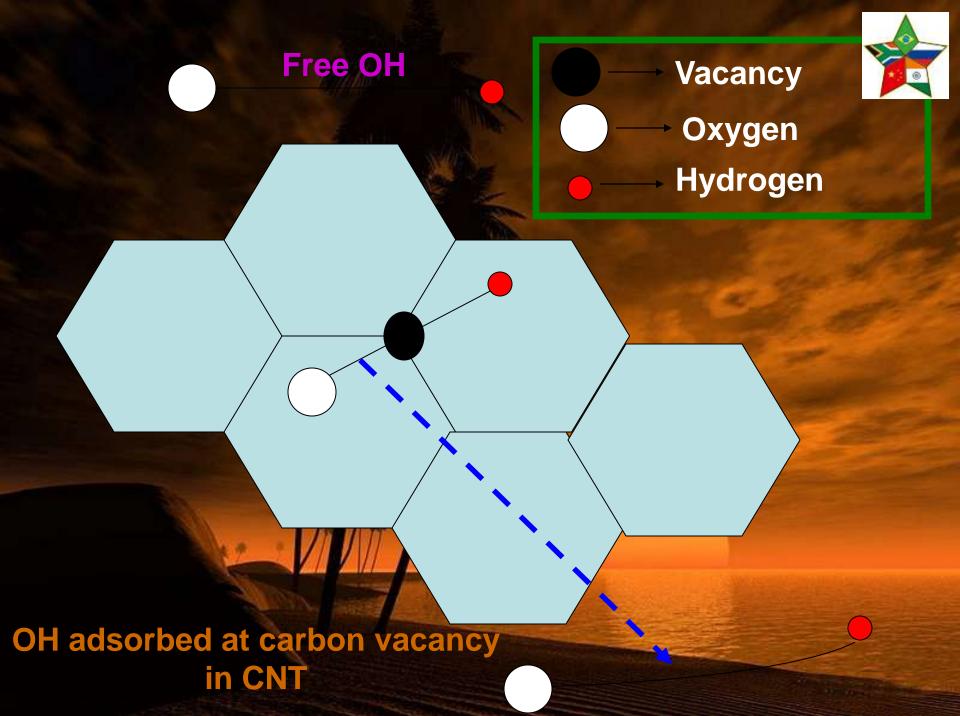


FTIR spectra of CNT electrode



(a) Immersed in the alkaline water and pre-dried and(b) Bare, without immersion in alkaline water.

Notice the presence of peak at ~3446 cm⁻¹ representing the OH radical.





- Applications of CNT as Electrode(anode) for electrolysis of water.
- Electrolysis taking place ~1.2V instead of ~2V will imply increasing electrolysis cell efficiency by ~40%.

H.P.---PV Route Medanta Near New Delhi



500 kW_p SPV Power Plant at Medanta Hospital Car Parking at Gurgaon, Haryana



115 kW_p SPV Power Plant at DMRC Anand Vihar metro station, Delhi



100 kW_p SPV Power Plant at Rockwell Industries, Hyderabad, Telangana

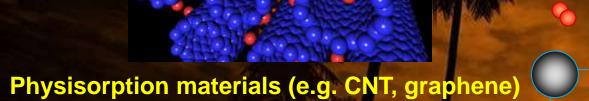


500 kWp SPV Power Plant at Kalinga Institute of Social Sciences



HYDROGEN STORAGE

Types of Hydrogen Storage Materials



Complex Hydrides (e.g. NaAlH₄)

Intermetallic Hydrides (e.g. LaNi₅)

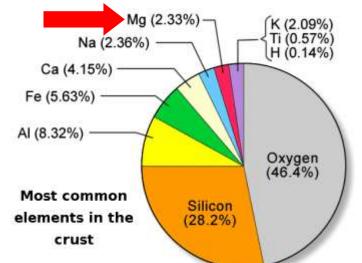
56

Metal Hydride MgH₂ (Pure and Catalysed) This Hydride seems to become State of the Art Hydride

57



Why MgH₂? **Advantages *Large deposit of Mg in earth crust.** Low cost *A very Light metal hydride High gravimetric storage capacity (7.6wt%) ISSUES



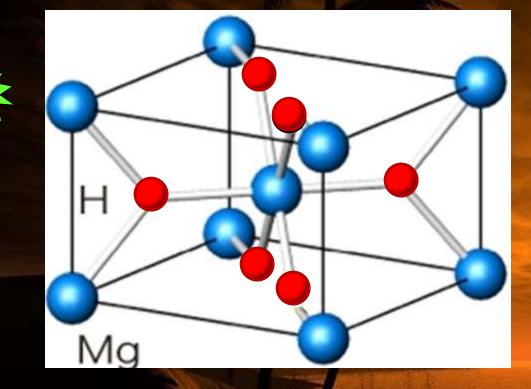
High Volumetric Storage capacity (110 kg/m³) ✤ High desorption Temperature above 400°C(desired ~150-200°C). High desorption activation energy ~97 kJ/mol. **Slow Kinetics.** roaches

Tailoring by Ball-milling followed by the deployment of different catalysts such as transition metals/alloys/oxides and carbon based nanostructures. Which reduces the desorption temperature and also enhances the uptake and releasing kinetics of the materials.

Role of Catalysts in Destabilizing and regenerating MgH₂



→Nano catalyst





- 1. Redox reactions
- 2. Variable oxidation states



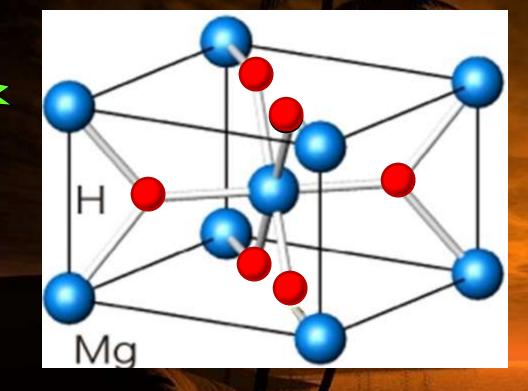
NEW CATYLYSTS DEPLOYED FOR MgH2 1.NANO TiO2 Of Different Sizes 2.TiF3 3. TiF3+SWNT 4.Leached Nano Quasicrystal

Theme (a) : a1-i Solar energy storage through storage of hydrogen in new exotic hydrides











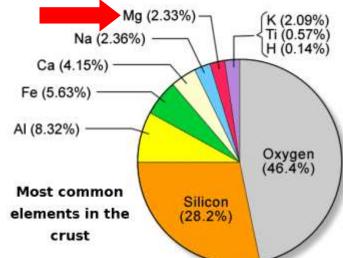
Effect of Catalyst on Light Weight Hydride (MgH₂)



Metal Hydride MgH₂ (Pure and Catalysed) This Hydride seems to become State of the Art Hydride

Why MgH₂? **Advantages** Large deposit of Mg in earth crust. Low cost *A very Light metal hydride High gravimetric storage capacity (7.6wt%) High Volumetric Storage capacity (110 kg/m³) ISSUES ✤ High desorption Temperature above 400°C(desired ~150-200°C). High desorption activation energy ~97 kJ/mol. **Slow Kinetics.** roaches

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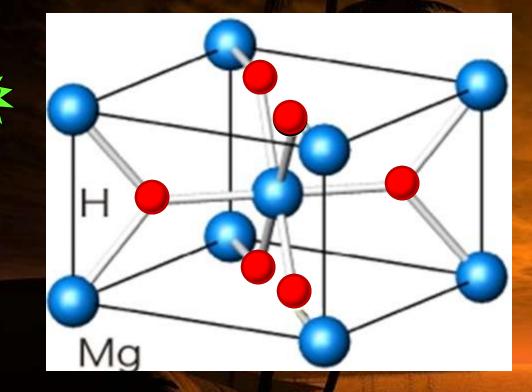


Role of Catalysts in Destabilizing and regenerating MgH₂





Nano catalyst





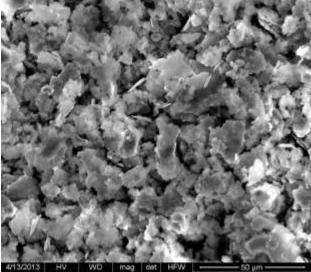
- 1. Redox reactions
- 2. Variable oxidation states



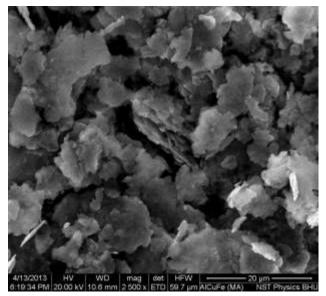
New Catylyst found by BHU

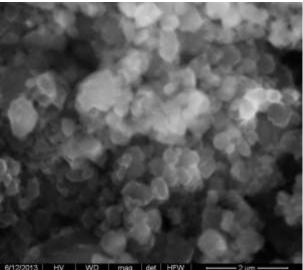
LEACHED QUACRYSTALLINE(AICuFe) MATERIALS AS NEW EXOTIC CATYLYST FOR HYDROGEN SORPTION IN MgH2

SEM: MgH₂ catalyzed with Leached ball-milled Al-Cu-Fe



4/13/2013 HV WD mag det H+W 50 mm 5:10:49 PM 20:00 kV 10.6 mm 1:000 x ETD 149 µm AlCuFe (MA) NST Physics BHU

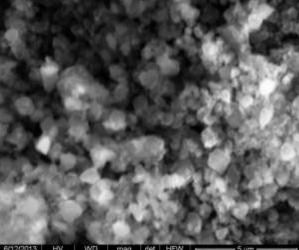




6/12/2013 HV WD mag det HFW _____2 μm _____ 2:07:39 PM 25:00 kV 10.1 mm 20:000 x ETD 7.46 μm M+ACF2 NSC Physics BHU Leached ball-milled Al-Cu-Fe

MgH₂ catalyzed with Leached ball-milled Al-Cu-Fe





39:21 PM 25:00 kV 10.1 mm 10:000 x ETD 14.9 µm M+ACF2 NSC Physics BHU

Fig 3: Absorption characteristic curve from 250°C to 100°C temperature

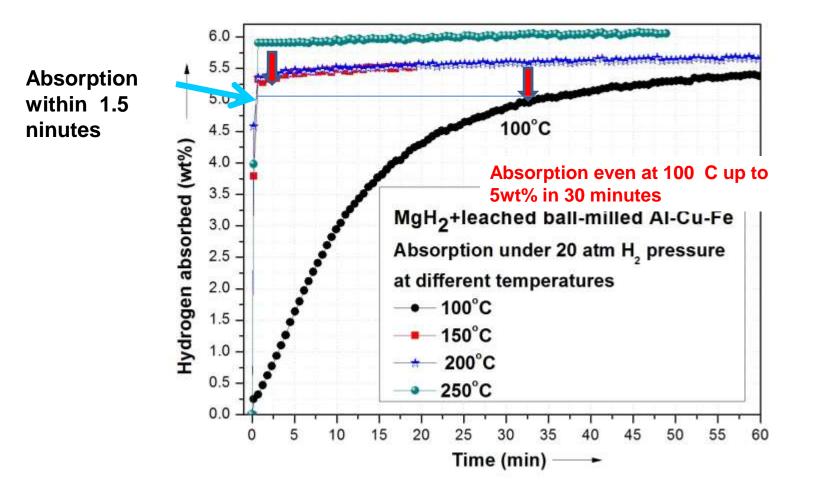
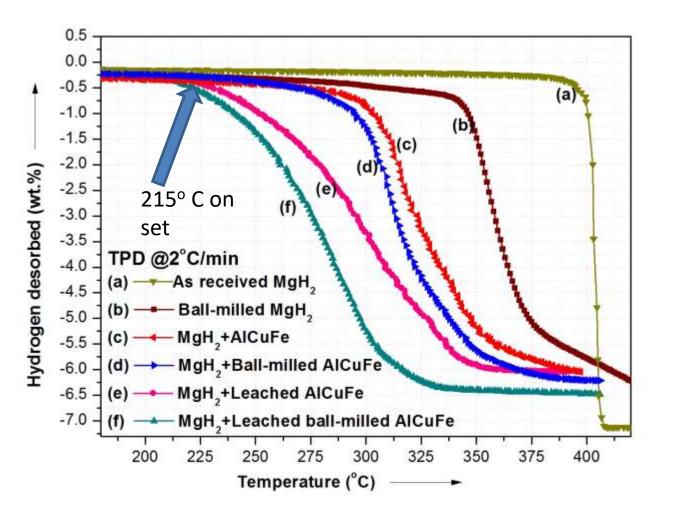


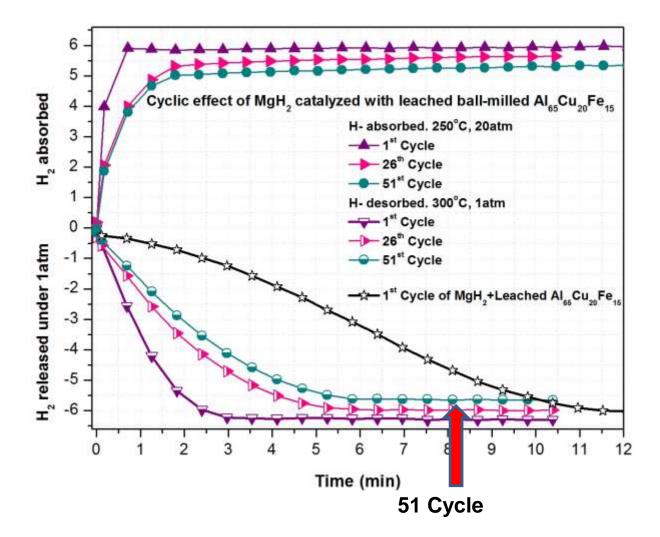
Fig 1: TPD curves of (a) as received MgH₂ (b) ball-milled MgH₂ and MgH₂ catalyzed with (c) Al₆₅Cu₂₀Fe₁₅ (d) Ball-milled Al₆₅Cu₂₀Fe₁₅ (e) Leached Al₆₅Cu₂₀Fe₁₅ and (f) Leached ball-milled Al₆₅Cu₂₀Fe₁₅



310°C

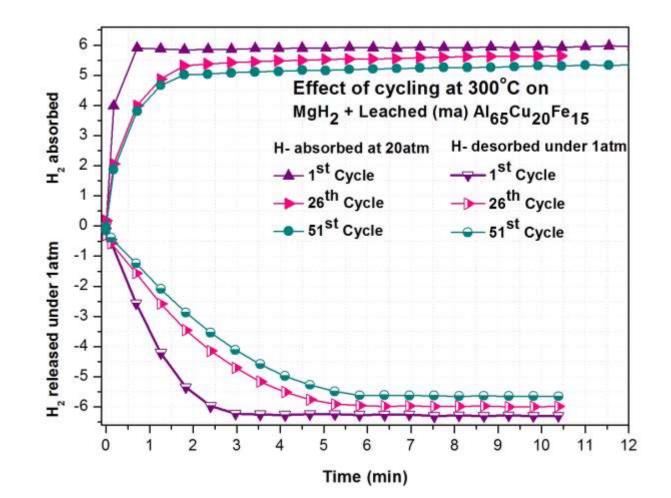


Fig 5: Cyclic effect of Leached ball-milled Al₆₅Cu₂₀Fe₁₅ catalyzed MgH₂

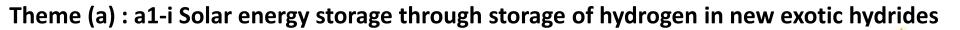


Theme (a) : a1-i Solar energy storage through storage of hydrogen in new exotic hydrides

51 Cycles of absorption and desorption



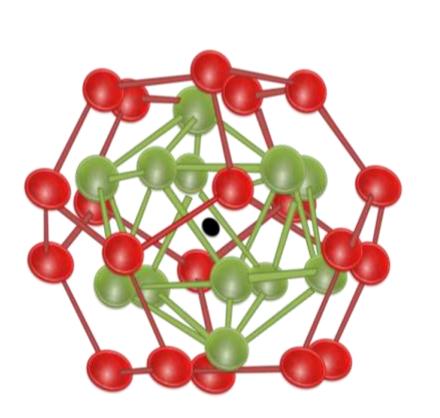


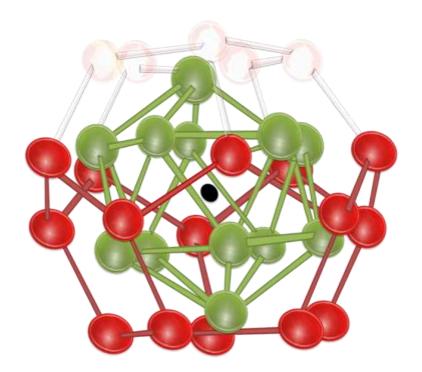


Cu

Fe

ΑΙ



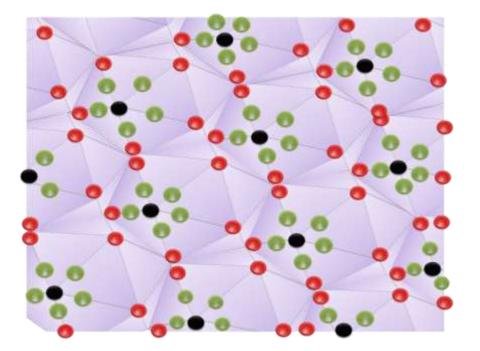


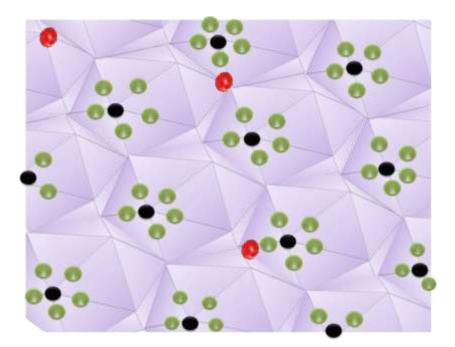
Before Leaching AlCuFe

After Leaching treatment AlCuFe

Theme (a) : a1-i Solar energy storage through storage of hydrogen in new exotic hydrides







Before Leaching AlCuFe

After Leaching treatment AlCuFe

Theme (a) : a1-i Solar energy storage through storage of hydrogen in new exotic hydrides

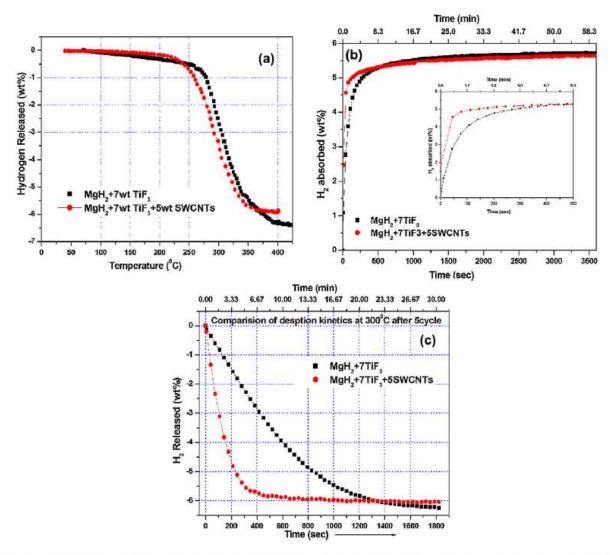
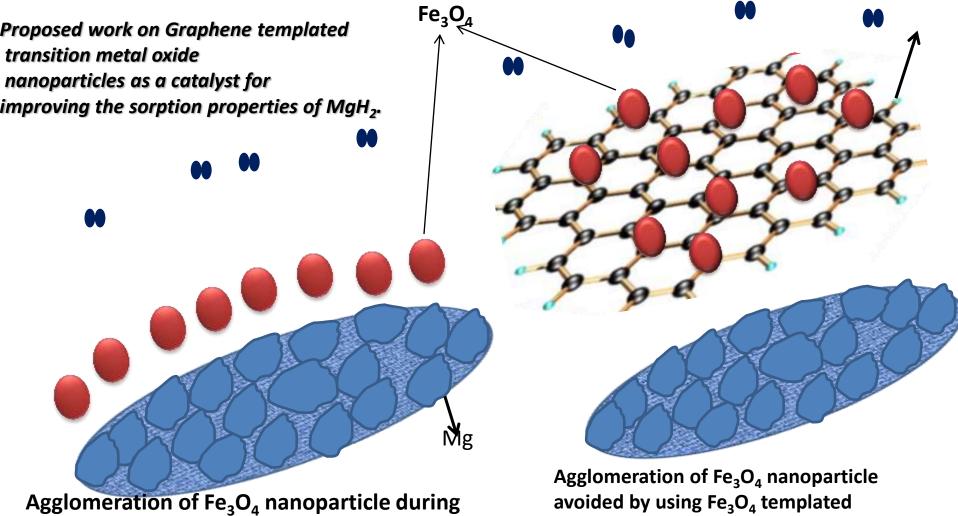


Fig. 4 TPD profile at 5 °C/min, (b) absorption kinetics plot at 27 °C, 1.2 MPa of hydrogen pressure and (c) desorption kinetics plot at 300 °C and 1atm for 5th cycle for $MgH_2 + TiF_3$ with and without SWCNTs.

<u>MgH₂ Catalyzed by TiF₃ and TiF₃ + SWCNT</u>



Theme (a) : a1-i Solar energy storage through storage of hydrogen in new exotic hydrides Graphene Shee



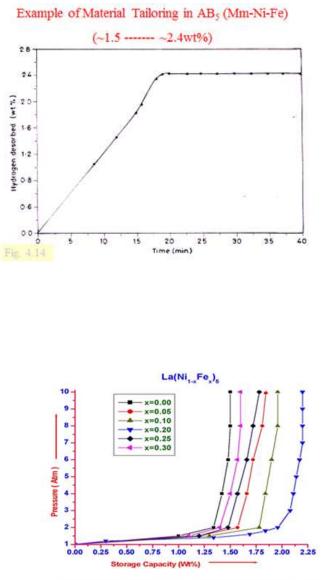
cycling de/rehydrogenation study MgH_2

Agglomeration of Fe_3O_4 nanoparticle avoided by using Fe_3O_4 templated Graphene ($Fe_3O_4@Graphene$) as catalyst cycling de/rehydrogenation of MgH₂



rogenation of MgH₂ catalyzed by Fe₃O₄ and Fe₃O₄@Graphene

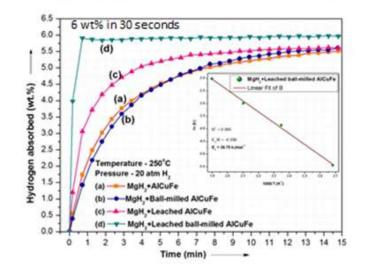
State of the art AB₅ type hydride (Mm-La-Ni_{4.5}Fe_{0.5}



Representative pressure-composition desorption isotherms of the La(Ni_{1-x}Fe_x)₅ alloys (x=0,0.05,0.10,0.20,0.25,0.30).

New hydride (upcoming) catalyzed MgH2

Fig 2: Absorption characteristic curve of the completely desorbed MgH₂ i.e. Mg catalysed by (a) Al₆₅Cu₂₀Fe₁₅ (b) ball-milled Al₆₅Cu₂₀Fe₁₅ (c) Leached Al₆₅Cu₂₀Fe₁₅ and (d) Leached ball-milled Al₆₅Cu₂₀Fe₁₅

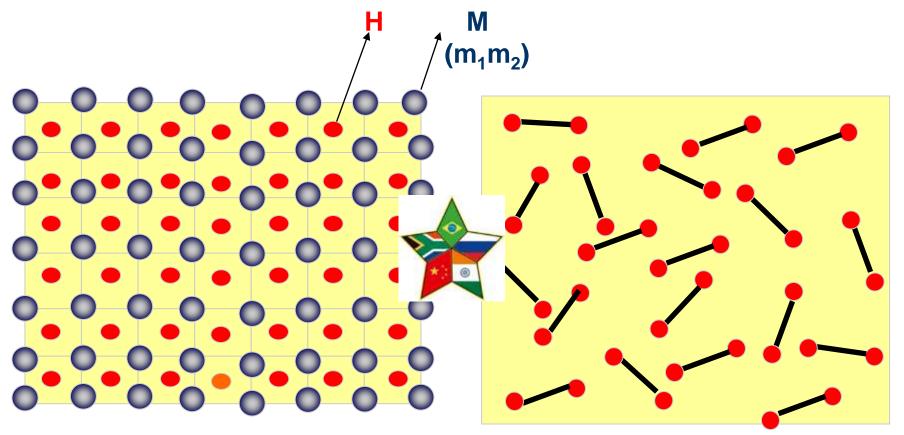


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- Why emphasis on solid state storage (Hydrides)?
- They are more efficient.
- They are safest mode of hydrogen storage.
- They generally satisfy the requirement of volumetric efficiency which is very important for vehicular applications.(Gravimetric efficiency?)
 They posses lot of potential for improvement through material tailoring.

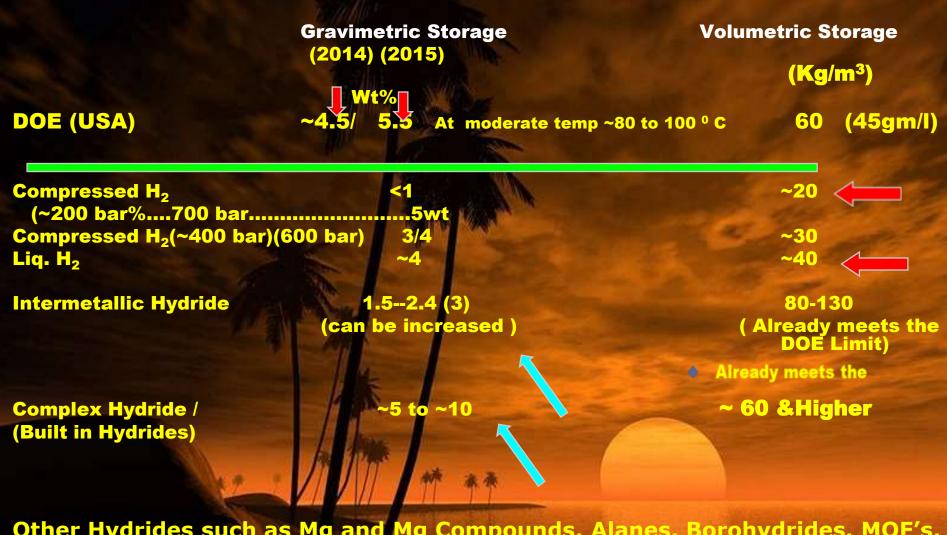




Metal Hydrides

Gaseous / Liquid Hydrogen

Required and Obtained Storage Gharacteristics



Other Hydrides such as Mg and Mg Compounds, Alanes, Borohydrides, MOF's, Zeolites, Clatherates, Liquid Hydrides etc. (Potential candidates which can satisfy the required storage capacity/efficiency, Intense R&D required)



(Gravimetric Storage Capacity) Gaseous Hydrogen is not a feasible and safe way of storage of hydrogen ..AT 700 atmosph. Storage capacity is ~5Wt%..... In Hydride ; MgH₂ at 20-50 atmosos. It is~6Wt. (Volumetric Storage capacity) At 700 atmos for high pressure gaseous VSC is 40 Kg/m3... For MgH₂ at 20-50 atmosos VSC is~ 110Kg/m3

Why Hydrogen Storage in Hydrides for Small Vehicles like Two and Three Wheelers? 1.Volumeric Storage Capacity 2.Safety



THANK YOU FOR YOUR ATTENTION Queries questions are welcome



- 3. Methodology and Plan of work (5 years)
- 3.1 Hydrogen Production: Methodology and Plan of work (5 years)
- 3.1.1. Use of carbon nano structures (CNT and Graphene) for increasing the efficiency of production of Solar Hydrogen
- 3.1.2. Use of graphene Templated TiO₂ for efficient Solar Hydrogen Production





- 3.2 Hydrogen Storage: Methodology and Plan of work (5 years)
- 3.2.1. Hydrogen Storage in light weight hydrides
- 3.2 Hydrogen Storage:
- Methodology and Plan of work (5 years) 3.2
- 3.2.2. Hydrogen Storage in Carbon / Graphene Aerogel



• 3.3 Hydrogen Applications and Plan of work (5 years)