Steel & Hydrogen

Jean-Pierre BIRAT, Secretary General, ESTEP

IEA Hydrogen Roadmap

Paris, 9-10 July 2013

Main messages

1. H_2 is (would be) a very good reducing agent to make steel from iron ore (integrated production route)
2. the steel sector produces large amounts of H_2
3. H_2 is competing with the direct use of electricity (electrolysis of iron ore) for steelmaking
4. steel would be an enabler of the H_2 economy

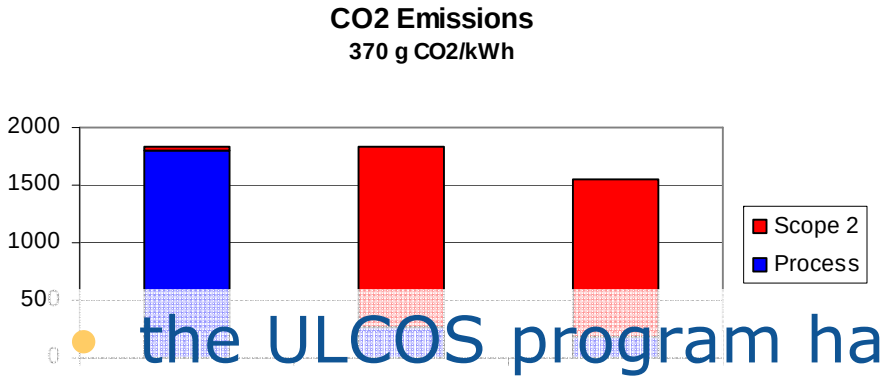
Hydrogen to substitute for coke? (1)

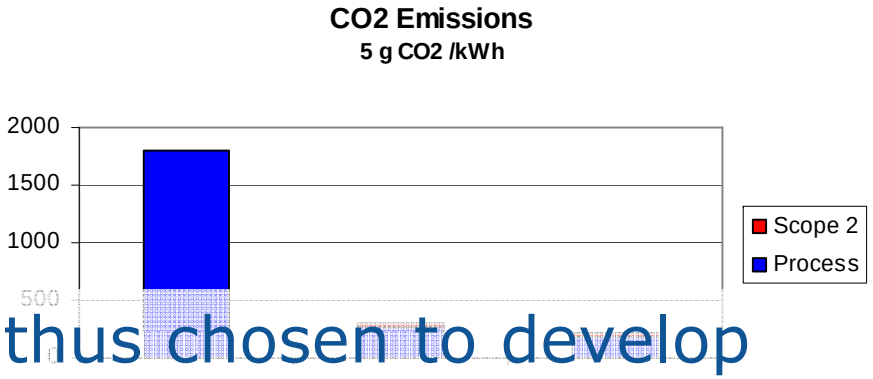
- 570 Nm^3/t DRI
- world potential need: 610 GNm^3/yr or 52 Mt/yr
- EU potential need: 68 GNm^3/yr or 5.8 Mt/yr
- historically, a CIRCORED plant was built and ran in Trinidad (presently mothballed & owned by ArcelorMittal). Other processes studied at pilot scale (TRL6) and lab.
- re-evaluated as part of the ULCOS program. Good substitute for coke (reducing agent), but no visibility in terms of availability and cost of hydrogen: work put on the back burner! Fundamental work in the US (flash smelter, Utah)
- potential market for H_2: 50% for transport, 25% for the chemical sector and 25% for the steel sector, major uncertainty!

H_2, a by-product of steel production? (2)

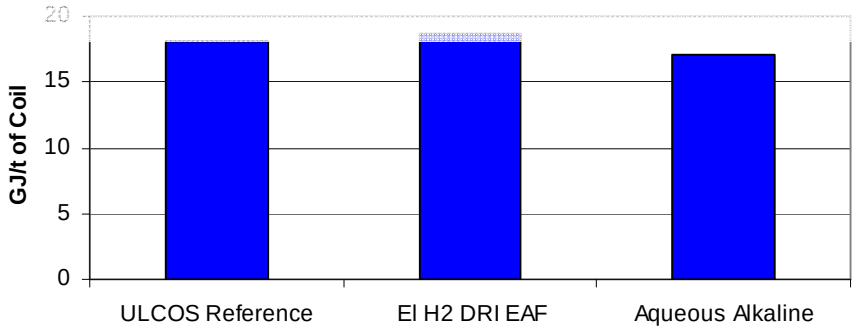
- H_2 is a major component of coke oven gas (COG) (60%)
- worldwide, 12.8 Mt/yr of H_2 in 2011
- today, COG is burned in the internal energy network of the steel mill (including power plant)
- many potentially higher value uses of COG were studied (ethanol, methanol, DME). One H_2 production unit used to be operated in Belgium (CARCOKE, 1980-1996). No implementation left today, except some injection in BF
- development work carried out to sell hydrogen ex COG and produce some more by reforming CH_4 in COG, driven by the expected market for FCV - which did not materialized as quickly as expected (JAPAN: COURSE 50)
- this H_2 might be made available to non-steel users, depending on price and price of substitution gas

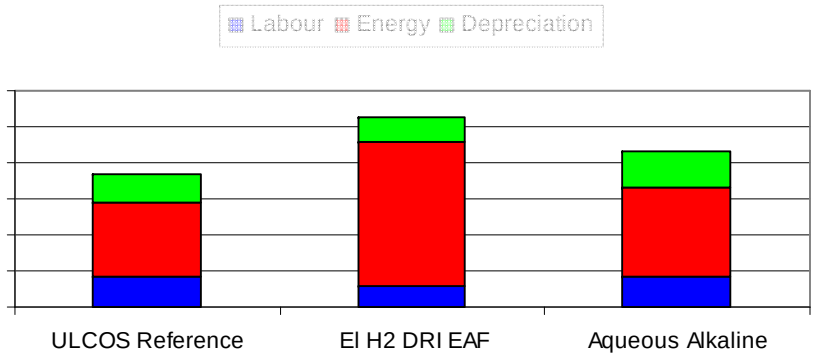
H_2 or direct use of electricity? (3)



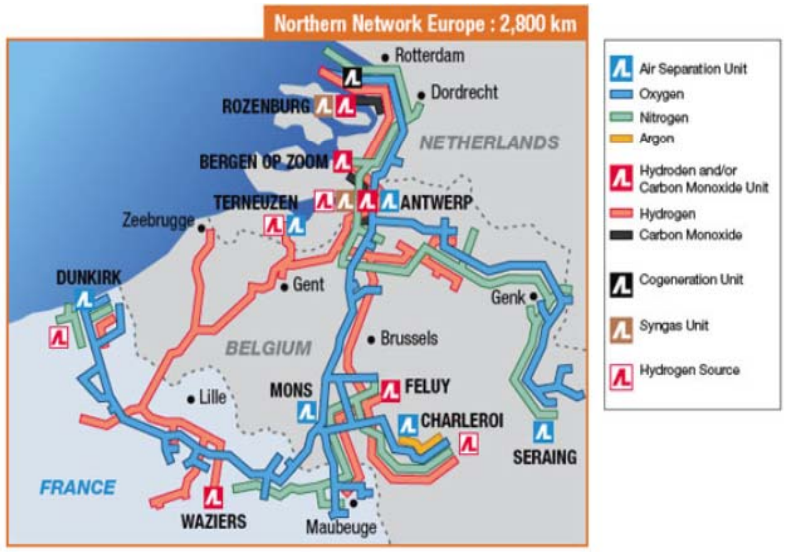


- the ULCOS program has thus chosen to develop electrolysis (ULCOWIN, ULCOLYSIS) as an "ULCOS solution", rather than H_2 direct-reduction





Steel an enabler for the H_2 economy? (4)



- pipelines for H_2 in Europe and USA stretch for 3000 km
- much work still goes into steel development to reduce risk of hydrogen embrittle-ment further (steel and welds)
- steel tanks are also a solution for storing H_2 in FCV (type I ≤300 bars) and, today, for transporting H_2 on trucks (200-300 bars)

Bibliography

Bibliography (1)

- A. Ranzani da Costa, D. Wagner, F. Patisson "Modelling a new, low CO2 emissions, hydrogen steelmaking process" J. Cleaner Production, (2013), 46, 27-35.
- A. Ranzani da Costa, D. Wagner, F. Patisson, D. Ablitzer "Modelling a DR shaft operated with pure hydrogen using a physical-chemical and CFD approach" Revue de Métallurgie, (2009), 10, 434-439.
- A. Ranzani da Costa, D. Wagner, F. Patisson "Cinétique et modélisation d'un nouveau procédé de réduction du minerai de fer par l'hydrogène" 12e Congrès de la Société française de génie des procédés, 14-16 oct. 2009, Marseille. Actes édités par SFGP sur dévédérom, coll. "Récents progrès en génie des procédés", n° 98, ISBN 2-910239-72-1, 1-6.
- A. Ranzani da Costa, D. Wagner, F. Patisson "Modelização de um forno de redução direta do mineral de ferro operado por H2 puro" Proceedings of the 2nd international workshop "Advances in cleaner production", 20-22 May 09, São Paulo, Brazil.
- A. Ranzani da Costa, D. Wagner, F. Patisson, D. Ablitzer "Modelling of a DR shaft operated with pure hydrogen using a physical-chemical and CFD approach" 4th ULCOS Seminar, Sep 2008, Essen, Germany. Proceedings edited by ULCOS consortium, No 4-8, 1-6.
- D. Wagner, O. Devisme, F. Patisson, D. Ablitzer "A laboratory study of the reduction of iron oxides by hydrogen" Sohn International Symposium "Advanced processing of metals and materials", 27-31 Aug. 06, San Diego. Proceedings edited by F. Kongoli and R.G. Reddy, TMS, vol. 2 "Thermo and physicochemical principles: iron and steel making", 111-120.

Bibliography (3)

E. Mostad, S. Rolseth, J. Thonstad, Electrowinning of iron from sulphate solutions, Hydrometallurgy 90 (2008) 213–220

J. Offroy, Brevet français FR 2 287 531 (1974)

A. Allanore, H. Lavelaine, G. Valentin, J.P. Birat and F. Lapicque, « Electrodeposition of Metal Iron from Dissolved Species in Alkaline Media », Journal of the Electrochemical Society, vol. 154, 187-193, (2007)

A. Allanore, « Etude expérimentale de la production de fer électrolytique en milieu alcalin: mécanisme de réduction des oxydes et développement d'une cellule », PhD Dissertation, Institut National Polytechnique de Lorraine, ENSIC-LSGC, France, (2007), available at http://tel.archives-ouvertes.fr/tel-00341283/fr/

A. Allanore, H. Lavelaine, G. Valentin, J. P. Birat and F. Lapicque, Iron Metal Production by Bulk Electrolysis of Iron Ore Particles in Aqueous Media, Journal of The Electrochemical Society, 155 (9) E125-E129 (2008)

Boyan Yuan, Ole Edvard Kongstein, Geir Martin Haarberg, Electrowinning of Iron in Aqueous Alkaline Solution Using a Rotating Cathode, Journal of The Electrochemical Society, 156 (2) D64-D69 (2009)

J.F. Monteiro, A.A.L. Ferreira, I. Antunes, D.P. Fagg , J.R. Frade, Thermodynamic restrictions on mechano synthesis of strontium titanate, Journal of Solid State Chemistry 185 (2012) 143–149

H. Lavelaine de Maubeuge: "Influence of geometric variables on the current distribution uniformity at the edge of parallel plate electrodes", Electrochimica Acta 56 (2011) 10603– 10611

S.Poznyak, V.Kharton, J.Frade, M.Ferreira, Electroplating of iron films: Microstructural effects of alkaline baths", Mat. Sci. Forum, 514-516 (2006) 88-92

S.Poznyak, V.Kharton, J.Frade, A.Yaremchenko, E.Tsipis, I.Marozau, M.Ferreira, Electrocatalytic behaviour of perovskite-related cobaltites and nickelates in alkaline media, Mat. Sci. Forum, 514-516 (2006) 1391-5

J.F. Monteiro, J.C.Waerenborgh, A.V.Kovalevsky, A.A.Yaremchenko, J.R.Frade, SynthesisofSr0.9K0.1FeO3-d electrocatalysts by mechanical activation, Journal of Solid Stat eChemistry 198 (2013) 169–175

Cox, Derek J. Fray, Mechanistic investigation into the electrolytic formation of iron from iron(III) oxide in molten sodium hydroxide, J Appl Electrochem (2008) 38:1401–1407

Deepak Khetpal, Andrew Ducret and Donald R. Sadoway, Towards Carbon-free Metals Production by Molten Oxide Electrolysis, presented at TMS Annual Meeting, Charlotte, March, (2004)

S.Poznyak, V.Karton, J.Frade, A.Yaremchenko, E.Tsipis, S.Yakovlev, I Marozau, Behaviour of (La,Sr)CoO3 and La2NiO4-based ceramic anodes in alkaline media: Compositional and microstructural factors", J.Solid State Electrochem., 12 (2008) 15-30

Sverre Rolseth, Henrik Gudbrandsen, Geir Martin Haarberg, Eirin Kvalheim, Tsuyoshi Murakami, Production of iron with low CO2 emissions. Electrowinning from molten, presented at ISE Meeting Foz do Iguaçu, Brazil – March 16-19 (2008)

Hervé Lavelaine de Maubeuge, Florian Stoesel, Jean-Pierre Birat, ULCOLYSIS: liquid steel from iron ore electrolysis in molten slag, LMPC 2011, International Symposium on Liquid Metal Processing and Casting, Edited by Matthew J.M. Krane, Rodney L. Williamson, Jean Pierre Bellot and Alain Jardy.

Andrei V. Kovalevsky, Eugene N. Naumovich, Aleksey A. Yaremchenko, Jorge R. Frade, High-temperature conductivity, stability and redox properties of Fe3−xAlxO4 spinel-type materials, Journal of the European Ceramic Society 32 (2012) 3255–3263

J.F. Monteiro, A.A.L.Ferreira, I.Antunes, D.P.Fagg, J.R.Frade, Thermodynamic restrictions on mechano synthesis of strontium titanate, Journal of Solid State Chemistry185(2012)143–149

E.M. Domingues, E.V. Tsipis, A.A. Yaremchenko , F.M. Figueiredo, J.C. Waerenborgh, A.V. Kovalevsky, J.R. Frade, Redox stability and electrical conductivity of Fe2.3Mg0.7O4±δ spinel prepared by mechanochemical activation, Journal of the European Ceramic Society 33 (2013) 1307–1315