Frekari þátttaka Íslands í alþjóðlegum vetnisverkefnum

Umfjöllun nefndar á vegum
Iðnaðar- og viðskiptaráðuneytisins
Júlí 2006

Efnisyfirlit

I. Inngangur

Þann 8. júní síðastliðinn skipaði þáverandi iðnaðar- og viðskiptaráðherra Valgerður Sverrisdóttir nefnd til að marka stefnu er varðar undirbúning og þátttöku í alþjóðlegum vetnisverkefnum í samráði við aðila utan stjórnkerfisins. Skipun nefndarinnar byggði á ákvörðun ríkisstjórnar frá 5. maí sl. en þar segir m.a. "*Á grundvelli fyrri stefnumörkunar stjórnvalda, góðs árangurs verkefna og í samræmi við alþjóðlega þróun á sviði vetnismála sem og orku- og loftslagsmála, er lagt til að undirbúin verði stefnumarkandi ákvörðun um þátttöku stjórnvalda í frekari vetnisverkefnum hér á landi á grundvelli hugmynda Nýorku. Mikilvægt er að hægt sé að viðhalda samfellu í slíkum rannsóknum hér á landi og þróa frekar innviði samfélagsins á þessu sviði*." Í nefndina voru skipaðir:

Baldur Pétursson, iðnaðar- og viðskiptaráðuneyti, formaður,
Halldór Árnason, forsætisráðuneyti,
Gunnar Pálsson, utanríkisráðuneyti,
Hugi Ólafsson, umhverfisráðuneyti,
Jóhann Guðmundsson, samgönguráðuneyti,
Þórður Reynisson, fjármálaráðuneyti.

Starfi nefndarinnar skyldi flýtt sem kostur er og lokið fyrir sumarfrí 2006.

Nefndin kom nokkrum sinnum saman í júní og júlí 2006 og fjallaði m.a. um tillögu sem fram kom frá fyrirtækinu Nýorku um alþjóðleg vetnisverkefni hér á landi, auk þess sem hún fékk á fundi sína aðila er tengjast alþjóðlegum vetnisverkefnum hér á landi. Einnig var fjallað um stefnumörkun, þátttöku og reynslu af vetnisverkefnum hér á landi.

Eftirfarandi er umfjöllun nefndarinnar, ásamt tillögum og gögnum sem starfinu tengist.

II. Samantekt og tillögur

II.1 Samantekt

Stefnumótun á sviði vetnismála
Árið 1998 mörkuðu íslensk stjórnvöld stefnu á sviði vetnismála er miðar að þróun í átt að vetnisvæddu samfélagi, svo fljótt sem það verður tæknilega og efnahagslega hagkvæmt. Þetta kom m.a. fram í ráðherrayfirlýsingu frá 27. október 1998 og þátt ríkisins í stofnun Vistorku 1998 sem stóð m.a. að stofnun Íslenskrar Nýorku það ár, ásamt fjölþjóðlegum fyrirtækjum. Þessi stefna er í samræmi við vaxandi alþjóðlega meðvitund um mikilvægi hreinnar orku. Jafnframt þjónar vetni sem unnið er úr endurnýjanlegum orkulindum því hlutverki að draga úr losun gróðurhúsalofttegunda sem talin eru hafa stuðlað að loftslagsbreytingum í heiminum.

Unnið hefur verið að ýmsum verkefnum á grunni þessarar stefnu og nýlega var hún áréttuð frekar í stefnuyfirlýsingu núverandi ríkisstjórnar frá því í mars 2003, en þar segir m.a.: "*Stefnt skal að frekari áföngum í vetnisvæðingu þjóðarinnar og að í framtíðinni byggist orkunotkun landsmanna á endurnýjanlegum orkugjöfum og verði þannig sjálfbær.*" Markviss skref hafa verið stigin á grunni þessarar stefnumótunar, þar sem stjórnvöld hafa boðið Ísland fram sem alþjóðlegan tilrauna- og þróunarvettvang fyrir vetnistækni á grunni samkeppnishæfra starfsskilyrða. Þessi stefnumörkun stjórnvalda og starfsskilyrði hafa verið grunnur að árangursríkum alþjóðlegum samstarfsverkefnum sem einstaklingar, fyrirtæki, stofnanir og háskólar hafa unnið að.

Reynsla og árangur af vetnisverkefnum
Vetnisverkefni, sem stjórnvöld hafa tekið þátt í og stutt, hafa skilað góðum árangri, skapað jákvæða umfjöllun erlendis og stuðlað að tækniþróun og tækniinnflutningi. Með aðild að ECTOS vetnisverkefninu hefur náðst verulegur árangur í rannsóknum hvað varðar tæknilegar, efnahagslegar og félagslegar hliðar á rekstri vetnisstrætisvagna hér á landi, en verkefnið var hið fyrsta sinnar tegundar í heiminum. Í kjölfar þess fóru svipuð verkefni í gang í 10 stórborgum Evrópu. Verkefnið hafði því umtalsvert frumkvöðulsgildi fyrir sambærileg verkefni annars staðar. Það hefur á sama tíma aukið möguleika íslenskra aðila á að taka þátt í frekari alþjóðlegum vetnisrannsóknum sem kostuð eru að stórum hluta til af erlendum aðilum. Þetta hefur komið fram í heimsóknum fulltrúa alþjóðafyrirtækja hingað til lands, m.a. frá General Motors og Shell Hydrogen. Sjá meðal annars bréf frá fyrirtækinu Shell Hydrogen og stefnumörkun þess í Viðauka IV og á vefsíðu fyrirtækisins.

Heildarvelta vetnisverkefna frá árinu 2000 til 2005 var um 2 milljarðar króna, en stærsti hluti fjárins (um 70%) kom erlendis frá. Um 25 ársverk eru unnin á sviði vetnismála á Íslandi. Um 4000 útlendingar frá ýmsum stofnunum og félagasamtökum hafa komið til landsins í tengslum við vetnismál, þar af rúmlega 400 frá fjölmiðlum, og áhugi fer vaxandi. Alls boðuðu um 300 fulltrúar erlendra fjölmiðla komu sína sumarið 2006, m.a. á vegum erlendra fyrirtækja á borð við Daimler Chrysler og GM sem hafa valið Ísland sem vettvang til markaðskynningar á nýrri tækni. Almenningstengslafyrirtækið Athygli ehf. hefur áætlað að verðgildi umfjöllunar í erlendum fjölmiðlum um vetnismál á Íslandi nemi hundruðum milljóna ef ekki milljörðum króna.[1]

Alþjóðleg þróun
Aukin áhersla hefur verið lögð á vetnisrannsókinr í alþjóðasamstarfi á liðnum árum, eins og hafa má stofnun IPHE (International Partnership for the Hydrogen Economy) árið 2003 og starfsemina innan ESB til marks um. Ör þróun á sviði vetnistækni hefur átt sér stað á síðustu árum og ýmsir af stærstu bílaframleiðendum heims undirbúa nú framleiðslu flota tilraunabifreiða á tímabilinu 2010 – 2015 og fjöldaframleiðslu fyrir almennan markað í kjölfarið. Unnið er að uppbyggingu staðbundinna dreifikerfa fyrir vetni í ýmsum löndum til þess að hægt verði að reka þessa tilraunaflota. Dæmi um þetta eru vetnisþjóðbraut (Hydrogen Highway) í Bandaríkjunum og Kanada, í Noregi (HyNor) á milli Oslóar og Stavanger og á nokkrum þéttbýlissvæðum í Japan, Þýskalandi og víðar.

[1] Svar iðnaðarráðherra við fyrirspurn frá Hjálmari Árnasyni - 430. mál : 2. mars 2003, um verðmæti umfjöllunar um vetnisáhrif. Fyrirtækið Athygli ehf., og Bracken Public Relations á Írlandi mat m.a. þessi atriði. Nefna má bækling um vetnisverkefni á Íslandi sem Shell Hydrogen dreifði og gerir enn í miklu magni á alþjóðlegum mörkuðum sem og vefsíðu sinni.

II.2 Tillögur nefndarinnar

Nefndin hefur kynnt sér þá valkosti sem fyrirtækið Nýorka hefur sett fram um frekari vetnisverkefni, þar sem reynt er að mati Nýorku að stilla kostnaði í hóf, án þess að slíkt komi niður á gæðum eða þátttöku erlendra aðila í verkefnunum.

Nefndin leggur til að stjórnvöld ákveði að styðja frekari alþjóðleg rannsóknarverkefni á sviði vetnis hér á landi. Tillagan tekur mið af stefnumörkun stjórnvalda á sviði vetnismála, góðum árangri íslenskra vetnisverkefna, áherslum í alþjóðastarfi og þróun á sviði vetnistækni í bílaiðnaði. Jafnframt hefur nefndin haft stefnu Íslands í orku-, rannsókna- og loftslagsmálum, samgöngumálum og utanríkismálum til hliðsjónar.

Á árinu 2006 lýkur ECTOS verkefninu og af því tilefni hefur fyrirtækið Nýorka unnið að undirbúningi framhaldsverkefna á sviði vetnis með innlendum sem erlendum aðilum, sem m.a. felst í tilraunaakstri vetnisbifreiða sem yrðu seldar eða leigðar til stofnana og fyrirtækja, auk þess sem settur yrði upp vetnisbúnaður um borð í skipum í tilraunaskyni. Með þessum verkefnum yrði tryggt að ekki slái í bakseglin í þróun vetnisverkefna á Íslandi og núverandi samkeppnisforskot tapist ekki, hvað varðar möguleika á því að Ísland verði vettvangur frekari vetnistilrauna og -þróunar. Tækju íslensk stjórnvöld ákvörðun um að taka ekki frekari þátt í alþjóðlegum vetnisverkefnum með fjárframlögum, má telja víst að afar erfitt yrði að fá erlenda fjármögnunaraðila til að taka þátt í stórum vetnisverkefnum hér á landi.

Nefndin mælir með því að stuðningur ríkisins taki mið af tillögu II í viðauka þessarar skýrslu, enda tryggi hún samfellu í vetnisverkefnum hér á landi. Tillagan gerir ráð fyrir rekstri allt að 30 vetnisbíla á Íslandi á árunum 2007 – 2009. Auk stuðnings íslenska ríkisins, myndu innlendir og erlendir aðilar fjármagna stærstan hluta verkefnisins. Heildarkostnaður þess er áætlaður um 533 millj. kr. Þar af yrði hlutur ríkisins 225 millj. kr. eða um 42%, en hlutur annarra aðila um 308 millj. kr., eða 58%. Fjármögnun stjórnvalda næmi um 75 millj. kr. á ári í þrjú ár og yrði háð því að fjármögnun annarra innlendra og erlendra aðila, samkvæmt tillögu II í fylgiskjali, gengi eftir.

Vegna sérstakra aðstæðna og aðhalds í ríkisfjármálum árið 2007, er mælt með því að fjármögnun stjórnvalda nemi 50 millj. kr. árið 2007, en 87,5 millj kr. 2008 og 2009 og verði háð því að fjármögnun annarra innlendra og erlendra aðila samkvæmt tillögu II í fylgiskjali, gangi eftir. Fjármagn vegna þessa rannóknaverkefnis verði tryggt með sérstakri fjármögnun stjórnvalda og verði veitt beint til verkefnisins í formi hækkunar á hlutafé ríkisins í Vistorku. Verði af þessu verkefni, er æskilegt að gerð verði grein fyrir framvindu þess til þeirra ráðuneyta sem að þessari umfjöllun komu, t.d. innan óformlegrar nefndar á vegum iðnaðarráðuneytis sem þegar er starfandi og fjallar um alþjóðlega vetnisverkefnið IPHE (International Partnership for Hydrogen Economy).

Að dómi nefndarinnar er verkefnið einkar mikilvægt fyrir þróun innviða vetnissamfélags á Ísland, auk þess sem stuðningur hins opinbera er forsenda fyrir mótframlögum erlendra samstarfsaðila. Talið er mikilvægt að viðhalda samfellu í vetnisrannsóknum og þróa frekar innviði samfélagsins á þessu sviði, vilji stjórnvöld halda áfram á þeirri braut sem mörkuð hefur verið til þessa. Jafnframt má benda á að torvelt kynni að reynast fyrir Ísland að taka upp þráðinn að nýju, verði umtalsvert hlé á þátttöku í slíkum verkefnum.

III. Stefnumörkun á sviði vetnismála og tengdra málaflokka

III.1 Orku- og vetnismál

Sýn til framtíðar
Í áratugi hefur það verið stefna íslenskra stjórnvalda að nýta á sjálfbæran hátt endurnýjanlegar orkulindir landsins í sátt við náttúru og umhverfi. Þessi stefna byggist á miklum rannsóknum og hagnýtingu á þeim miklu auðlindum sem er að finna á sviði vatns- og gufuorku landsins.

Ísland hefur náð því takmarki að hætta allri raforkuframleiðslu með jarðefnaeldsneyti. Endurnýjanlegar orkulindir anna nú um 72% af allri frumorkuþörf í landinu. Markmið stjórnvalda er að hækka þetta hlutfall enn frekar og stefna í átt að kolefnalausum orkubúskap í framtíðinni þar sem endurnýjanlegar orkulindir gegna veigamiklu hlutverki. Stefnumörkun og verkefni á sviði vetnismála eru veigamikill hluti af þessari stefnu.

Á árinu 1998 mótuðu stjórnvöld skýra stefnu á sviði vetnismála. Stefnumörkun til lengri tíma miðar að framleiðslu vetnis með endurnýjanlegum orkugjöfum, sem geti komið í stað jarðefnaeldsneytis í samgöngum og á skipum um leið og slíkt verður tæknilega og efnahagslega hagkvæmt.

Vetni er mengunarlaus og kraftmikill orkuberi sem má framleiða með mismunandi leiðum, m.a. með endurnýjanlegum orkulindum landsins. Markmið íslenskra stjórnvalda er að auka hlut innlendra endurnýjanlegra orkulinda og að draga úr mengun og losun gróðurhúsalofttegunda með hagsmuni umhverfis, hagkerfis og almannahagsmuni að leiðarljósi. Með þessu móti leggur Ísland jafnframt af mörkum í alþjóðlegri baráttu til verndunar lofthjúps jarðar.

Alþjóðlegur vettvangur fyrir vetnisrannsóknir
Rannsóknir er varða framleiðslu vetnis með endurnýjanlegri innlendri orku, hafa verið stundaðar við Háskóla Íslands um áratuga skeið og hafa leitt til aukins alþjóðlegs samstarfs og rannsókna á þessu sviði.

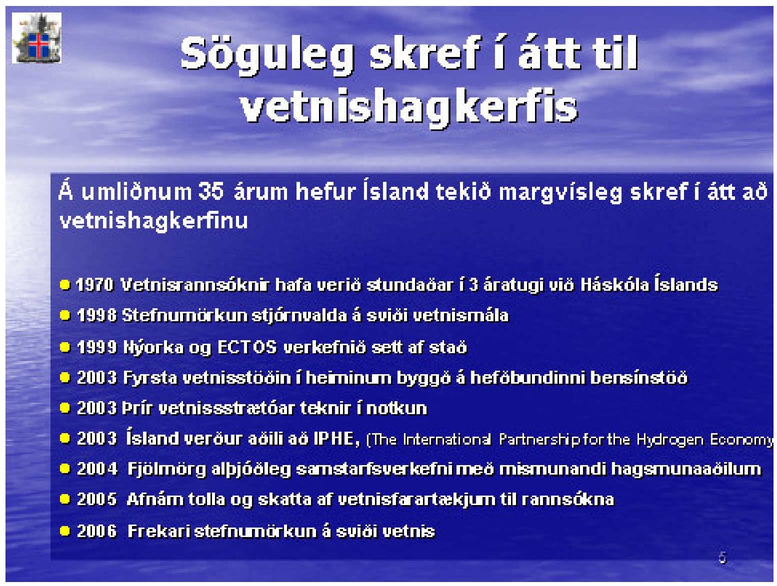
Á þessum grunni hafa íslensk stjórnvöld lagt áherslu á að bjóða upp á samkeppnishæft starfsumhverfi fyrir rannsóknir og tilraunir, sem byggist á alþjóðlegu samstarfi opinberra aðila og einkaaðila – þannig að til verði heppilegasta starfsumhverfi fyrir framþróun og þekkingu á þessu sviði.
Stefnu íslenskra stjórnvalda má skipta í eftirfarandi fimm þætti:

- samkeppnishæft starfumhverfi,
- alþjóðlegt samstarf,
- vetnisrannsóknir og tilraunir,
- kynningu, menntun og þjálfun,
- frekari stefnumörkun og verkefni.

Starf á sviði vetnismála varðar í vaxandi mæli eftirfarandi þrjá málaflokka:

- **Orkumál**
  - öryggi í framboði á orku,
  - nýting endurnýjanlegra orkulinda.
- **Loftslags- og umhverfismál**
  - barátta gegn loftslagsbreytingum af mannavöldum,
  - gæði lofts og heilbrigði.
- **Efnahags- iðnaðar- og tæknimál**
  - aukin tækifæri og verðmæti,
  - hafa áhrif á þróun tækni og umhverfis,
  - alþjóðleg samvinna einkaaðila og opinberra aðila.

Vaxandi tengsl eru á milli þessara málaflokka, sem eru helstu drifkraftar þróunar á sviði vetnismála. Á alþjóðavettvangi hefur verið lögð aukin áhersla á öryggi í orkuöflun með frekari þróun nýrra valkosta, ekki síst vegna hækkandi orkuverðs og ótryggs framboðs orkugjafa, einkum olíu og gass. Samhliða hafa aukin gróðurhúsaáhrif beint sjónum manna að mótaðgerðum, m.a. með því að draga úr mengun í samgöngugeiranum, en með aukinni notkun vetnis í samgöngum er hægt að draga verulega úr losun gróðurhúsalofttegunda. Síðast en ekki síst hafa alþjóðleg bifreiðafyrirtæki lagt aukna áherslu á tækninýjungar í orkusparnaði.



Miklu máli skiptir að alþjóðlegu samstarfi verði fram haldið í vetnismálum svo unnt verði að ná tökum á þeim tæknilegu viðfangsefnum sem enn er við að etja.

Starfsskilyrði rannsókna

Aukin nýting endurnýjanlegra orkuauðlinda í formi vatnsafls og jarðvarma hefur stuðlað að aukinni velsæld íslensku þjóðarinnar á undanförnum áratugum. Erlend fjárfesting á sviði orkufreks iðnaðar hefur verið snar þáttur í þessari þróun.

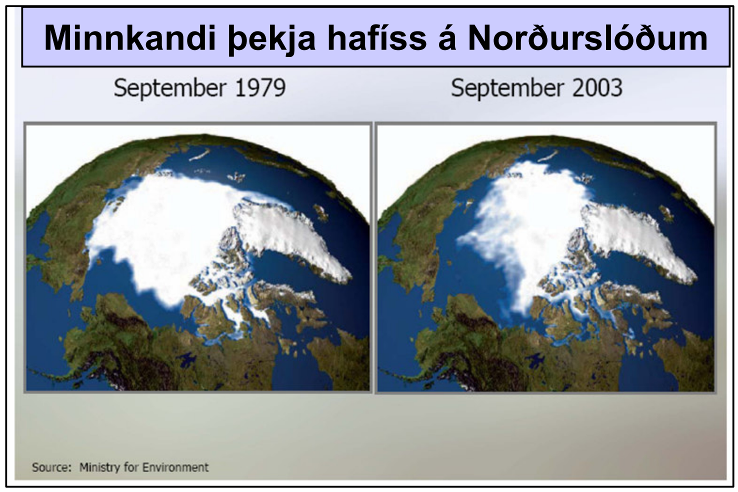
Íslenskt samfélag er tæknivætt og hagkerfið þróað. Frelsi á sviði erlendra fjárfestinga, einfalt stjórnkerfi, hátt menntunarstig og sveigjanlegt vinnuafl hafa laðað að erlenda fjárfestingu, m.a. á sviði vetnismála.

III.2 Loftslags-, umhverfis- og vetnismál

Vetnisverkefni og loftslagsmál

Verkefni á sviði vetnismála falla vel að markmiðum stjórnvalda í loftslagsmálum. Vetnið er unnið úr endurnýjanlegum orkulindum á Íslandi og kæmi í stað innflutts jarðefnaeldsneytis, en við bruna þess myndast gróðurhúsalofttegundir, einkum koltvíoxíð, sem stuðlar að hlýnun lofthjúpsins.

Í stefnu Íslands í loftslagsmálum frá árinu 2002 kemur fram að "Gerðar verði tilraunir með orkugjafa sem komið geta í stað olíu s.s. vetni. Jafnframt verði vel fylgst með þróun annarrar nýrrar tækni hvað þetta svið varðar."



Í umræðu um endurskoðun á stefnu Íslands í loftslagsmálum, sem nú stendur yfir, hefur komið fram að líta beri til lengri tíma og stefnumörkunin tengd betur við aðra málaflokka, m.a. þróunarsamvinnu, gjaldeyrissparnað í eldsneytis-kaupum og skógrækt og landgræðslu. Þróunarverkefni á sviði vetnis og annarrar loftslagsvænnar tækni væri auðvelt að setja í slíkt samhengi.

Miklu skiptir að tekin verði upp heildstæð stefna í loftslagsmálum. Þróunarverkefni á sviði vetnis eða annarra loftslagsvænna orkugjafa og tækni þjóna því markmiði að dregið verði úr áhrifum loftslagsbreytinga til lengri tíma litið. Jákvæð skref hafa verið stigin í samræmi við loftslagsstefnu stjórnvalda varðandi gjaldtöku á undanförnum misserum, með tímabundinni lækkun á gjöldum á vetnisbíla og aðra loftslagsvæna bíla, auk upptöku olíugjalds í stað þungaskatts.

Í tengslum við endurskoðun loftslagsstefnunnar hefur m.a. verið rætt um ívilnandi aðgerðir vegna sparneytinna bíla, loftslagsvænt eldsneyti og loftslagsvænni tækni. Í slíku umhverfi væru tilraunaverkefni á sviði vetnisbíla og skipa rökréttur liður í heildstæðri loftslagsstefnu, þar sem hagrænir hvatar væru notaðir til þess að draga úr losun gróðurhúsaloftegunda og skapa loftslagsvænni tækni betri samkeppnisstöðu, jafnframt því sem unnið yrði að því að greiða götu tækniþróunar á afmörkuðum sviðum.

Á þessu stigi verður ekkert fullyrt um hvaða tækni er líklegust til að skila árangri í loftslagsmálum. Æskilegt er að almennir hagrænir hvatar verði látnir stýra tækniþróuninni. Jafnframt er þó nauðsynlegt að hlúa að frekari rannsóknarverkefnum á ákveðnum sviðum. Þannig væri eðlilegt að Íslendingar legðu fyrst og fremst af mörkum þar sem mikil sérþekking er til staðar, t.d. á sviði djúpborana og annarra rannsóknaverkefna í jarðhita, bindingar kolefnis með landgræðslu og skógrækt og vetnistilrauna.

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Vetnisverkefni og sjálfbær þróun
Í stefnumörkun Íslands um sjálfbæra þróun, "Velferð til framtíðar", sem samþykkt var í ríkisstjórn árið 2002 kemur m.a. fram að "Hlutfall endurnýjanlegra orkugjafa í orkunotkun þjóðarinnar verði aukið og að því stefnt að notkun jarðefnaeldsneytis verði óveruleg innan fárra áratuga. Stefnt verði að því að farartæki nýti orku sem framleidd er með endurnýjanlegum orkugjöfum eins fljótt og kostur er og hagkvæmt þykir."

Verkefni sem miða að framleiðslu vetnis úr endurnýjanlegum orkugjöfum og nýtingu þess í bílum og skipum, svo og önnur rannsóknar- og þróunarverkefni á sviði loftslagsvæns eldsneytis og orkutækni, þjóna þessum markmiðum einkar vel.

III.3 Skattar og gjöld – stefnumörkun á sviði vetnismála

Með lögum nr. 72/2005, sem samþykkt voru á vorþingi 2005, voru gerðar tímabundið eða til 31. desember 2008 umfangsmiklar breytingar á lögum nr. 50/1988, um virðisaukaskatt, lögum nr. 29/1993, um vörugjald af ökutækjum, eldsneyti o.fl, lögum nr. 97/1987, um vörugjald, og tollalögum, nr. 55/1987, með síðari breytingum. Til að mynda er eftir gildistöku laganna nú heimilt að fella niður eða endurgreiða virðisaukaskatt að fullu af vetnisbifreiðum og af sérhæfðum varahlutum í þær og ekki þarf að greiða vörugjald eða toll af ökutækjum eða sérhæfðum varahlutum í þau ökutæki sem nota vetni sem orkugjafa.

Framangreindar breytingar höfðu það að markmiði að gera skatta- og tollaumhverfi fyrir innflutning vetnisbifreiða og sérhæfðra varahluta í þær hagstæðari. Umræddar breytingar voru gerðar í samræmi við stefnu íslenskra stjórnvalda sem miða að sjálfbæru vetnissamfélagi í framtíðinni. Í því skyni m.a. að bæta samkeppnishæfni Íslands var talið nauðsynlegt að veita vetnisbifreiðum ákveðnar ívilnanir þar sem framleiðsla þeirra var enn á rannsóknar- og tilraunastigi, og verð slíkra bifreiða því mun hærra en annarra ökutækja. Litið var svo á að með bættri samkeppnishæfni væri mögulegt að fá hingað til lands aukinn hluta af þeim alþjóðlegu rannsóknarverkefnum sem unnið er að og greiða um leið fyrir þeirri þróun að vetni komi í stað olíu sem eldsneyti í samgöngum í samræmi við stefnu ríkisstjórnarinnar.

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III.4 Stefnumörkun á sviði samgöngumála og þróun vetnisbifreiða

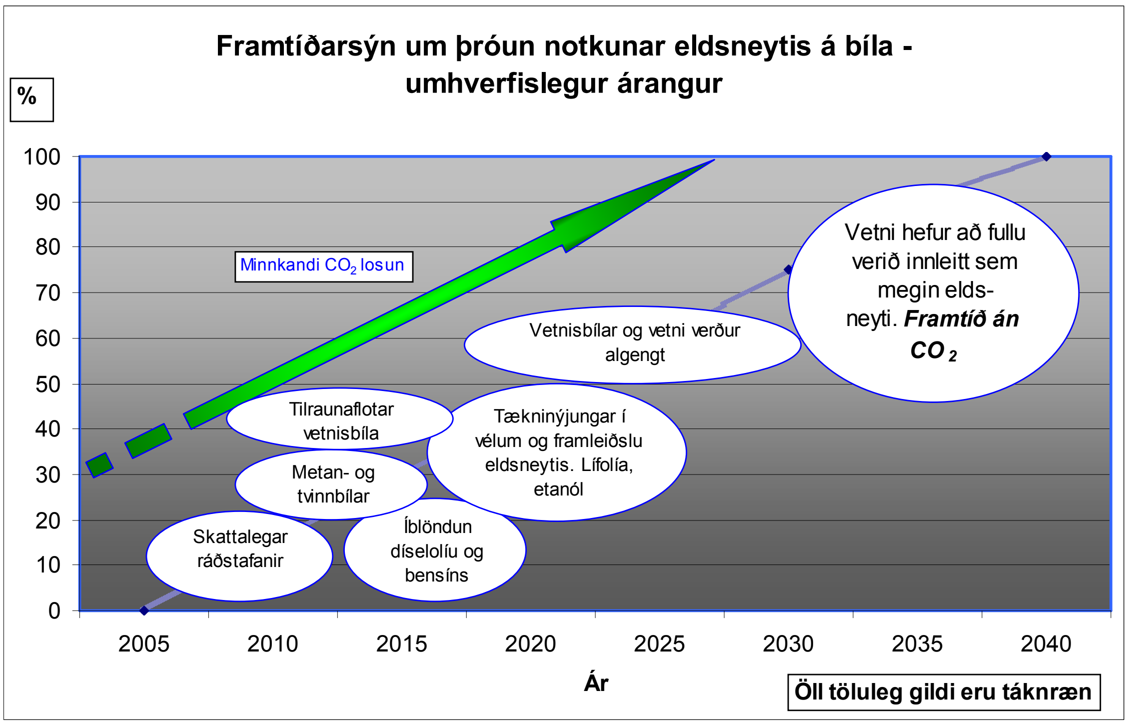
Frekari þátttaka íslenska ríkisins í vetnisverkefnum er einnig í samræmi við stefnu stjórnvalda í nýrri samgöngumálum, en drög að henni fyrir tímabilið 2007-2018 voru kynnt á samgönguþingi í apríl 2006.

Eitt af markmiðum stjórnvalda er að stefnt skuli að sjálfbærum samgöngum. Markmiðið felur í sér að umhverfisáhrifum samgangna, bæði hnattrænum, svæðisbundnum og staðbundnum, verði haldið innan ásættanlegra marka. Dregið verði úr losun gróðurhúsalofttegunda með minni notkun jarðefnaeldsneytis og stefnt að því að samgöngutæki nýti orku sem framleidd er með endurnýjanlegum orkugjöfum auk orkusparandi aðgerða við farartæki sem eru og verða fyrir hendi í landinu, eins fljótt og kostur er og hagkvæmt þykir. Markmið þessi taka mið af Kyoto sáttmálanum um losun gróðurhúsalofttegunda, sem Ísland hefur staðfest. Sáttmálinn gildir til 2012 eða um helming áætlunartímabilsins. Á þeim tíma mun umferð bíla aukast, en nauðsynlegt er að útblástur gróðurhúsalofttegunda aukist ekki að sama skapi.

Í fyrrnefndum drögum að samgönguáætlun er sett fram að meðal aðgerða til að ná þessu markmiði verði:

1) Stuðlað að nýtingu umhverfisvænna orkugjafa. Miðað verði við að í lok áætlunartímabilsins verði notkun vistvæns eldsneytis 20% af heildarnotkun í samgöngum. Einnig verði lögð áhersla á beitingu orkusparandi aðferða og rannsókna til að auka orkusparnað núverandi fiskiskipaflota landsmanna.

2) Skattlagning eignarhalds og notkunar bíla með þeim hætti að sparneytnir bílar, tvinnbílar, bílar sem nota vistvænt eldsneyti og bílar sem nota gasolíu sem eldsneyti verði fýsilegri kostur en nú er. Sama skal gilda um notkun vistvænna skipavéla sem nota svartolíu og sparneytna aðal- og hjálparvél og vistvænna véla í flugvélum þar sem þetta getur átt við.



Meginhugsuninni í samgöngustefnunni hvað þetta varðar má skipta í þrjú stig. Í fyrsta stigi verði sem fyrst tekist á við að breyta skattlagningu bifreiða þannig að hvatt sé til notkunar á sparneytnari bifreiðum. Þetta er afar brýnt til þess að draga úr innflutningi á jarðefnaeldsneyti. Næsta stig, en stigin eru reyndar öll samfallandi að hluta, er að skapa rými fyrir annars konar eldsneyti. Getur þar verið um að ræða eldsneyti sem kalla mætti lífrænt, svo sem etanól, bíódísel og metan.

Því er spáð að miklar framfarir verði í slíkri framleiðslu á næstunni þar sem gerlegt verður að framleiða svokallað 2. kynslóðar eldsneyti úr trénisríkari efnum sem jafnvel gæti opnað nýja möguleika hér á landi. Skapa þarf svigrúm fyrir slíka innleiðingu nýs eldsneytis með skattalegum ívilnunum í byrjun. Notkun á þessu eldsneyti verður sífellt algengari í nágrannalöndunum og hefur ESB þegar sett sér það markmið að hlutur þess í samgöngum aðildarríkja verði 5.75% árið 2010. Þriðja stigið er vetni, ef vonir sem við það eru bundnar, verða að veruleika.

III.5 Vegvísir á sviði vetnismála

Unnið hefur verið, á vegum iðnaðarráðuneytisins, að dröum að vegvísi á sviði vetnismála, í samræmi við sambærilega vinnu í öðrum löndum og tilmæli á vettvangi IPHE. Í meginatriðum skiptist umfjöllunin í eftirfarandi fimm meginsvið: 1. vetnisframleiðslu, 2. geymslu vetnis, 3. innviði á sviði vetnis, 4. tilraunaverkefni og 5. rannsóknarverkefni. Samkvæmt vegvísinum er meginatriði á þessu sviði alþjóðlegra rannsókna að byggja upp samstarf við alþjóðlega aðila á sviði rannsókna og tilrauna. Nánari grein er gerð fyrir þessum atriðum í Viðauka III.

IV. Aljóðleg þróun

IV.1 Þátttaka í IPHE

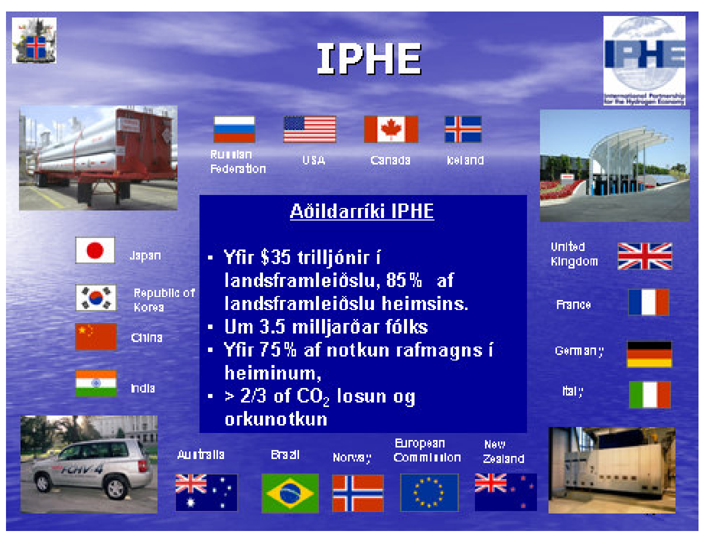
Árið 2003 var Alþjóðavettvangur um vetnisþróun, IPHE (International Partnership for Hydrogen Economy) stofnaður. Ísland var meðal stofnaðila IPHE, en nú eru alls 17 ríki aðilar að samtökunum, sem hafa það að markmiði að efla alþjóðlegt samstarf og rannsóknir á sviði vetnis.


Ísland stofnaðili að alþjóðlegu vetnisverkefni

Vorið 2004 var undirrituð viljayfirlýsing á milli Manitóba í Kanada og Íslands á sviði vetnis og ýmis önnur alþjóðleg samstarfsverkefni eru í gangi á þessu sviði á milli aðila á markaði.

Stefna IPHE felst m.a í áherslu á aukið alþjóðlegt samstarf, samræmingu, rannsóknir, kynningu og samstarf á milli einkaaðila og opinberra aðila. Vaxandi umsvif eru á sviði vetnismála hjá flestum aðildarríkjum og auknu fjármagni er varið til málaflokksins.

Áherslur á sviði vetnis tengjast stefnumörkun margra landa á sviði umhverfismála og viðleitni til að draga úr mengun og gróðurhúsalofttegundum, sem og að treysta öryggi í orkuöflun. Takmarkaðar olíubirgðir heims og sveiflur á verði olíu hefur ýtt enn frekar undir þróun á vetni sem sem orkubera.



Þátttaka Íslands í starfi IPHE er í samræmi við stefnumörkun stjórnvalda á sviði vetnis- og orkumála er miðar að þróun í átt að vetnisvæddu hagkerfi, svo fljótt sem það verður tæknilega og efnahagslega hagkvæmt. Einn þáttur þessarar stefnu er að á Íslandi geti orðið vettvangur alþjóðlegra vetnisrannsókna, þar sem lögð verði áhersla á hagstæð starfsskilyrði, alþjóðlegt samstarf, þróun tilraunaverkefna og þekkingu. Verkefni á sviði vetnisrannsókna hér á landi hafa þegar vakið alþjóðlega athygli.

Tvö ráðuneyti, iðnaðarráðuneytið og utanríkisráðuneytið, eiga sæti fyrir Íslands hönd í stýrinefnd IPHE, en Bandaríkin fara með formennsku í henni. Ísland fer með formennsku, ásamt Þýskalandi, í framkvæmdanefnd IPHE. Nýlega var ákveðið að þessi skipan formennsku yrði óbreytt næstu tvö ár.

Fundur stýrinefndar IPHE verður haldinn á Íslandi í september 2006, en slíkir fundir eru haldnir til skiptis í aðildarríkjunum. Fundur framkvæmdanefndar IPHE var haldinn á Íslandi haustið 2004.

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IV 2 Vetniskynning á alþjóðlegum vettvangi

Að frumkvæði utanríkisráðuneytisins hefur mikil áhersla verið lögð á að kynna möguleika vetnisnýtingar á alþjóðlegum vettvangi.

Ísland stóð að kynningarfundum fyrir fastanefndir aðildarríkja hjá Sameinuðu þjóðunum, alþjóðastarfslið samtakanna, Þróunarstofnunina (UNDP) og Umhverfisstofnunina (UNEP) í nóvember 2004 þar sem kynntar voru áherslur Íslands í vetnismálum og tengsl þeirra við sjálfbæra orkustefnu Íslendinga.

Í framhaldi af fundunum var stofnað til samstarfs við efnahags- og félagsmálaskrifstofu Sameinuðu þjóðanna (DESA) um að haldið yrði fræðslunámskeið um vetnistækni og vetnisþróun í tengslum við fjórtánda ársfund nefndar Sameinuðu þóðanna um sjálfbæra þróun (CSD-14) í New York í maí 2006. Jafnframt var ákveðið að Ísland og DESA skyldu standa sameiginlega að alþjóðlegri ráðstefnu um sjálfbæra orkunýtingu í þróunarríkjum með áherslu á jarðhita og vetnistækni í Reykjavík í beinu framhaldi af fundi stýrinefndar IPHE í september 2006.

Á ráðstefnunni verða kynnt vetnisáform Íslandinga þar sem stefnt er að því að auka hlut endurnýjanlegrar orku í orkubúskapnum enn frekar. Þá verða kannaðir möguleikar þess að koma á fót samstarfsverkefni í litlu eyþróunarríki um þróun samkeppnishæfrar jarðhitanýtingar í tengslum við vetnisframleiðslu til að draga úr innflutningi jarðefniseldsneytis og stuðla að sjálfbærum orkubúskap. Niðurstöður ráðstefnunnar verða lagðar fyrir næsta ársfund nefndar Sameinuðu þjóðanna um sjálfbæra þróun (CSD-15) í New York í maí 2007.

Með þessu móti vilja íslensk stjórnvöld nýta alþjóðlegt samstarf á sviði vetnismála til að kynna málstað sjálfbærrar orkuþróunar og styrkja jákvæða ímynd Íslands á sviði orkumála. Athygli er vakin á viðleitni landsins til að nýta reynslu sína af sjálfbærri orkunýtingu í þágu þróunarríkja og áherslu Íslendinga á sjálfbæra nýtingu náttúruauðlinda til lands og sjávar.

IV.3 Aukin áhersla á vetnisþróun í öðrum ríkjum

Flest ríki OECD og vaxandi fjöldi þróunarríkja hafa rannsóknar- og þróunaráætlanir á sviði vetnismála. Greinileg aukning er á framlögum þeirra til vetnismála á allra síðustu árum sem ber vott um sannfæringu margra stærstu ríkja heims um að vetni muni gegna lykilhlutverki í orkubúskap framtíðarinnar. Umhverfisstofnun Sameinuðu þjóðanna (UNEP) áætlar að heildarframlag hins opinberra til vetnisþróunar víðsvegar um heim nemi árlega jafnvirði allt að hundrað milljörðum íslenskra króna. Framlög einkafyrirtækja nema enn hærri upphæðum.

Hér að neðan eru nokkur dæmi sem bera vott þessarar þróunar. Ljóst er að allir bifreiðaframleiðendur heims eru nú að vinna að þróun vetnisbílsins og er þróunin hröðust þar sem þeir hafa sínar höfuðstöðvar. Fáir geta þó keppt við Íslendinga um hreina orkukeðju byggða á endurnýjanlegum frumorkugjöfum til vetnisframleiðslu fyrir tilraunabíla.

Bandaríkin
Bandaríkin hafa lagt aukna áherslu á rannsóknir og lausnir á sviði vetnismála á seinustu árum eins og glöggt má sjá í stefnuræðum forseta Bandaríkjanna og hefur háum fjárhæðum verið varið til rannsókna á þessu sviði þar í landi. Einstök fylki Bandaríkjanna hafa einnig lagt sérstaka áherslu á þessi mál. Kalifornía hefur verið leiðandi aðili í nýtingu vetnis í samgöngum um all langt skeið, en þegar í kringum 1990 voru settar þar reglugerðir um að eingöngu þeir sem settu á markað vistvæna bíla mættu selja bíla í fylkinu. Nú þegar hafa verið byggðar á annan tug vetnisstöðva, flestar þó smáar og án vetnisframleiðslu á staðnum. Hvergi eru jafn margir vetnisbílar í umferð eins og í Kaliforníu og ljóst er að sú þróun mun halda áfram enda stefna stjórnvalda þar mjög skýr.

Kanada
Mikil áhersla hefur verið lögð á þróun vetnis í Kanada á síðustu árum, bæði af hálfu stjórnvalda sem einkafyrirtækja. Þannig eru mörg af fremstu fyrirtækjum heims á sviði vetnistækni staðsett í Kanada, m.a á sviði vetnisrafala sem í mörgum tilvikum eru þegar komnir í fjöldaframleiðslu í ýmsum farartækjum s.s. lyfturum og smærri farartækjum. Glögglega má einnig sjá að þróun á þessu sviði er að færast frá rannsóknum og yfir í fjöldaframleiðslu. Tæknistofnanir á sviði vetnis og samtök fyrirtækja á sviði vetnis eru mjög öflug í Kanada sem um leið gerir aðstæður til þróunar á þessu sviði hagstæðari en ella.

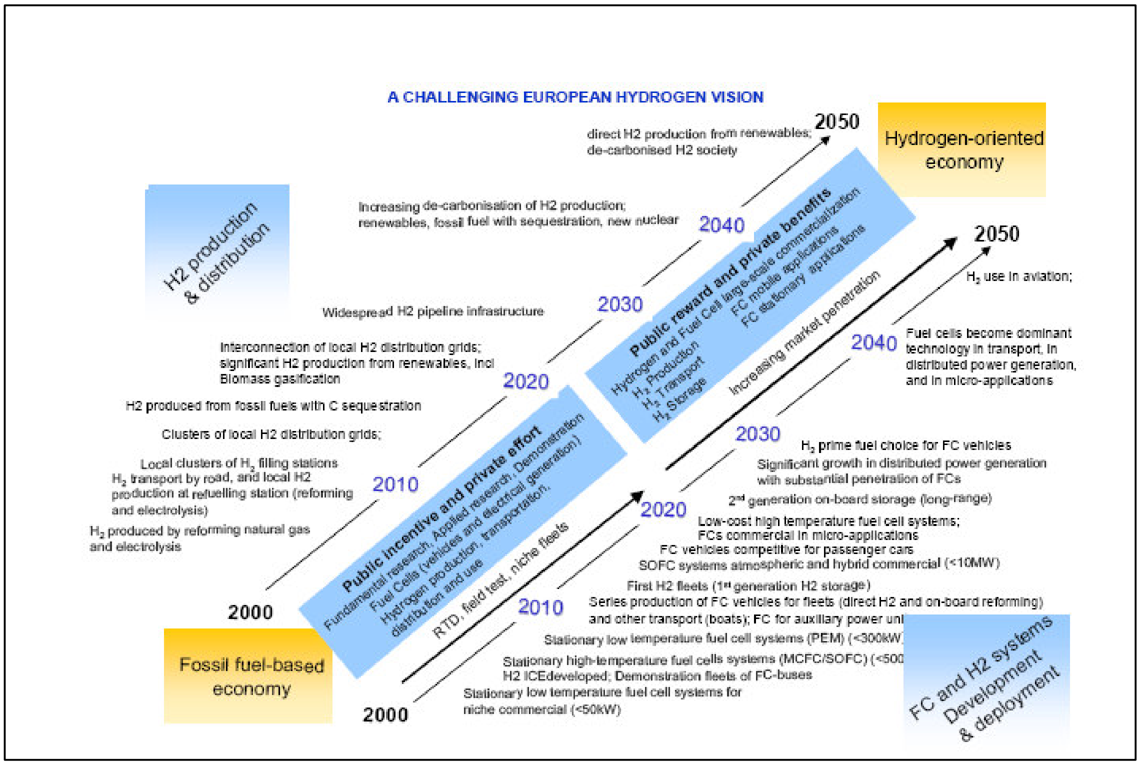
Þýskaland
Áhersla á vetni í Þýskalandi hefur stóraukist á undanförnum mánuðum og árum. Hér er bæði átt við borgir, fylki og ríkisstjórn. Nú þegar hafa verið byggðar fjórar vetnisstöðvar í Þýskalandi, Hamborg, Berlín (2) og Munchen. Stærsti vetnisstrætisvagnafloti sem nú er starfræktur er í Hamborg og Berlín hefur einnig fest kaup á fjórtán vögnum í tengslum við Evrópusambandsverkefni.

Japan
Japan hefur markað skýra stefnu. Japönsku bifreiðaframleiðendurnir eru allir að þróa vetnisbíla og eru með tilraunaverkefni í gangi í Japan, þó að hluti þeirra bíla fari einnig til Kaliforníu. Stjórnvöld vilja að japanskir bifreiðaframleiðendur verði í fremstu röð í þróun vetnisbíla. Japanska ríkið hefur þannig byggt níu vetnisstöðvar í Yokohama þar sem vetni er afgreitt ókeypis. Þetta gerir öll rannsóknarverkefni mun auðveldari í framkvæmd. Talið er hugsanlegt að Japanir verði fyrstir til að fjöldaframleiða vetnisbíla.

Norðurlöndin
Mikil umsvif eru nú í Noregi og eru þrjár vetnisstöðvar í byggingu þar. Norðmenn hafa stofnað til samvetnisverkefnisins ”HyNor” sem miðar að því að samþætta aðgerðir og upplýsingaöflun þar í landi. Í gegnum það samstarf og með verulegum styrkjum frá norskum rannsóknarsjóðum hafa sextán vetnisbílar verið keyptir og stefnt er að þeir komi á götuna á seinni hluta árs 2006. Svipaða sögu er að segja í nágrannalöndunum Svíþjóð og þó sérstaklega í Danmörku. Myndaður hefur verið samstarfshópur um skandinavíska vetnisþjóðveginn (The Scandinavian Hydrogen Highway”) sem á að ná frá Jótlandi í gegnum Svíþjóð, Osló og til Stavanger í Noregi. Fjárframlög til vetnismála í þessum löndum hefur stóraukist. Þannig nemur opinber stuðningur í Danmörku til vetnismála um 100 milljónum DK á þessu ári og hefur verið ákveðið að tvöfalda árlegan stuðning hins opinbera á næsta ári.

Evrópusambandið

Innan Evrópusambandsins hefur verið lögð áhersla á auknar rannsóknir á sviði vetnismála, ekki síst hvað varðar rannsóknir er tengjast þróun vetnisbifreiða. Íslendingar hafa notið góðs af slíkum áherslum, þar sem verulegir fjármunir frá ESB hafa runnið til verkefna á Íslandi á þessu sviði s.s. ECTOS verkefnisins. Þessi áhersla á vetnisrannsóknir og þróun fer vaxandi innan ESB, samanber margvíslegar áætlanir og verkefni á þessu sviði. Á grunni EES-samningsins á Ísland aðild að þessum verkefnum ESB.



IV. Þátttaka í alþjóðlegum verkefnum á sviði vetnismála

IV.1 Verkefni Nýorku

Vetnisstrætisvagnaverkefnið (ECTOS – HyFleet :CUTE) er enn stærsta og mikilvægasta verkefni fyrirtækisins. Í því felst rekstur vetnisstöðvarinnar við Grjótháls í samvinnu við Skeljung og einnig rekstur þriggja vetnisvagna í samvinnu Strætó bs. Fyrri hluta verkefnisins er lokið en seinni hlutanum lýkur í janúar 2007.

Öðru sýningarverkefni, sem er í gangi á Keflavíkurflugvelli og gengur að óskum, mun ljúka á svipuðum tíma. Um er að ræða tilraunir sem styrktar eru af rannsóknarsjóðum bandaríska hersins þar sem gengið er úr skugga um áreiðanleika efnarafals sem varaaflsstöðvar fyrir lýsingarbúnað.

NýOrka er einnig að vinna í sex öðrum verkefnum sem styrkt eru af sjóðum Evrópusambandsins. Flest þeirra miða að því að kanna samfélagsleg, efnahagsleg, og vistræn áhrif vetnis. Megináhersla hefur verið lögð á að rannsaka uppbyggingu innviða og efnahagslegar forsendur þess að nýta innlenda raforku til vetnisframleiðslu. Samhliða því er verið að kanna dreifikerfi raforku enda mikilvægt að skilja samþættingu raforkuframleiðslu og dreifingu samfara uppbyggingu á vetnisinnviðum. Sú reynsla sem NýOrka býr yfir á þessu stigi hefur nýst vel og samvinna við íslensku orkufyrirtækin hefur aukist. Samfara þessu hefur fyrirtækið kannað áhrif samfélagsins og umhverfisins á vetnisframleiðslu með tilliti til hugsanlegrar framtíðarþróunar.

Kennsla og kennsluefnisgerð hefur verið all stór þáttur starfseminnar. Fyrirtækið hefur dreift kennsluefni til allra grunnskóla á Íslandi og heldur að meðaltali um 20 fyrirlestra á alþjóðlegum ráðstefnum á ári. Athygli blaðamanna hefur einnig verið mikil en á síðustu 2,5 árum hafa meira en 400 blaðamenn komið og heimsótt fyrirtækið og eru greinar, þættir og viðtöl í erlendum fjölmiðlum fleiri en tölu verður á komið.

Starfsemi VistOrku

VistOrka var stofnuð sem eignarhaldsfélag til að annast eignarhlut Íslendinga í NýOrku (á móti DaimlerChrysler, Shell Hydrogen og Norsk Hydro). Helstu eigendur eru orkufyrirtækin Landsvirkjun, Orkuveita Reykjavíkur, Hitaveita Suðurnesja og síðan Nýsköpunarsjóður, Háskóli Íslands, Iðntæknistofnun og Ríkissjóður ásamt nokkrum öðrum. Meginverkefni VistOrku er að samþætta starfsemina á Íslandi og skoða þá lykilþætti sem hafa þarf í huga vegna uppbyggingar vetnissamfélags.

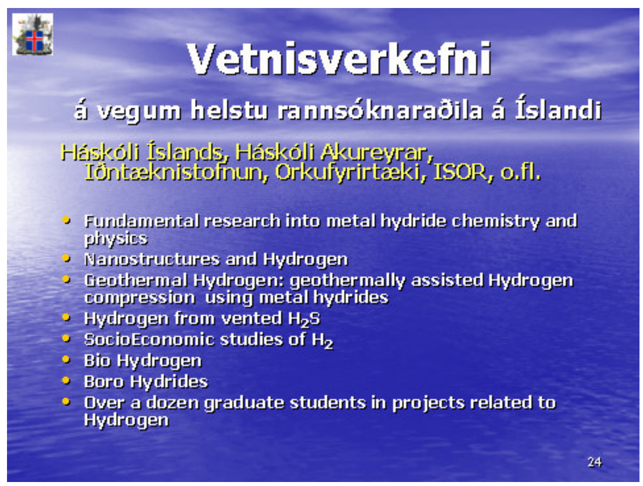
Í upphafi starfseminnar var Nýsköpunarsjóður leiðandi aðili en á undanförnum árum hafa orkufyrirtækin þrjú aukið hlut sinn verulega og er nú svo komið að bæði stjórnarformaður VistOrku og NýOrku kemur frá þessum fyrirtækjum.

Orkufyrirtækin gera sér far um að afla sér upplýsinga um þróunina og hvernig sé rétt að bregðast við henni nú þegar markaður fyrir vetni virðist í nánd. Þau hafa því tekið mun virkari þátt í verkefnum NýOrku og þá sérstaklega þeim sem lúta að innviðum samfélagsins, framtíðar dreifikerfi og samspili raforku og vetnis. Í athugun er að starfsemi VistOrku verði aukin og að fyrirtækið taki að sér ýmis verkefni sem hugsanlega falla utan starfssviðs NýOrku.

IV.2 Vetnisrannsóknir við Háskóla Íslands

Frá árinu 1970 hafa verið stundaðar rannsóknir á vetni við Háskóla Íslands. Með því að tengja rannsóknir við Háskóla Íslands rannsóknum í Þýskalandi var í raun lagður sá grunnur sem núverandi vetnisverkefni NýOrku byggir á.

Um þessar mundir starfa alls fjórir kennarar við HÍ að vetnisrannsóknum. Þessi verkefni eru notkun jarðhita til þess að þrýsta vetni með notkun málmhýdríða, gerð hvarfakerfis sem tengir jarðhitakerfi frá hitaveitu við þrýstibúnað og vinnsla vetnis úr brennisteinsvetni á háhitasvæðum Íslands.



Í samstarfi við Íslenska NýOrku hefur verið staðið fyrir menntunarnámskeiðum sem haldin eru allt að vikulega fyrir erlenda gesti. Stærstu hópar sem tekið hafa þátt í þessum námskeiðum hafa veið frá Tokyo Gas Corporation, Osaka Gas Corporation, Singapore Development Association, Hollenska arkitektasambandinu, en alls hafa um 300 aðilar sótt þessi námskeið síðustu misseri.

Norrænn sumarskóli um vetni var haldinn á Íslandi 2003 og sumarið 2006 voru 60 og 40 manna háskólastúdentahópar fræddir um vetni við Háskóla Íslands. Í formennsku sinni í framkvæmdanefnd International Partnership for the Hydrogen Economy hefur Ísland lagt til stofnun svokallaðra "Master Class on Hydrogen" sem byggja mjög á reynslu Íslendinga af þessum þætti. Íslenskir háskólastúdentar hafa tekið þátt í kennslu í vetnisverkefnum í Háskóla unga fólksins undanfarin tvö sumur.

Unnið hefur verið að ýmsum verkefnum, m.a. á sviði örtækni sem beinist að því að ryðja braut fyrir nýrri tegund vetnisgeymslu þar sem geymsluefnið er hannað og meitlað í örbyggingu efna, nýja tegund gerviefna sem nú ryðja sér til rúms.

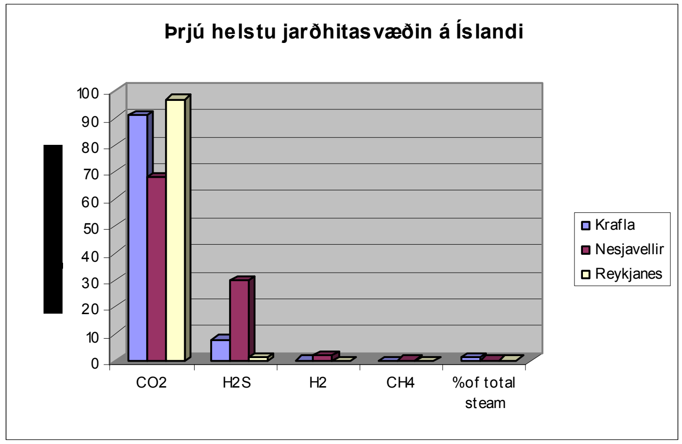
Styrkir og kostun verkefna við HÍ eru að stórum hluta með framlagi rannsóknasjóða, samkeppnissjóða á Íslandi, á Norðurlöndunum og í Evrópu. ECTOS verkefnið við Háskóla Íslands hefur notið styrkja úr fimmtu og sjöttu rammaáætlunum EU. Fjármögnun frá Norrænum sjóðum er einnig mikilvæg í verkefnum HÍ. Ætla má að styrkir til rannsókna geti margfaldað grunnframlag Háskólans til vetnisverkefna á ári hverju. Starfandi er rannsóknahópur á sviði vetnis, en að honum koma: Þrír háskólakennarar. Tveir nýdoktorar (postdoc.). Fjórir doktorsnemar. Þrír meistaranemar. Auk tæknimanna og þátttöku stúdenta í almennu námi má gera ráð fyrir að um 20 manns komi beint að vetnisverkefnum tengdum Háskóla Íslands.

IV.3 Vetnisrannsóknir á Iðntæknistofnun

Iðntæknistofnun Íslands hefur tekið þátt í mótun vetnisrannsókna frá árinu 1999, eða frá því að skýrsla nefndar iðnaðarráðherra um nýtingu innlendra orkugjafa til framleiðslu eldsneytis lauk störfum. Í júní 2006 eru nokkur verkefni í gangi á Iðntæknistofnun og má þar nefna eftirfarandi.

Vetni úr jarðhitagasi

Markmið verkefnisins er að skoða möguleika þess að vinna vetni úr jarðhitagasi með því að kljúfa brennisteinsvetni upp og minnka þannig orkukostnað við rafgreiningu vetnis úr vökvanum.



Vetnistæknimiðstöð

Iðntæknistofnun hefur beitt sér fyrir stofnun vetnistæknimiðstöðvar í húsnæði Efna- og líftæknihúss á Keldnaholti. Verkefnið hefur verið unnið í samvinnu við fyrirtæki, stofnanir og háskóla hérlendis, og hafa allir sem vinna í vetnisrannsóknum komið að málinu.

Orkunýting í vetnisvögnum

Í þessu verkefni verður unnið áfram með upplýsingar og gögn sem safnast hafa við akstur vetnisvagnanna þriggja á leiðakerfi Strætó síðustu ár. Verkefnið mun fjalla um orkunotkun og orkunýtingu vetnisknúinna strætisvagna með efnarafal og kanna áhrif ýmissa ytri þátta á nýtnina, svo sem hitastig, seltustig, færð o.fl.

Verið er að semja við samstarfsaðila á Norðurlöndum um samstarf að verkefni, sem leitast mun við að gefa heilsteypta mynd af áhrifum vetnisvæðingar og skilgreina þá þætti sem greitt geta fyrir eða torveldað þá þróun.

Vetnisvæðing mun leiða af sér ýmsar áskoranir en einnig mýmörg tækifæri til endurbóta og þróunar og nauðsynlegt er að skilgreina mikilvægustu skrefin í átt að vetnissamfélagi, ef sú leið skyldi valin. Með niðurstöðum rannsóknarinnar mun verkefnið skilgreina hugsanlega hvata, hindranir, kostnað og ávinninga við vetnissamfélag og einnig raunhæfa aðgerðaráætlun. Ísland mun notað sem rannsóknardæmi. Gefur það góða möguleika á að áætla heildaráhrif vetnisvæðingar á nútímaþjóðfélag og veita þannig yfirsýn og samhengi. Hins vegar mun stillt upp mismunandi framtíðarsýnum varðandi orkuumhverfi, til að skapa þverfaglegt hjálpargagn, er nothæft yrði til ákvarðanatöku og stefnumörkunar bæði á Íslandi og annars staðar í Evrópu.

Iðntæknistofnun er þátttakandi í ýmsum öðrum samstarfsverkefnum á sviði rannsókna með Norðurlöndunum.

Viðauki I – Tillögur Nýorku - Tillaga I – stærri tillaga

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INE´s SMART-H_2
Lighthouse-project
Version I

SUMMARY

The goal is to establish a new lighthouse project in Iceland called the SMART-H_2. It might not be a fully correct name as the project involves a mixture of internal combustion engines and fuel cells. The project also evaluates both transportation and usage of hydrogen and fuel cells in marine environment.

The project will involve a large fleet of total of 36 vehicles and an auxiliary unit for a whale watching boat. The project also involves a mobile refuelling station of small scale which could both produce and dispense a small quantity of hydrogen.

This is a follow up of the so-called ECTOS/HyFleetCUTE programs which involved building a hydrogen fuelling station and test driving 3 fuel cell buses over a 3 year period. The overall experience from the project should prepare the Icelandic society for the estimated change that will take place after 2012, when most vehicle manufacturers expect serial production of hydrogen vehicles to start.

By having a large and mixed fleet the results regarding Life Cycle Analysis, Well to Tank studies, infrastructure and economic analysis along with others studies which will be performed will give a very broad results which will benefit the future hydrogen society.

Iceland's aim it to evaluate the potential of becoming the first hydrogen society and the first results are available. However further analysis regarding vehicles performances, infrastructure usage, economics, maintenance, etc. are of utmost importance so full understanding can be established regarding the impact of the new energy carrier for a modern society.

Introduction

The SMART-H_2 project is viewed as a follow up from the ECTOS/HyFleetCUTE projects which have been operating in Iceland from 2001. In these projects the key activity has been the learning from operation a hydrogen bus fleet and a commercial hydrogen refuelling station. The learning from these projects has been very important and has demonstrated the viability of the technology for use in normal society.

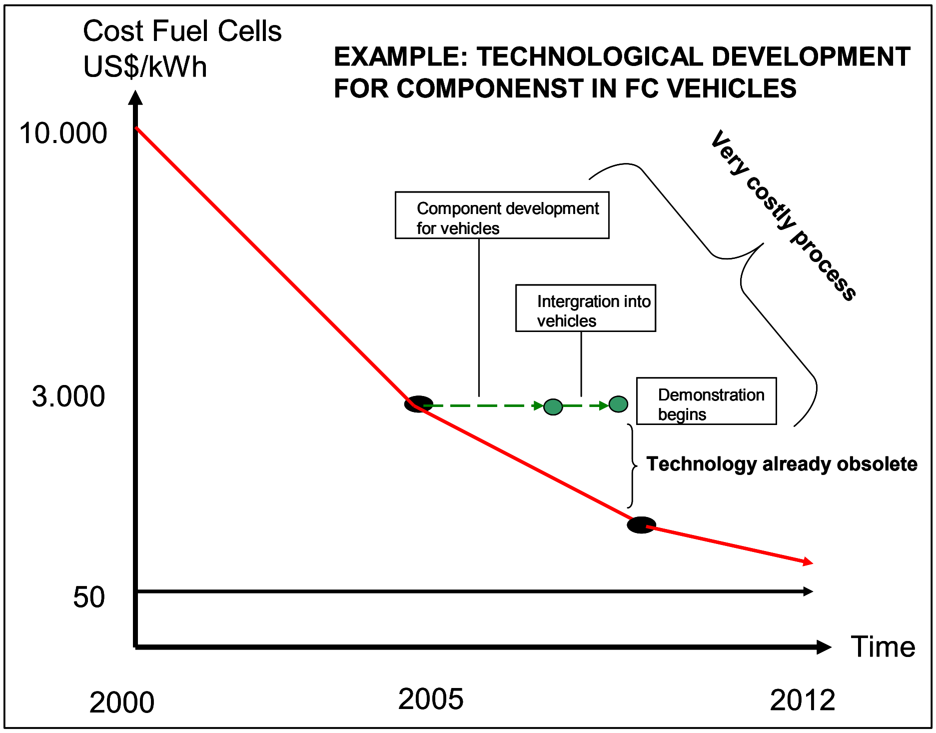
At this point in time when it is crucial to prepare for the future serial and the commercial production of H2 vehicles to continue the preparation of the society and increase the learning of operation H2 vehicles. Already INE has approached most of the key car manufacturers in the world and the general view is that potential serial production of hydrogen vehicles will commence around 2012 and that the commercial stage will be reached shortly after 2015. However it is very difficult to get demonstration projects going as most of the vehicle developers state that the development is going according to plans or faster. Due to such fast technological development the cost curve of components for the hydrogen vehicle is actually steeper at the current timeframe than expected and therefore they are convinced that the plans for launching larger fleets (serial produced) in 2010-2015 timeframe should be sound.

The picture here below shows what many of the vehicle manufacturers state regarding the cost curve of different hydrogen components (in this case the cost of a Fuel Cell was chosen as that is well known, 50 US$ a kWh is always claimed to be the price of a conventional ICE gasoline engine). The graph also shows that taking components out of the development curve for integration into the vehicles is not only time consuming but also very costly. Therefore the vehicle manufacturers would like to limit the number of vehicles put into demonstrations. They all agree that it is absolutely necessary to demonstrate the vehicles and they are all doing so but the number of vehicles to verify the technology only needs to be 10-30 vehicles. This they are all doing and therefore they can not increase the production. Most of these demonstrations are taking place in the companies home country and in California due to specific legislation.

This is the key reason why a potential fleet of OEM manufactured vehicles will not be available for any large “lighthouse” projects in the next couple of years. Therefore the only option for Iceland is either a very small fleet from OEM´s, 1-3 vehicles or to evaluate the use of retrofitted vehicles.

Retrofitted vehicles could though be available for a larger fleet, i.e. + 50 cars. Development of such vehicles has escaladed in the last few months as vehicles are needed for demonstrations and increase use of hydrogen infrastructure for learning, along with all other necessary research activities in connection to such demonstrations.

Producers of these vehicles have now been able to demonstrate safe operation of such vehicles and do fulfil all available codes and standards. Governments, national and regional are now purchasing such vehicles and these vehicles fulfil all available homologation documents and can therefore come into wider use. The producers of these vehicles also now provide them with a warranty package which is very important for future users/owners.



This picture demonstrates a potential cost curve for Fuel Cells for vehicles. It indicates the problems for the vehicle manufacturers to build large car fleets with the current technology as that is very expensive and time consuming. All key car manufacturers are already building a number of vehicles to verify the technology but the number of cars they are already building is large enough to verify the viability of the technology. Therefore building a fleet of +50 cars for different demonstrations would only slow down the development as that would be very costly and take a lot of effort from the development of the vehicles.

NOTE: this graph is made by INE for illustration purposes only, it is not a fact sheet from any other sources, but based on interviews with all the concerned parties.

This document describes the SMART-H_2 project which is mostly focused on demonstrating vehicles that have been retrofitted for hydrogen, in this case Toyota Prius, Ford Escape and GM Pick-up Sierra. This paper also discusses the use of a couple of DC F-Cell vehicles and potentially a GM FC vehicles. In such a broad lighthouse project it is important to bring together the two different technologies, i.e. the internal combustion engine (retrofitted vehicles) and the fuel cell technology. Also as the goal of Iceland is to become free of fossil fuel use this project involves the first trial of hydrogen used in marine application. A combination of using hydrogen on land and at sea will establish a unique know-how regarding the future hydrogen infrastructure and how the society can integrate hydrogen as the main energy carrier of the future.

This lighthouse project is therefore unique for combining research on vehicles, both ICE and FC, use of hydrogen in marine applications and the investigation of integration of the future infrastructure. It is viewed as a bridge between the current state of technology until the world will see and increased production of hydrogen vehicles, competing with the conventional gasoline engine.

Project description

The project is split into 3 years, 2007-2009. In the chapters here below each year is described briefly, key activities, etc. At the end of the description there is a table showing a full overview of the project and a draft of the budget.

2007

Vehicles
The goal of the project is to have the first vehicles delivered in the 1Q. In this case there will be 2 F-Cell A Class DaimlerCrysler vehicles which would go into service. These vehicles are rented (leased) for 12-24 months. In the 2-3Q the first Toyota Prius vehicles would arrive and a no of Ford Escape vehicles. These vehicles are retrofitted by Quantum in the US. In this case the gasoline hybrid engine is removed and a hydrogen ICE system installed. For the Prius there are two option for storage, i.e. 1,6 kg and 2,4 kg of hydrogen. If the larger system is used the driving range is +160 km but then the spare tire has been removed[3], however that option is more expensive (increases the cost of the vehicles of US$ 30.800). Currently less is know about the Ford Escape as the first vehicle of that type will be tested in Detroit in March. The details regarding storage of hydrogen and range is not fully clear but will be made available within a few weeks.

These vehicles would not require any new infrastructure to be provided in Iceland. These vehicles would be given to fleet operators which would all fuel at the same location. Though the current hydrogen buses would also be operated there would still be enough hydrogen.

Marine application

During the winter time of 2007-2008 a team will install a auxiliary FC unit on board the Elding, a whale watching boat (or a different boat. INE has in this sense been approached by a few boat operators). In this case Icelandic technicians will install the system both the FC system and the storage bottles. The fuel cell system will be a roughly 10 kW+ system similar to a system on board a fuel cell vehicle. There would be a removable storage which could be hauled down into the boat and out again for refuelling. It would depend on the usage how frequently this needs to be done.
This exercise would not only train the Icelandic team but would also be a unique project in the world that you can stop the engines of the boat while enjoying the beauty of worlds largest creatures without disturbing them with vibrations and/or noise.

2008

Vehicles

In 2008 6 new vehicles would be added to the fleet. The two F-Cell vehicles would continue to be in service (if available). The new vehicles will be a retrofitted GM Sierra pick-up trucks, made by an Canadian-US consortium. A large part of the trunk space has been removed for the hydrogen storage bottles which gives the vehicle a range of 250 km, storing roughly 10 kg of hydrogen. The goal at this point would then be to add a GM FC vehicle to the fleet[4]. This means that in total in 2008 there will be 26-28 vehicle in operation.

It should though be noted that the purchase of vehicles would be fully in line with demand from customers.

Marine

During 2008-2009 the FC and hydrogen technology will be tested in the Icelandic harsh waters for evaluating the future potential use of FC and hydrogen in marine applications.

2009

Further 8-9 cars will be added in 2009. Five from alternative vehicle producers, and potentially 3 new (DC) FC vehicles will be added to the fleet (given that negotiations and predictions of DC come through). This fleet is more undetermined than the fleet of the first 2 years. The reason is that the development of new cars is difficult to predict and the goal of this project is to maximize the learning by using as wide range of available vehicles as possible. At this point in time INE expects to have new information on the development and availability of vehicles in the future.

Infrastructure

[4] This has not been negotiated nor confirmed.

As the vehicle fleet grows it will be necessary to install a mobile fuelling station. This can be a small mobile production and dispensing station which could be also connected to a trailer for added amount of hydrogen depending on the behaviour of the customer operation. This will make the vehicles more customer accepted as people can refuel in more than one location. Again the behaviour of the customer will in a sense determine if this station needs to be installed in 2008 or later.

One of the key research part of the project is to evaluate the energy efficiency of the vehicles and therefore the future energy needs of the hydrogen society. The interrelation between the hydrogen production and available energy in Iceland needs to be carefully calculated so that current energy companies can evaluate the potential reserves needed for a future hydrogen economy. Also during the project period the partners will be in close contact with key vehicle manufacturers to get full understanding of when serial produced cars will be come available (currently forecasted for 2012) and when commercialisation can start (forecasted after 2015-). This will bring important features into the Icelandic energy society for evaluating the total energy needs of the future hydrogen economy.

Budget and financing

Estimating a cost to such a large scale project can be difficult to estimate. Already we have a cost proposal from the Toyota Prius team, i.e. Quantum, but only a cost estimate is available for the pick-up trucks. No prices are available for the FC vehicles and they are therefore a pure price estimate. In the proposal the INE team does not expect to pay any VAT nor import duties on the cars, though the governmental regulations are only valid until the end of 2008.

Regarding the cost of hydrogen the price is estimated at kr. 800/kg (roughly US$ 12) excluding VAT. This might be a price which could be acceptable for the range of the Prius vehicles but is relatively high for the pick-up vehicles since they are not equipped with hybrid engines and therefore have a far lower fuel efficiency.

Therefore many of the estimates in the budget and financing here below are unconfirmed, however based on the current knowledge this is the best estimate available. It does not include any service for the vehicles as that is viewed as part of the operation cost of the car, except in the case of the FC vehicles where specific maintenance is needed (then it is included).

Lighthouse project in Iceland 2007-2009 / SMART-H2

Project cost **US$**

	2007		2008		2009	
Vehicle cost	Units		Units		Units	
Prius vehicles/no range extender	5	750000				
Prius vehicles/with range extender	5	900000				
GM Pick-up Sierra			5	900000		
F-Cell/DaimlerChrysler	2	240000			3	600000
Ford Escape (Quantum)	10	1800000				
GM FC vehicle			1	120000	1	120000
Other manufacturers					5	800000
Research cost		150000		150000		150000
Marine project cost						
Auxiliary unit for Elding	1	700000		50000		50000
Infrastructure cost						
Mobile refueller					1	400000
Maintenance current station		250000		250000		250000
New filling station 300 Nm3/700 bar						
Homologation cost		15000		15000		15000
Project management		163333		163333		163333
TOTAL		4968333		1648333		2548333

Funding

	2007		2008		2009	
Vehicles						
Vehicle customers Prius	10	650000				
Vehicle customers Escape	10	750000				
Vehicle customers/other manuf.					8	600000
Vehicle Customers Pick-up			5	375000		
Vehicle customers/rent/DC/GM	2	84000	1	42000	1	42000
Research grant		100000		100000		100000
Marine project cost						
Owners Elding		75000		50000		50000
Nordic grant		350000		0		0
Infrastructure cost						
Mobile refueller/owner contribution					1	400000
Maintenance current station/cost		250000		250000		250000
New filling station 300 Nm3/700 bar		0		0		0
Hydrogen fuel sales		21095		35095		55095
Homologation cost		0		0		0
Project management		83333		83333		83334
TOTAL		2363428		935428		1580429

	US$	Icelandic kr / 1 US$ = 70 kr.	
3 year total cost	**9.164.999**	**641.549.930**	%
Vehicle customer funding	2.543.000	178.010.000	0,2775
Research grant/unknown source	300.000	21.000.000	0,0327
Nordic grant	350.000	24.500.000	0,0382
Marine owner, input	175.000	12.250.000	0,0191
New owner mobile refuller	400.000	28.000.000	0,0436
INE owners funding/maint/manag.	1.000.000	70.000.000	0,1091
Income from fuel sales	111.285	7.789.930	0,0121
Government of Iceland	4.285.714	300.000.000	0,4676
TOTAL	0	0	

Viðauki II – Tillögur Nýorku - Tillaga II – minni tillaga

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INE´s SMART-H_2
Lighthouse-project
Version II

SUMMARY

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This is a follow up of the so-called ECTOS/HyFleetCUTE programs which involved building a hydrogen fuelling station and test driving 3 fuel cell buses over a 3 year period. The overall experience from the project should prepare the Icelandic society for the estimated change that will take place after 2012, when most vehicle manufacturers expect serial production of hydrogen vehicles to start.

By having a mixed fleet the results regarding Life Cycle Analysis, Well to Tank studies, infrastructure and economic analysis along with others studies which will be performed will give a very broad results which will benefit the future hydrogen society. The size of the fleet in this case is large enough to have reliable conclusions i.e. on different economic, social and environmental factors.

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Introduction

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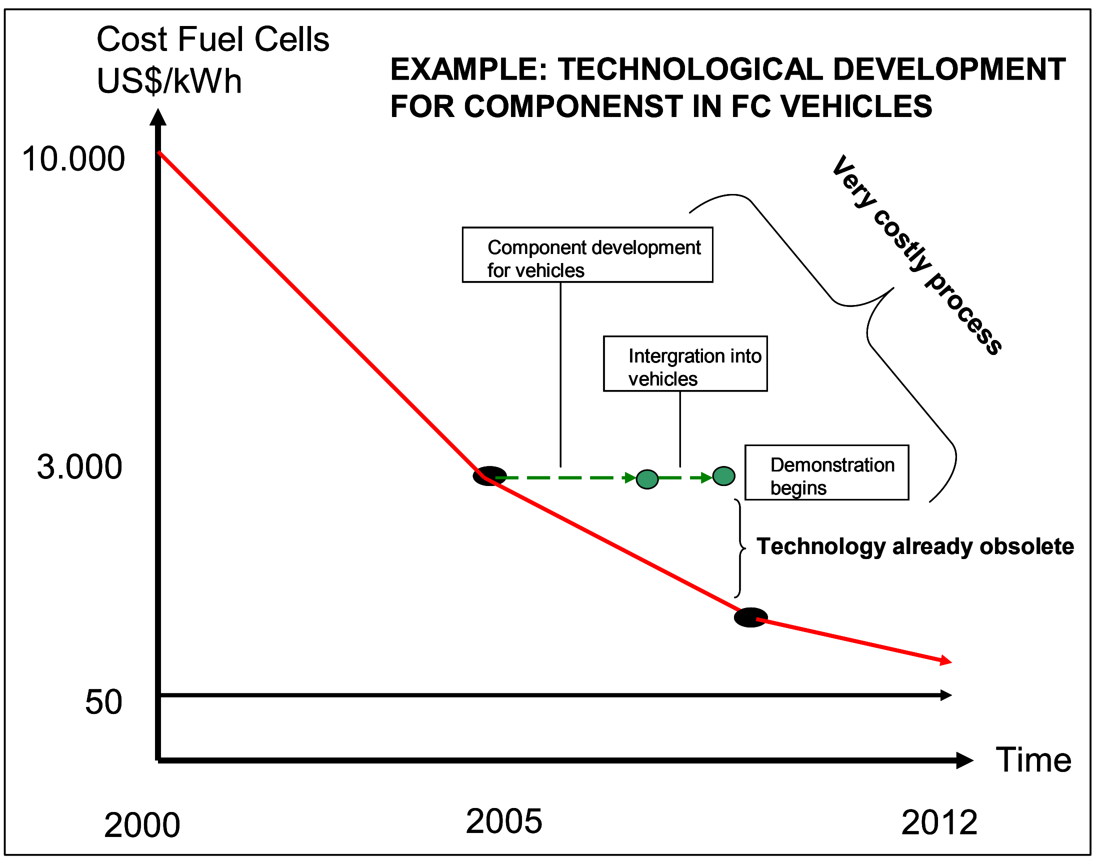

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Retrofitted vehicles could though be available for a larger fleet, i.e. + 50 cars. Development of such vehicles has escaladed in the last few months as vehicles are needed for demonstrations and increase use of hydrogen infrastructure for learning, along with all other necessary research activities in connection to such demonstrations.

Producers of these vehicles have now been able to demonstrate safe operation of such vehicles and do fulfil all available codes and standards. Governments, national and regional are now purchasing such vehicles and these vehicles fulfil all available homologation documents and can therefore come into wider use. The producers of these vehicles also now provide them with a warranty package which is very important for future users/owners.

This document describes the SMART-H_2 (*version II*) project which is mostly focused on demonstrating vehicles that have been retrofitted for hydrogen, in this case Toyota Prius, Ford Escape and GM Pick-up Sierra. This paper also discusses the use of a couple of DC F-Cell vehicles and potentially a GM FC vehicles. In such a broad lighthouse project it is important to bring together the two different technologies, i.e. the internal combustion engine (retrofitted vehicles) and the fuel cell technology. Also as the goal of Iceland is to become free of fossil fuel use this project involves the first trial of hydrogen used in marine application. A combination of using hydrogen on land and at sea will establish a unique know-how regarding the future hydrogen infrastructure and how the society can integrate hydrogen as the main energy carrier of the future.
This lighthouse project is therefore unique for combining research on vehicles, both ICE and FC, use of hydrogen in marine applications and the investigation of integration of the future infrastructure. It is viewed as a bridge between the current state of technology until the world will see and increased production of hydrogen vehicles, competing with the conventional gasoline engine. The size is adequate to get reliable conclusions. Smaller fleets will become more costly as of number of purchased vehicles and also information gathered might not be as reliable.

Project description

The project is split into 3 years, 2007-2009. In the chapters here below each year is described briefly, key activities, etc. At the end of the description there is a table showing a full overview of the project and a draft of the budget.

2007

Vehicles

The goal of the project is to have the first vehicles delivered in the 1Q. In this case there will be 2 F-Cell A Class DaimlerCrysler vehicles which would go into service. These vehicles are rented (leased) for 12-24 months. In the 2-3Q the first Toyota Prius vehicles would arrive and a no of Ford Escape vehicles. These vehicles are retrofitted by Quantum in the US. In this case the gasoline hybrid engine is removed and a hydrogen ICE system installed. For the Prius there are two option for storage, i.e. 1,6 kg and 2,4 kg of hydrogen. If the larger system is used the driving range is +160 km but then the spare tire has been removed[5], however that option is more expensive (increases the cost of the vehicles of US$ 30.800). Currently less is know about the Ford Escape as the first vehicle of that type will be tested in Detroit last March. The details regarding storage of hydrogen and range is not fully clear but will be made available within a few weeks.

[5] The space in the vehicle is the same as in a normal gasoline version.

These vehicles would not require any new infrastructure to be provided in Iceland. These vehicles would be given to fleet operators which would all fuel at the same location. Though the current hydrogen buses would also be operated there would still be enough hydrogen.

Marine application

During the winter time of 2007-2008 a team will install a auxiliary FC unit on board a boat (potential demonstrator might be Elding, a whale watching boat (or a different boat. INE has in this sense been approached by a few boat operators)). In this case Icelandic technicians will install the system both the FC system and the storage bottles. The fuel cell system will be a roughly 10 kW+ system similar to a system on board a fuel cell vehicle. There would be a removable storage which could be hauled down into the boat and out again for refuelling. It would depend on the usage how frequently this needs to be done.
This exercise would not only train the Icelandic team but would also be a unique project in the world that you can stop the engines of the boat while enjoying the beauty of worlds largest creatures without disturbing them with vibrations and/or noise.

2008

Vehicles

In 2008 6 new vehicles would be added to the fleet. The two F-Cell vehicles would continue to be in service (if available). The new vehicles will be a retrofitted GM Sierra pick-up trucks, made by an Canadian-US consortium. A large part of the trunk space has been removed for the hydrogen storage bottles which gives the vehicle a range of 250 km, storing roughly 10 kg of hydrogen. The goal at this point would then be to add a GM FC vehicle to the fleet[6]. This means that in total in 2008 there will be 19 vehicle in operation.

It should though be noted that the purchase of vehicles would be fully in line with demand from customers.

Marine

During 2008-2009 the FC and hydrogen technology will be tested in the Icelandic harsh waters for evaluating the future potential use of FC and hydrogen in marine applications.

2009

Further 8-9 cars will be added in 2009. Five from alternative vehicle producers, and potentially 3 new (DC) FC vehicles will be added to the fleet (given that negotiations and predictions of DC come through). This fleet is more undetermined than the fleet of the first 2 years. The reason is that the development of new cars is difficult to predict and the goal of this project is to maximize the learning by using as wide range of available vehicles as possible. At this point in time INE expects to have new information on the development and availability of vehicles in the future.

Infrastructure

As the vehicle fleet grows it will be necessary to install a mobile fuelling station. This can be a small mobile production and dispensing station (or only dispensing) which could be also connected to a trailer for added amount of hydrogen depending on the behaviour of the customer operation. This will make the vehicles more customer accepted as people can refuel in more than one location. Again the behaviour of the customer will in a sense determine if this station needs to be installed in 2008 or later.

[6] This has not been negotiated nor confirmed.

One of the key research part of the project is to evaluate the energy efficiency of the vehicles and therefore the future energy needs of the hydrogen society. The interrelation between the hydrogen production and available energy in Iceland needs to be carefully calculated so that current energy companies can evaluate the potential reserves needed for a future hydrogen economy. Also during the project period the partners will be in close contact with key vehicle manufacturers to get full understanding of when serial produced cars will be come available (currently forecasted for 2012) and when commercialisation can start (forecasted after 2015-). This will bring important features into the Icelandic energy society for evaluating the total energy needs of the future hydrogen economy.

Budget and financing

Estimating a cost to such a large scale project can be difficult to estimate. Already we have a cost proposal from the Toyota Prius team, i.e. Quantum, but only a cost estimate is available for the pick-up trucks. No prices are available for the FC vehicles and they are therefore a pure price estimate. In the proposal the INE team does not expect to pay any VAT nor import duties on the cars, though the governmental regulations are only valid until the end of 2008.

Regarding the cost of hydrogen the price is estimated at kr. 6-800/kg (roughly US$ 12) excluding VAT. This might be a price which could be acceptable for the range of the Prius vehicles but is relatively high for the pick-up vehicles since they are not equipped with hybrid engines and therefore have a far lower fuel efficiency.

Therefore many of the estimates in the budget and financing here below are unconfirmed, however based on the current knowledge this is the best estimate available. It does not include any service for the vehicles as that is viewed as part of the operation cost of the car, except in the case of the FC vehicles where specific maintenance is needed (then it is included).

Lighthouse project in Iceland 2007-2009 / SMART-H2

Project cost — US$

	2007		2008		2009	
Vehicle cost	Units		Units		Units	
Prius vehicles/no range extender	4	600000				
Prius vehicles/with range extender	4	720000				
GM Pick-up Sierra			5	750000		
F-Cell/DaimlerChrysler	2	240000			3	600000
Ford Escape (Quantum)	5	900000				
GM FC vehicle			1	120000	1	120000
Other manufacturers					5	800000
Research cost		125000		125000		125000
Marine project cost						
Auxiliary unit for Elding	1	700000		50000		50000
Infrastructure cost						
Mobile refueller					1	400000
Maintenance current station		230000		230000		230000
New filling station 300 Nm3/700 bar						
Homologation cost		15000		15000		15000
Project management		153333		153333		153333
TOTAL		3683333		1443333		2493333

Funding

	2007		2008		2009	
Vehicles						
Vehicle customers Prius	8	536000				
Vehicle customers Escape	5	375000				
Vehicle customers/other manuf.					8	600000
Vehicle Customers Pick-up			5	375000		
Vehicle customers/rent/DC/GM	2	84000	1	42000	1	42000
Research grant		100000		100000		100000
Marine project cost						
Owners Elding		75000		50000		50000
Nordic grant		350000		0		0
Infrastructure cost						
Mobile refueller/owner contribution					1	400000
Maintenance current station/cost		250000		250000		250000
New filling station 300 Nm3/700 bar		0		0		0
Hydrogen fuel sales		18095		30095		50095
Homologation cost		0		0		0
Project management		93333		93333		91762
TOTAL		1881428		940428		1583857

		US$		Icelandic kr / 1 US$ = 70 kr.	
3 year total cost		**7.619.999**		**533.399.930**	%
Vehicle customer funding		2.054.000		143.780.000	0,2696
Research grant/unknown source		300.000		21.000.000	0,0394
Nordic grant		350.000		24.500.000	0,0459
Marine owner, input		175.000		12.250.000	0,0230
New owner mobile refuller		400.000		28.000.000	0,0525
INE owners funding/maint/manag.		1.028.428		71.990.000	0,1350
Income from fuel sales		98.285		6.879.930	0,0129
Government of Iceland		3.214.286		225.000.000	0,4218
TOTAL		0		0	

Viðauki III – Vegvísir á sviði vetnismála - Roadmap

DRAFT

The Icelandic Hydrogen Energy Roadmap

Prepared for the Icelandic Ministry of Industry and Commerce

Guðbjörg Hrönn Óskarsdóttir, Editor

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Foreword

Hydrogen holds the potential to become a reliable and affordable energy carrier that can transmit Iceland's clean and renewable energy resources and thus enhance Iceland's economy, environment, and security. This Roadmap provides a blueprint for the coordinated, long-term, public and private efforts required for hydrogen economy development.

In the coming decades, the world will need new energy supplies and an upgraded energy infrastructure to meet growing demands for electric power and transportation fuels that will contribute to reduction in greenhouse gas emission. Hydrogen provides high efficiency, can be produced from a variety of domestically available resources, and by using domestic renewable energy sources it offers near-zero emissions of pollutants and greenhouse gases. Developing hydrogen as a major energy carrier, however, will require solutions to many challenges in the areas of infrastructure, technology, and economics.

The Ministry of Industry and Commerce initiated the roadmap process in an effort to coordinate the different parties that are working in the area and to highlight the desirable direction and tasks that need to be addressed for the hydrogen economy to become a reality in Iceland.

This roadmap is neither a government research and development plan nor an industrial commercialization plan. Rather, it explores the wide range of activities required to realize hydrogen's potential in contributing to Iceland's energy security, diversity, and environmental needs.

A vision for the future today

From The Icelandic Ministry of Industry and Commerce

For decades Icelandic governments have actively promoted the utilization of the country's abundant renewable energy resources in harmony with the environment. This policy is based on explorations and investigations of Iceland's abundant hydropower and geothermal resources. Iceland has reached the state of having eliminated fossil fuels from all stationary energy needs. Thus renewables account for more than 70% of the countries primary energy supply. It is the Government's goal to go further and head towards a carbon free future where indigenous renewable energy will as far as possible replace fossil fuels, also in transportation. The policy and priorities on hydrogen are a central point in this vision.

In 1998, the Icelandic government made a clear policy statement towards the hydrogen economy. The document's long-term vision envisages that hydrogen produced from renewable energy sources could replace fossil fuels in the country's transport sector and fishing fleet as soon as this becomes technically and economically feasible.

Hydrogen as an energy carrier is promising for Iceland as it has abundant renewable energy resources to produce hydrogen, a clean, energy efficient fuel that can be derived from diverse sources. The aim of the hydrogen policy is to make further use of domestic renewable energy, less pollution and a reduction in the emission of greenhouse gasses, along with all the attendant benefits for the environment, economy and public health. In this way Iceland will contribute further to the global effort to protect the climate.

International Platform for Hydrogen Research

Research related to the production of synthetic fuels, mainly hydrogen, from Iceland's renewable resources has been conducting at the University of Iceland for decades. This has lead to close international co-operation in this field.

Building on this foundation a major goal of the Icelandic government policy on hydrogen is the creation of a favorable international platform for research and testing within the country, based on close co-operation between the public and private sectors and offering a unique framework for future development and collective expertise. While Iceland is not capable of making major advances in this area on its own, major steps can be taken in co-operation with other nations, agencies and key industry operators worldwide.

Icelandic governmental policy on hydrogen can be classified into five main categories.

- On-going policy formulation
- Favorable framework for business
- International co-operation
- Research
- Education and training

Public and private co-operation work on policy formulation on hydrogen will continue. Emphasis will be laid on international consultation and co-operation as the problems to be solved are global in nature. Iceland realizes the importance of working with others on the hydrogen issue to make it an integral part of a global agenda to succeed.

Some Facts

Iceland – Energy – Hydrogen

To date, Iceland has harnessed only a small proportion - about 15% - of its natural energy potential, and this does not include what could be derived from wind power. If utilized to the full, the remainder would be sufficient to serve the entire electricity needs of a country the size of Denmark.

During the global oil crises of the 1970s, a concerted effort was made to replace imported fossil fuels with geothermal energy as a source of space heating throughout Iceland, and today close to 99% of the country's houses and buildings are heated using renewable energy. As a result, there are basically no greenhouse gas emissions from stationary energy use in Iceland. Two-thirds of such emissions come from the nation's cars and fishing fleet, and the remainder largely from industrial processes.

Today, Iceland has reached the stage where over 70% of its primary energy consumption is met by domestically produced renewable energy. Like the rest of the world, however, the country is forced to use fossil fuels to drive its motor vehicles and fishing fleet, all of which must be imported.

Producing hydrogen from water using electrolysis powered by local hydropower and geothermal energy would provide Iceland with its own source of domestically produced clean fuel, replacing fossil fuel imports.

Since 2002, electricity production in Iceland has been the highest per capita in the world. Converting all the country's cars and fishing vessels to hydrogen fuel cell power would require an additional use of roughly 10% of the remaining electricity potential by electrolyzing fresh water, a natural resource in which the country also abounds.

Through long experience, expertise and commitment to innovative research on the exploitation of sustainable, renewable energy resource, Icelandic energy companies, universities and research institutes are making a contribution towards creating a hydrogen future for both Icelanders and the world at large.

In 2005 a proposal for lowering taxes on hydrogen powered vehicles was placed in the Icelandic Parliament. The objective of the proposal was to make hydrogen vehicles more attractive for Icelandic consumers as well as making Iceland more attractive for hydrogen vehicle makers.

1. Hydrogen Production

Hydrogen is not an energy source but an energy carrier, and as such it requires an energy source for its manufacture.

Current Status

Many methods have been developed for hydrogen production, but today the primary means of production is catalytic reforming of hydrocarbons, especially of natural gas. In particular steam reforming of methane accounts for approximately 95% of hydrogen produced in the world, and most of the hydrogen produced is used in industrial processes of ammonia synthesis and in the refining of crude oil.

The steam reforming method for producing hydrogen is undesirable since large amounts of CO_2 are produced in the process. Because of this, other more environmentally friendly approaches to hydrogen production are being pursued around the world. In Iceland current hydrogen production is via electrolyses. But because electrolysed hydrogen is created indirectly, using electricity as an energy carrier, the economical aspects of this method is linked to the price of electricity.

Iceland is fortunate to have abundance of sustainable environmental friendly energy sources, such as hydropower and geothermal sources. It is clear that it is the basis for Iceland's interest in hydrogen that it will be produced utilizing these sources and in the future possibly combined with other clean electricity sources such as tidal or wind power. Today hydrogen in Iceland is produced by electrolysers. This is beneficial as all of the electricity used is made from clean sustainable sources.

In addition to electrolysis several additional options are being considered which all are based on utilization of renewable energy sources. For example Iceland's geothermal sites emit hydrogen and hydrogen sulfite components from boreholes which could potentially be harnessed. Estimates for the currently utilized geothermal sites are that the total annual emission of H_2S in Iceland amount to 13.000 tons and about 740 tons of H_2. Assuming one filling of a hydrogen car takes 4kg this gives around 400.000 fillings, which approximates to fueling over 15.000 cars per year.

Other methods being studied around the world also hold the promise of producing hydrogen without carbon dioxide emissions, but are in various stages of research and development. They include thermochemical water-splitting using nuclear and solar heat, photolytic (solar) processes using solid state techniques (photoelectrochemical electrolysis), fossil fuel hydrogen production with carbon sequestration, and biological techniques (algae and bacteria). Iceland is participating in and leading efforts in research programs around some of these. Figure 1 shows the timeline for when some of these methods could be expected to impact hydrogen production in Iceland.

Iceland and Turkey are also looking at the possibility of converting H_2S gas, which comes out of boreholes in Iceland and can be found in suboxic zone in the Black Sea.

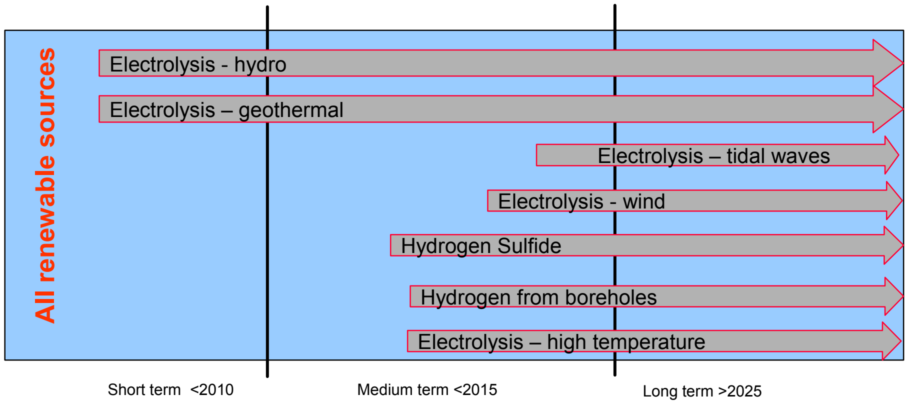


Figure 1. Schematic diagram listing the likely intercept of different hydrogen production techniques.

Key Challenges

Hydrogen production costs are high relative to conventional fossil fuels.

In Iceland we are well equipped from nature to approach clean production of hydrogen. We have abundance of waterfalls and hydrothermal energy which is used to produce clean electricity. The challenge therefore lies in securing a cheap supply of electricity to use in the manufacturing process. Assuming all vehicles in Iceland transferred to a hydrogen fuel, more geothermal power and/or hydropower would need to be harnessed and more power plants would have to be built. To ensure the most economical solution cost analysis and risk assessment for the plant and distribution system is necessary.

Today about 23% of the practicable hydropower and about 7% of the practicable geothermal energy is being harnessed, about 8,4 TWh/a are being produced compared to 50 TWh/a which experts have estimated to be available. Studies have shown that less than 8 TWh/a would be needed for in order to supply the energy needed to sustain all of Iceland's vehicles on hydrogen power assuming they are powered by fuel cells.[7]

[7] J.B. Skulason et al. Framsyni i Orkumalum, 2003

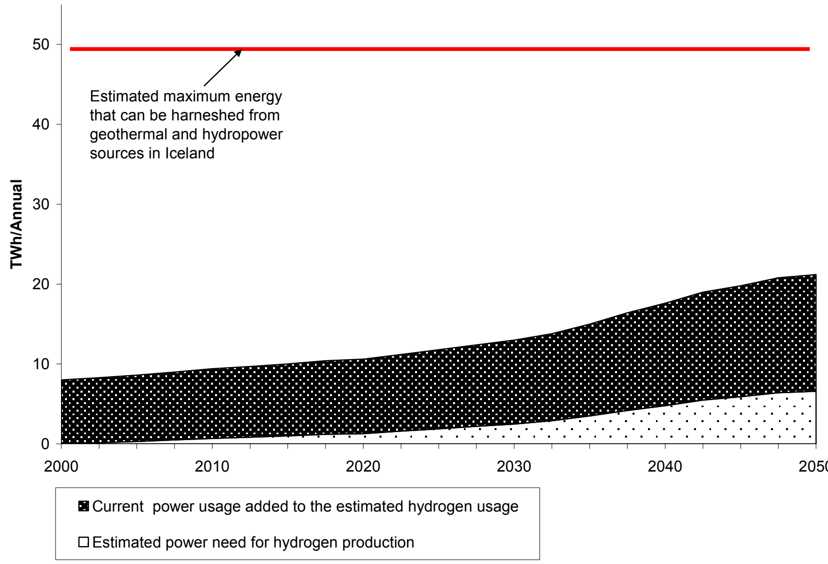


Figure 2. The potential for renewable power and estimated power need for - hydrogen production vs. time. The estimate does not consider changes in electrical use due to new industrial requirements. [8]

Low demand inhibits development of production capacity.

A prerequisite before investment is set into increasing the power for a massive hydrogen production is a stable and predictable demand for the new fuel. Today there is very limited use of hydrogen in industries in Iceland and so government program might be needed to drive public and private production demonstrations.

Vision/Strategy

In the United States and continental Europe the vision for hydrogen economy is that in the short to medium term CO_2 emitting processes will be used for hydrogen production due to the greater cost addition of the CO_2 free processes[9],[10].

In Iceland the vision is to build solely on hydrogen produced from renewable energy sources with minimal air pollution. Most of the hydrogen produced will be through electrolysis but other complimentary processes such as vented hydrogen from boreholes and hydrogen from H_2S could also become a production path. It is also possible that Iceland's 'green' hydrogen can be exported and sold to other countries where policy measures are expected to support CO_2 free hydrogen production methods.

Foreseen areas of interest for further study for production in the local settings are:

- A detailed study of the optimal combination of plant size, storage capacity and production phases.
- The feasibility of using high heat combined with electricity for electrolysis
- The feasibility of using H_2S for production of hydrogen and trapping hydrogen emitted from boreholes.

[8] J.B. Skulason et al. Framsyni i Orkumalum, 2003
[9] National Hydrogen Energy Roadmap, United States Department of energy, 2002

[10] Hydrogen Energy and Fuel Cells, a visioin for our future, High Level Group, 2003

- Building demand for hydrogen by continuing demonstration of the technology and facilitating the integration of hydrogen projects and research in Iceland.

About 72% of the energy used in Iceland comes from domestic renewable sources, the remaining 28% comes largely from imported fossil fuel used in transportation applications. It is the vision that Iceland through its potential of using green energy e.g. to produce hydrogen could become the world's first community which runs 100% on energy from renewable energy sources.

Moving Forward

Moving forward it is important to tackle the key challenge facing hydrogen production in Iceland, this is the supply of low-cost electricity. The energy for electricity production is there but work needs to be done to ensure the best and most economic use of these resources and to get the most economical price of electricity for the hydrogen production.

In addition close collaboration with global leaders in research and development of solution in the field of hydrogen production by electrolysis is important. As are the collaborations between the Icelandic energy companies and the research community to build, test and demonstrate various types of production facilities.

It is important to enact policies that foster collaboration between the key stakeholders on hydrogen production; the National Energy Authority in Iceland and the fuel distribution companies.

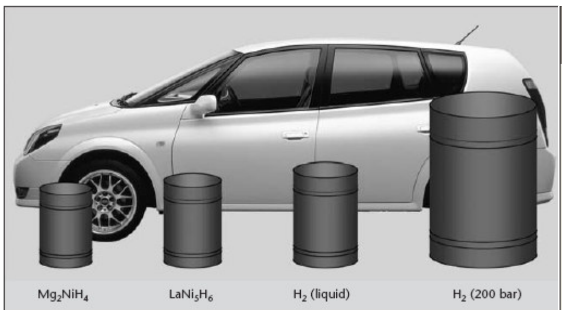
To ensure the demand for the hydrogen produced demonstration projects are needed, where production technologies are done in tandem with applications. Demonstrations are expensive especially and thus there may be little initial demand for the hydrogen produced. Demonstrations that integrate the production technology with other elements of hydrogen infrastructure, including a market use will be more cost effective. This type of project has already been successfully demonstrated by the ECTOS project which ran 2002-2005 in Iceland and included three hydrogen buses and a fueling station where hydrogen was produced with electrolysis.

2. Hydrogen Storage

Hydrogen is a gas at ambient temperatures and pressures, but it can be stored as a gas, a liquid or a solid. Despite these different options the storage of hydrogen for transportation and mobile applications remains one of the greatest challenges that face the actualization of hydrogen as a mainstream fuel type.

Current Status

The US Department of Energy has set up a target of 6.5% hydrogen by weight of storage media or 62 kg H_2/m^3 and several storage techniques are able to meet these requirements (magnesium being an example). These techniques do not, however, show other needed features like release or filling rate at proper temperature or even reversibility.



	Compressed hydrogen	Liquid hydrogen	Gasoline reformer	Methanol reformer
BMW		■		
DC	■	■		■
Ford	■			
GM	■	■	■	
Hyundai	■			
Honda	■			■
Nissan	■			
Opel	■			
Renault	■		■	
Toyota	■			■
VW	■	■		
Fiat	■			

Figure 3. Size comparison for different hydrogen storage media and a listing over the different storage media the major automotive companies are designing for. [11]

In Iceland the hydrogen produced today, is stored as compressed gas. This is the most mature hydrogen storage technology, although the very low density of hydrogen translates to inefficient use of space aboard a vehicle. Despite this most car manufacturers today design their vehicles based on storage of compressed hydrogen. Cylinders that withstand pressure as high as 1200 bars are currently being tested, while the first generation of cylinders used kept hydrogen under a pressure of 360 bars.

Research is ongoing to look at various options and improvements for hydrogen storage. Storage tank designs are advancing with increased strength-to-weight ratio materials and optimized structures that provide better containment, reduced weight and volume, improved impact resistance, and improved safety. Solid state storage has received great interest, and some different approaches that are being researched as potential solutions in this field are listed below:

Hydrogen adsorption on solids with large surface areas, such as carbon nanostructures

Hydrogen storage in metal hydrides

Water based carriers

The various hydrogen storage technologies and their volumetric vs. gravimetric properties are shown in figure 4 and compared to the conventional transport fuels, diesel fuel and gasoline. As

[11] Riso Energy Report 3, Hydrogen and its competitors, 2004

one can see various technologies are able to meet the US Department of Energy goal for these two parameters but at this time they face other challenges mainly kinetics of loading and release of the hydrogen on demand.

Iceland is involved in several storage research projects including evaluation and development of the use of $NaBH_4$ for hydrogen storage, see appendix.

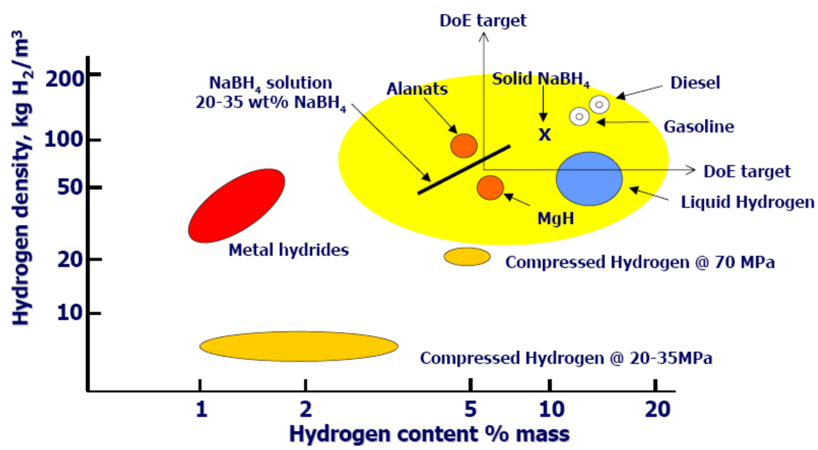


Figure 4. Schematic diagram listing the different hydrogen storage media and the set US DOE goal vs. their volumetric density and mass properties.

Challenges

The challenges that face the hydrogen storage are dependent upon the type of storage technology. For the compressed gas and liquid hydrogen, safer and lighter design which can meet the set US Department of Energy (DOE) goals for size and weight limits is the greatest challenge. For the solid state storage it is the loading and release kinetics that are the challenge in addition to the heat which is released by the formation of the stable metal hydrides, this heat formation could make it necessary to include a cooling system which tend to be bulky and heavy.

Public perceptions of safe use has been raised as a potential issue around hydrogen vehicles and storage, there are some concerns that high pressure tanks will seem undesirable to the public and this makes solid state storage options more attractable. Yet, during surveys the expectations and public acceptance measures very high and the people of Iceland have expressed their expectations through survey in the ECTOS project to welcome the idea of using hydrogen as the main fuel, even in spite of high costs during the introductory phases.[12]

Vision/Strategy

The vision for hydrogen storage is that a selection of different safe, clean, reusable, lightweight, low-cost, and low-volume hydrogen storage devices will be available.

Iceland will likely not be a producer of such systems but will use these for vehicle transport applications as well as a storage system for possible export of hydrogen.

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[12] M. Maack, Socio Economic Results from Ectos, Hy-Pro-Files Conference, 2005.

Moving forward

Follow developments and improvements in the area. Contribute to the technology development by collaboration and facility sharing, as well as technology demonstrations by linkage to projects linked to other aspects of the hydrogen society.

3. Infrastructure

"Hydrogen infrastructure" refers to the physical links between sites where hydrogen is produced and where it is consumed. This is irrespective of the type of hydrogen production site and consumption.

Current Status

Around the world hydrogen is produced in a number of plants and is used for making chemicals or upgrading fuels. It is transported by pipeline or by road via cylinders, tube trailers, and cryogenic tankers, with a small amount transported by rail car or ships.

In Iceland there is no pipeline distribution system, all hydrogen distribution has been handled by use of gas cylinders which have been transported by trucks or ships. In the ECTOS project the hydrogen production occurs on site at the point of delivery and thus no site transportation is necessary. In Iceland the energy used by households is electricity and geothermal hot water, use of natural gas for power or heating applications is very limited and no pipeline for gas distribution exists.

Figure 5. Norsk Hydro high pressure electrolyser container used in hydrogen fueling station in Iceland. [13]

Challenges

It is likely that in Iceland hydrogen production will occur via electrolysis of water. The delivery and transport of hydrogen will be greatly impacted by where the hydrogen is produced and delivered to. For the hydrogen production three delivery systems need to be considered, the

[13] www.electrolyzers.com

delivery of electricity to the production site, the delivery of water to the production site and the delivery of hydrogen from the production site to the user. The first two elements are already distributed to every household in the country. Since no current infrastructure around hydrogen delivery exists it is important that each of these be considered and an overall optimization including production, delivery and end use be done in a comprehensive life cycle analysis (LCA) study.

It is important that a hydrogen delivery system be flexible to accommodate new generations of hydrogen production technology and next generation applications. A central issue is the need for strategies to create hydrogen infrastructures that can grow gradually as demand increases.

Vision/Strategy

In Iceland the most likely method for hydrogen delivery is directly from hydrogen production sites via transport of compressed gas in cylinders. This will be most economical in the beginning as the volume of hydrogen use will not be sufficient to make hydrogen distribution pipelines economical. As the hydrogen economy grows pipelines between the sites where most hydrogen traffic lies could be started and built up around that.

A vision for hydrogen delivery in Iceland is that hydrogen production will be done onsite in various locations at all highly populated areas and that small scale pipeline distribution systems from these sites to neighboring fuel stations will exist. In areas of lower population hydrogen will be transported in cylinders from the nearest hydrogen production facility. Another possibility is that each household will have a small scale electrolyser where hydrogen for their own use will be produced and loaded to their hydrogen fueled applications such as their hydrogen vehicles. This could be expected to put high strain on the electrical distribution system but should be considered once affordable and efficient electrolyzers/fuel cells come to market, a good Life Cycle Analysis (LCA) analysis of this approach is needed and should be compared to the option of centralized hydrogen production sites.

Moving forward

Hydrogen delivery and distribution is a critical step for a successful implementation of hydrogen fuel economy. Since the introduction and growth of hydrogen fuel in the transportation sector can be expected to increase gradually it is important that the delivery and distribution system be flexible and adaptable to both initial low volumes and later growing demands. Several possible scenarios of solutions for distribution systems are possible.

Hydrogen produced at fuel stations or other locations where short distance transportation between places could occur in tanks (decentralized).

Hydrogen produced at power plants where long distance distribution and transportation could be in tanks transported by cars or via pipelines (centralized production).

Due to the lack of gas distribution systems in Iceland and low population density building a pipeline grid to support gas distribution might not be economical but, to understand which solution or a mix of solutions is the best option a full scale Life Cycle Analysis (LCA) combined with simulation of overall end cost for the different delivery options combined with the different production options needs to be done. This should be the first step moving forward to ensure that the right start of a hydrogen distribution system be taken.

4. Conversion and Application

Hydrogen can be used both in internal combustion engines and in fuel cells. Engines can combust hydrogen in the same manner as gasoline or natural gas, while fuel cells use the chemical energy of hydrogen to produce electricity and thermal energy. Since electrochemical reactions are more efficient than combustion at generating energy, fuel cells are more efficient than internal combustion engines. However the fuel cell technology is not yet economically competitive.

Current Status

The use of hydrogen in internal combustion engines is a fairly well developed technology — the National Aeronautics and Space Administration (NASA) in USA and the US Department of Defense use it in the space shuttle's main engines and unmanned rocket engines. Other combustion applications are under development, including new combustion equipment designed specifically for hydrogen in turbines and engines. Vehicles with hydrogen internal combustion engines are now in the demonstration phase, and the combustion of hydrogen blends is being tested.

Fuel cells are in various stages of development. Current fuel cell efficiencies range from 40 to 50 percent at full power and 60 percent at quarter-power, with up to 80-percent efficiency reported for stationary combined heat and power applications. To find out more about the current state of the art in the hydrogen conversion technology there are scientific review articles published regularly and IPHE and The US Department of Energy have links to new reports in the field from their websites.

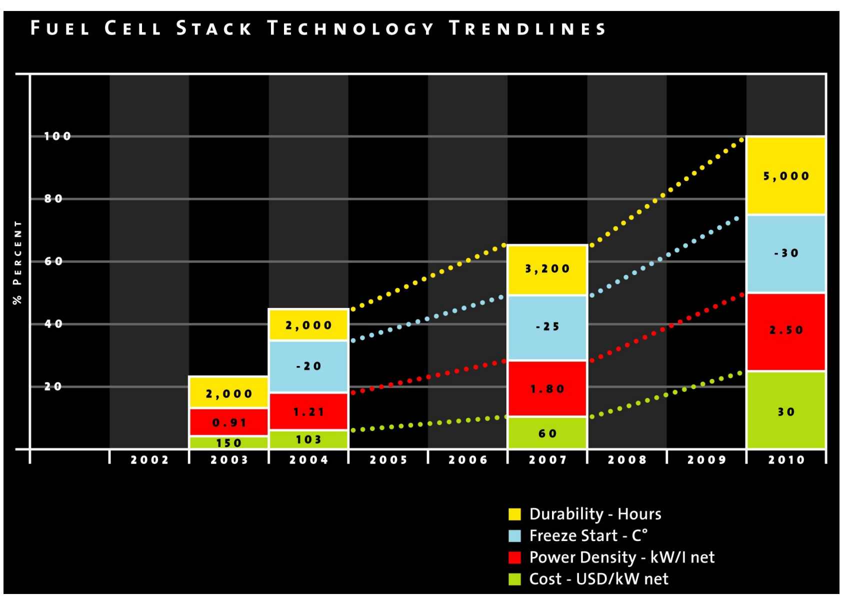

Figure 6. Predicted Fuel Cell technology trendline for some of the key operating parameters from Ballard Power Systems[14]

Keflavik Fuel Cell Project

At present a project based on cooperation between US and Iceland using stationary fuel cell system to light up artwork at the Keflavik International Airport. This is a demonstration project with the aim to proof the reliability of such a system and by that to investigate how such a system could be used for example as a backup power in critical applications. The second aim in this project is to demonstrate the security of such a stationary systems and to train personnel in handling and working with hydrogen power systems. In near future one could expect to see such backup systems in use in hospitals, fire brigade and emergency telephone systems, which use today diesel powered engines. This new system should outperform diesel systems in start up times, which is very critical for computer based systems.

Challenges

Iceland needs to build up infrastructure to support bigger applications and conversion volumes. Training of technicians and handling experts in maintenance and safety protocols is crucial as well as training and information flow to all those who will be impacted by the change to hydrogen fuel use.

Vision/Strategy

In Iceland the primary use for hydrogen will be for vehicle and transport applications, not the least on board the extensive fishing fleet. Stationary applications are possible in remote areas where electricity delivery is not feasible, and other fluctuating renewable energies such as ocean tides or wind can be harnessed, and converted to hydrogen to be stored and used as an energy source at off peak hours.

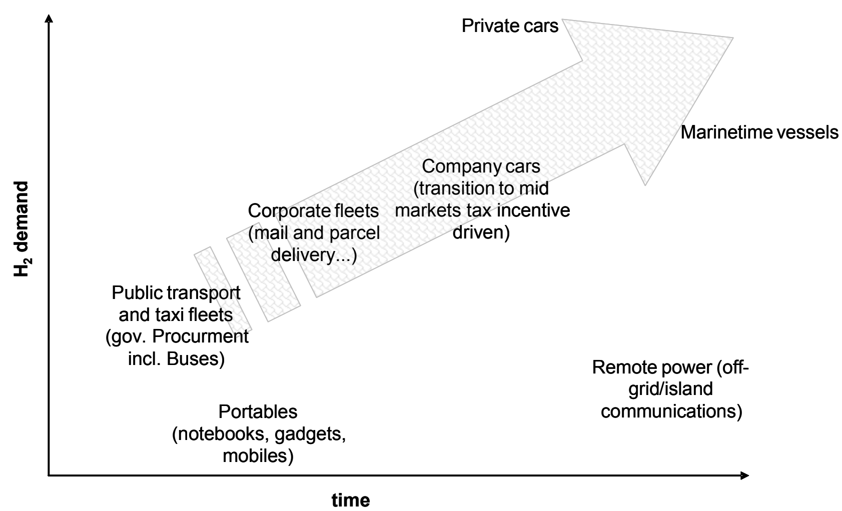

Figure 8. Various hydrogen end use products and their expected hydrogen consumption and possible time of commercialization.

For transportation application the vision is that the first hydrogen vehicles will be public transportation and corporate fleet cars which then will be followed with commercial private vehicles. The first steps of public transportation fleets has already started with the ECTOS demonstration project where hydrogen buses have been used as a part of the public transportation system.

[14] www.ballard.com

Moving Forward

Emphasis will be put on Iceland's participation in international application and conversion projects. Iceland has a history of involvement in demonstration projects and should continue to use the size and positive attitude of Icelandic government towards these types of projects.

Government incentive could help companies take the first steps towards building up a hydrogen car fleet which would have a domino effect on other aspects such as infrastructure development.

Figure 9 shows a prediction of the relative H_2 market share for various commercializations in Iceland.

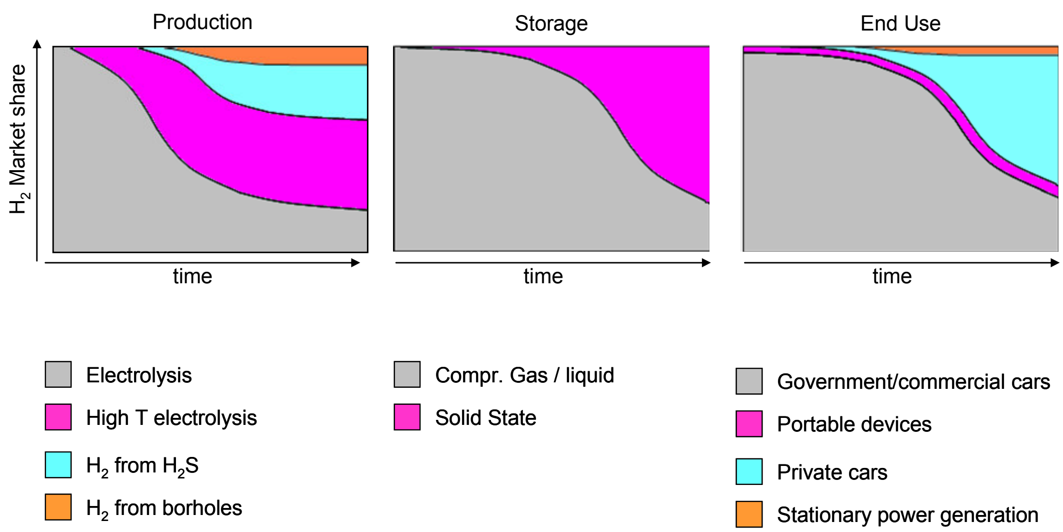

Figure 9. Expected relative market share of different hydrogen groups.

5. Hydrogen Research

The challenge of making hydrogen fuel feasible for transportation and other applications requires new solutions and development. To find these, extensive research in the area is needed.

The world community recognizes the need for new solutions and research in the field of hydrogen fuel technology and specific funds for this area have been dedicated by most major institutes and international councils. Here in Iceland most research in the area has been through international collaboration. The international research projects have proven to be very beneficial to all parties and encouraging for future participation. It is important for the progress of hydrogen economy in Iceland that the government and key energy, and research funding authorities continue to see the benefit of such collaborations and continue to endorse and match the cost requirements needed for such participation.

Hydrogen Production

The challenge for hydrogen production is to provide hydrogen at an affordable and competitive price. It is clear that Iceland will rely on electricity for much of it's hydrogen production and thus following and implementing new technologies in electrolysis and potentially high temperature electrolysis will be crucial. Developing technologies that allow other resources such as converting H_2S from geothermal sites and capturing H_2 emitted from boreholes are research fields where Iceland could provide leadership that could benefit the international hydrogen community.

Hydrogen Delivery and Distribution

To allow a successful implementation of hydrogen as a fuel, a smooth integration with hydrogen delivery to the end user is crucial. Careful studies and system analysis of different production/end uses configuration need to be encouraged and performed. Due to Iceland's confined geometry these types of optimization studies could be used as a starting point to benefit in a larger scheme of international hydrogen economy.

Socio Economic

To compliment the development of a world class technology a careful study of environmental and socio-economic study of different energy converter configurations and transition pathways is essential. Here again Iceland can offer a concise manageable set for data collection and analysis that could be used to understand the impact to larger size communities around the world.

Hydrogen Storage

Hydrogen storage for transportation applications is one of the biggest challenges that the hydrogen economy faces. Icelandic researchers are actively participating in international research in this area and continuing research involvement and monitoring of all breakthrough progress in the field should be closely monitored.

International Research

Setting the direction for strategic research agenda for Iceland requires co-operation between a broad range of stakeholders including academic research centers, industry, end-users, civil society, small and medium enterprises and public authorities at all levels. Just as Iceland as a country and a nation has much to offer internationally in areas such as in hydrogen production, distribution, delivery and socio-economic research, we can benefit from international collaboration in areas such as conversion technologies and hydrogen storage. Continuing international research collaboration, participation in international hydrogen councils and societies is of essence for a successful introduction of the hydrogen economy.

Appendix A

Alternative Solutions for Fossil Fuel Free Transportation

Other environmental fuels are also being considered to replace the fossil fuels. For transport vehicle applications cars that run on batteries charged by electricity and methane fuel are being developed and many so of so called hybrid cars have sold well, these are cars which run on two types of energy sources, usually gasoline and electricity so that much less gasoline is consumed per mile driven than for a regular gasoline engine driven car. Some companies are considering the same idea for hydrogen, that is to produce a hydrogen/electric hybrid car.

There are several hybrid cars on the roads of Iceland today and several methane fueled cars and recently two methane fueled buses were bought by Straeto bs.

Alternative vehicle technologies which are being developed:

Clean Diesel, Gasoline-hybrid, Diesel-hybrid, Hydrogen-hybrid, Biofuel, Plug-in hybrid

Appendix B

Hydrogen Production by Electrolysis[15]

Principle

The decomposition of water by electrolysis involves two partial reactions that take place at the two electrodes. The electron-conducting electrodes are separated by an electrolyte that conducts ions but not electrons. Hydrogen is produced at the negative electrode (cathode) and oxygen at the positive electrode (anode). Energy to split the water molecules is supplied as electricity to the two electrodes, and the necessary exchange of charge occurs as ions flow through the electrolyte. The following sections describe electrolysis processes as optimized for hydrogen production: the well-tested low-pressure electrolysis method, and two processes – high-pressure and high-temperature electrolysis – that are still under development. Chloro-alkali electrolysis is not discussed further here.

Conventional water electrolysis

Conventional water electrolysis uses an alkaline aqueous electrolyte. The cathode and anode areas are separated by a microporous diaphragm to prevent mixing of the product gases. At output pressures of 2-5 bar the process can reach efficiencies of around 65%. Instead of the alkaline electrolyte with an inert diaphragm, a solid acid proton conductor of the Nafion type (as used in PEMFCs) can also be used as a combined electrolyte and diaphragm [18]. Electrolysers are commercially available in capacities of 1 kW-125 MW. The Electrolyser Corporation Ltd. (Canada), Norsk Hydro Electrolysers AS (Norway) and DeNora (Italy) are well-established manufacturers of electrolysers for hydrogen, though much of their business is in the chlor-alkali market. Electrolyser manufacturers with a more specialized background in hydrogen include Ammonia Casale and Stuart Energy.

High-pressure electrolysis

As the volumetric energy density of gaseous hydrogen is rather low, it is an advantage to produce pressurized hydrogen directly. High-pressure water electrolysers now being developed can generate hydrogen at pressures up to 120 bar from an alkaline electrolyte. A 5 kW prototype was tested at Forschungszentrum Jülich in Germany [19]. Another advantage of the high-pressure electrolyser is that its internal electrical resistance is lower, so the overall energy efficiency increases.

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[15] Riso Energy Report 3, Hydrogen and it´s competitors, 2004

High-temperature electrolysis

High-temperature electrolysers started as an interesting alternative during the 1980s. If part of the energy required to split the water molecules is supplied in the form of high-temperature heat, less electricity is needed. High temperatures also speed up the reaction kinetics, decreasing the internal resistance of the cell and increasing the energy efficiency. High-temperature solid oxide electrolyser cells (SOECs) have the advantage that they can also split CO_2 into CO and O_2. A mixture of steam and CO_2 can be electrolysed to give a mixture of H_2 and CO – synthesis gas – from which hydrogen carriers such as methane (CH_4) and methanol (CH_3OH) may be easily produced. Note that such artificial CH_4 will be a CO_2 neutral hydrogen carrier provided CO_2 can be acquired from other sources.

The original idea was to use heat from solar concentrators or waste heat from power stations for high-temperature electrolysis. Low energy prices halted this work around 1990, but the current emphasis on hydrogen has brought renewed interest. If fossil fuels become scarce, high-temperature electrolysis may have a future as a way to use heat from renewable or nuclear energy sources. Several R&D projects on SOECs are in progress in Europe and the USA.

Hydrogen Production from H_2S[16]

Hydrogen could be produced from H_2S by using various different decomposition methods. Mainly, these are the plasma, electrochemical, photochemical and thermal methods. The plasma process uses microwave plasma chemistry to dissociate H_2S into H_2 and S. Back reaction of the products to H_2S is minimized by in situ cyclonic separation and a rapid quench of the products. Furthermore, experiments with water and carbon dioxide concentrations typical of acid-gas streams from refinery operations and natural gas production have demonstrated that these components are compatible with the proposed process. A preliminary economic evaluation indicates that the plasma-chemical process will be substantially cheaper to operate than the conventional sulfur recovery technology and that the sulfur emissions will also be lower.

Photochemical reactions use photocatalysts that absorb ultra-violet light from the solar spectrum to power chemical reaction. But this method is not effective since using UV light is very expensive to produce hydrogen from H_2S.

Most of the hydrogen sulfide produced in the catalytic hydrodesulphurization of fossil fuels is processed in a Clauss process, producing sulfur and low-valued steam but doesn't produce any hydrogen. But for a long time, it has been known that H_2S can be converted to H_2 and elemental sulfur by thermal decomposition of H_2S at high temperatures (900-1100 K). H_2S can be catalytically decomposed to hydrogen and sulfur and the catalyst preparation, operating conditions, catalyst type have a significant effect on the amount of hydrogen produced and on the economics of the process. The stoichiometric equation of the thermal decomposition reaction is

$2H_2S \leftrightarrow 2H_2 + S_2$ $\Delta H = 50$ kcal/mol (Activation energy)

[16] M. Haklidir et al. Proceedings International Hydrogen Energy Congress and Exhibition IHEC 2005.

Appendix C

European Timeline View for Hydrogen Implementation from High Level Group Report[17]

In the short and medium term (to 2010):

• Intensify the use of renewable energy sources for electricity which can be used to produce hydrogen by electrolysis or fed directly into electricity supply grids.

• Improve the efficiency of fossil-based technologies and the quality of fossil-based liquid fuels.

• Increase the use of synthetic liquid fuels produced from natural gas and biomass, which can be used in both conventional combustion systems and fuel-cell systems.

• Introduce early applications for hydrogen and fuel cells in premium niche markets, stimulating the market, public acceptance and experience through demonstration, and taking advantage of existing hydrogen pipeline systems.

• Develop hydrogen-fuelled IC engines for stationary and transport applications, supporting the early deployment of a hydrogen infrastructure, provided they do not increase the overall CO_2 burden; Considerable fundamental research is needed throughout this period, on key technology bottlenecks, e.g. hydrogen production, storage and safety, and fuel cell performance costs and durability.

In the medium term (to 2020):

• Continue increasing the use of liquid fuels from biomass.

• Continue using fossil based liquid and gaseous fuels in fuel cells directly and reforming fossil fuels (including coal) to extract hydrogen. This enables transition to a hydrogen economy, capturing and sequestering the CO_2. The hydrogen thus produced can then be used in suitably modified conventional combustion systems, hydrogen turbines and fuel cell systems, reducing greenhouse gas and pollutant emissions.

• Develop and implement systems for hydrogen production from renewable electricity, biomass; continue research and development for other carbon-free sources, such as solar thermal and advanced nuclear.

In the medium to long term (beyond 2020):

• Demand for electricity will continue to grow, and hydrogen will complement it. Use both electricity and hydrogen together as energy carriers to progressively replace the carbon based energy carriers by the introduction of renewable energy sources and improved nuclear energy. Expand hydrogen distribution networks. Maintain other environmentally benign options for fuels.

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[17] Hydrogen energy and fuel cells, a vision for our future, High Level Group for hydrogen and fuel cells, Report 2003. http://www.epsoweb.org/Catalog/projects/index.htm

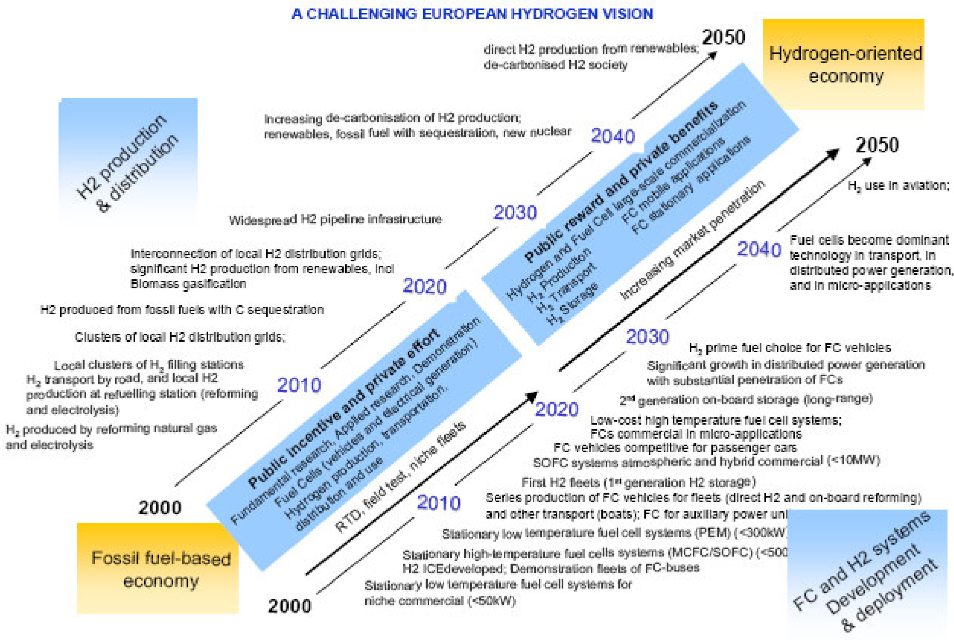

Figure A. Skeleton proposal from High Level Group for European hydrogen and fuel cell roadmap for various hydrogen end use products and their expected hydrogen consumption and possible time of commercialization.

Viðauki IV – Shell Hydrogen – Stefnumörkun á sviði vetnismála

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The Ministry of Industry & Commerce
Permanent Secretary
Mr. Kristjan Skarphedinsson
Arnarhvoll
IS-150 Reykjavik
Iceland

Friday, 28 July 2006

Dear Mr Skarphedinsson,

I very much enjoyed meeting with you and Mr Petursson last week to start the dialogue about the future of hydrogen in Iceland, and in particular Icelandic Government Hydrogen policy, programmes and progress.

For years the Icelandic government has been at the forefront of new energy development and has an ambitious and highly praised target of creating the first carbon free economy. We in Shell Hydrogen have been contributing towards its realisation through our investment and continued participation in Icelandic New Energy Limited (INE) and the Shell/Skeljungur hydrogen fuelling station in Reykjavik.

As we discussed, the purpose of my visit was also to better understand how we can jointly take the steps in fulfilling **our** longer term vision for Iceland to become the world leader in developing a Hydrogen economy. For road transport these steps clearly involve more vehicles and construction of more integrated fuelling sites, which would offer customers convenient refuelling. At this early stage in the development of hydrogen technologies when investments are not yet commercially viable and industry participants have to set priorities, government commitment and support remains critical. Therefore I hope that the proposal made by INE will be considered favourably, as vehicles remain crucial for the next step of the market development. From my side, I will be engaging in further discussions with auto manufacturers, Icelandic and international stakeholders on how we can support this next stage.

During the visit I also learnt that the transition to cleaner/renewable marine fuel is an important priority for the government and will look into this opportunity from the energy supplier perspective.

We would like to see Iceland continue developing a Hydrogen economy as I believe your country has everything it takes to become the leader in truly renewable hydrogen development in the world. I look forward to continuing our dialogue and wish you all success in achieving this great vision.

Yours sincerely,

D.J.Macleod
Vice President
Shell Hydrogen B.V

cc
Mr. Baldur Petursson Head of Unit Ministry of Industry & Commerce
Mr Hjalmar Arnason Member of Parliament
Mr. Jon Bjorn Skulason General Manager Islensk Nyorka
Professor Thorsteinn I. Sigfusson

Shell

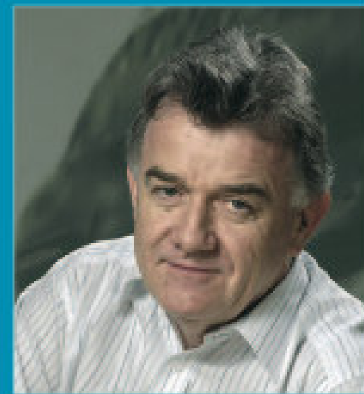
Hydrogen

Experience Choice

Shell Hydrogen

Real Results

Introduction



Much of our world worries about similar issues: about the environment and air quality; about energy supply security; and about energy prices. With over 100 years of experience in delivering innovative energy solutions to society, the Shell Group[1] believes it is our responsibility to give governments and consumers greater choice in how they address these problems. Today, Shell is developing bio-fuels, gas to liquid fuels and also hydrogen, all of which can become key parts of the world's future energy mix.

Hydrogen is a clean energy carrier that, when used in fuel cells, emits nothing more harmful than water vapour. It can be made in a number of ways, so countries can make best use of their resources and governments can exercise additional choice in their energy policy. In the medium term, hydrogen will be made from conventional sources such as gas and coal - but in the longer term, hydrogen may increasingly come from renewable sources.

Shell Hydrogen was set up seven years ago and owns or participates in a number of retail sites - in Amsterdam, Luxembourg, Reykjavík, Tokyo and Washington, D.C. - that demonstrate how we can deliver hydrogen safely and reliably to our customers. Each site is unique - and each one teaches us something new. These standalone projects are helping us to introduce a new fuel into the market and are part of an exciting programme that is helping to educate consumers about the possibilities of hydrogen. These sites allow us to build strong relationships with governments and the car and bus companies who will use our fuels. Collectively, these projects demonstrate that we can apply hydrogen technology in a variety of different environments.

But this is just the beginning. The next stage is to link these projects into mini-networks in urban centres. We are going to expand these networks - in California and New York, in Europe, China and Japan - to provide hydrogen fuel to more vehicles and this will take us closer to a mass market for hydrogen. Working with other industry players, we are learning how to develop the Hydrogen Economy by reducing the costs of manufacturing and retailing in a series of steps. When mass production of vehicles starts - perhaps around 2015 - we want to be at a point where we can provide hydrogen at a price comparable with existing fuels.

My vision is that, in 10 or 15 years, our children will be driving these vehicles. Many of the world's major cities will have hydrogen buses and cars; and countries like China, India and Russia will be seeing the benefits of a Hydrogen Economy. When you put all of this together, you are talking about a substantial new energy business for companies like Shell.

I am lucky to be leading such a new energy business in Shell. I have a great team of people who share this vision and are committed to making it real. I believe that the steps we are taking today are helping to ensure that our children will have further choices in how they power the world of tomorrow.

Duncan Macleod, Vice President, Shell Hydrogen

1 Each of the companies that make up the Shell Group of Companies is an independent entity and has its own separate identity. In this publication the expression "Shell Hydrogen" or "Shell" is sometimes used for convenience in contexts where reference is made to these companies in general, or where no useful purpose is served by identifying a particular company.

The Case for Hydrogen

The emergence of clean alternatives to fossil fuels and concerns about global climate changes and air quality arouse strong emotions. As a global leader in the provision of energy, Shell espouses an evidence-based view of the benefits of hydrogen. The facts are clear: hydrogen is already delivering cleaner energy and can play an important part in the world's future energy mix. However, for every benefit there is a challenge. And for every challenge, Shell Hydrogen is pioneering - with other industry players - the activities that ensure they are overcome. The future is in our hands - provided we all make the right choices about hydrogen today.

People and Society

Shell believes:

Consumers who experience the Hydrogen Economy are positive about it.

The facts:

Today, societies are choosing zero-emission hydrogen-powered vehicles for cleaner transportation and to meet agreed environmental targets. They are making hydrogen part of plans to deliver cleaner, competitive energy solutions in the next twenty years. Some surveys in locations where hydrogen buses have been implemented indicate that people are generally positive about their use.

The Challenge:

As with many new technologies, there are public concerns about the viability of hydrogen as an energy carrier; concerns that can only be addressed via education and research.

What Shell is doing:

Shell actively educates a wide variety of different audiences - from the grass roots to the very highest levels - about the merits of hydrogen. Shell representatives speak regularly at major energy fora in all key markets and Shell is regularly asked to comment on alternative energy issues in the world's most influential newspapers and magazines. With each of its retail sites, Shell conducts extensive stakeholder and community engagement programmes; while their everyday operation adds to the education level of the general public. Shell testifies to government and inter-government groups on the need for market-based incentives to drive up demand, especially for hydrogen vehicles. Shell continues to research ways of reducing the costs of hydrogen and is working with the car industry to apply improved technology and economies of scale to the production of hydrogen Fuel Cell Vehicles (FCVs).

Environment and Air Quality

Shell believes:

Greater use of hydrogen in transportation and power will result in a reduction of greenhouse gases and an improvement in air quality.

The facts:

Studies indicate that, when compared with a gasoline-powered vehicle, high efficiency Proton Exchange Membrane hydrogen fuel cells reduce greenhouse gas emissions substantially where hydrogen is obtained from natural gas. Electricity generated at nuclear stations is another way to produce hydrogen with next to zero carbon dioxide (CO_2) emissions.

The Challenge:

Over time, we need to shift the means of hydrogen production away from fossil fuels like natural gas or coal and towards renewable, 'green' sources that will enable the greatest possible reductions in greenhouse gases. Shell believes that the first step to greener hydrogen is clean hydrogen.

What Shell is doing:

Production of hydrogen must avoid introducing CO_2 into the environment if it is to become a major contributor to the world's energy supply. In the long term, this will be achieved through the production of hydrogen from renewable sources that are cost-competitive with existing technologies - Shell's ultimate goal. In the medium term, CO_2 reduction can be achieved in a number of ways. Firstly, Shell works with public and private entities around the world to develop publicly-acceptable solutions for CO_2 sequestration - the capture and secure storage of CO_2, a technology in which Shell is an industry leader. Shell is also conducting research into: production of liquid hydrogen which captures CO_2 more efficiently than does production of gaseous hydrogen; and hydrogen production through coal gasification in combination with CO_2 capture. Shell also tests a variety of different types of equipment, such as electrolysers, at its various hydrogen retail outlets.

Energy security and efficiency

Shell believes:

Hydrogen reduces dependence on oil by allowing countries to diversify their energy supply and that fuel cells are more efficient than combustion-based power generation.

The Facts:

Rising oil prices and diminishing supplies have moved energy security up the agenda of governments around the world. President Bush has stated that hydrogen enables the US to reduce its dependence on conventional energy sources, which are often located in unstable locations. Also, a recent EC report indicated that the capability of local production and distribution of hydrogen reduces exposure to terrorist attack.

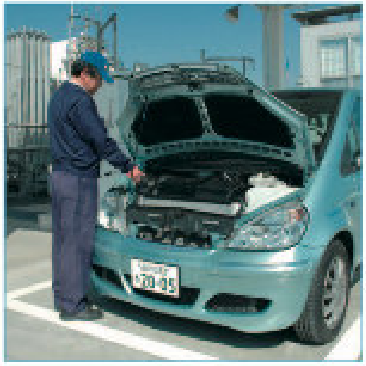
Car companies and governments are actively working on fuel cell solutions today: BMW, DaimlerChrysler, Ford, General Motors, Honda, Nissan, Toyota and Volkswagen are among those conducting Hydrogen Fuel Cell (HFC) test projects.

The Challenge:

To create a bridge between the isolated projects of today and the Hydrogen Economy of the future, the cost and durability of HFC technology must improve. Also, the vehicles and the infrastructure to fuel them need to develop simultaneously: there is little point in companies like Shell investing in the production and distribution of hydrogen if there are no cars on the roads and, similarly, there is no incentive for car manufacturers to bring the vehicles to market if there is nowhere to refuel them.

What Shell is doing:

Shell is applying its unique expertise in manufacturing, distribution and retail to building the refuelling infrastructure that will power the Hydrogen Economy. However, through its close alliances with a wide range of experts, Shell is also supporting activity in all parts of the hydrogen value chain. It has commercial alliances with many of the world's leading car manufacturers, such as General Motors, to advance fuel cell technology and align the commercial roll-out of vehicles with the fuelling infrastructure. It is part of many research and development organisations, including the California Fuel Cell Partnership and has created alliances with world-leading academic institutions such as MIT in the US, Imperial College in the UK and Tongji University in China. Shell is also supporting early-stage development of fuel cell technology through its participation in focused venture capital funds in North America and Europe.



Safety

Shell believes:

Hydrogen fuel is as safe as other fuels.

The facts:

Shell has more than 40 years' experience in the safe handling of hydrogen. In the unlikely event of any leakage, hydrogen escapes quickly into the atmosphere as a very diffuse gas. Hydrogen is generally considered to be harmless to health and to the environment.

The Challenge:

The industry has the codes and standards in place that cover almost the entire hydrogen supply chain. However, some challenges do remain, primarily in the area of retail marketing and more Research & Development is being done to address the codes and standards for retail environments. In addition, there is a need:

- For further dialogue with governments and regulators about hydrogen's properties and safety codes and standards;
- To standardise safety codes and procedures prevalent among various manufacturers, institutes, research centres, and even different countries and regions;
- For communities to adopt the latest hydrogen-related codes and standards.

What Shell is doing:

Shell is actively working with governments, car companies, energy companies and the National Labs to ensure a safe hydrogen industry. Shell Hydrogen has adopted robust standards in design, installation and operation to ensure the safety of our hydrogen refuelling stations. In the United States, Shell's Benning Road station - the nation's first integrated retail fuelling station - demonstrates and implements safety measures adopted by Shell and practices prevalent in the industry. In addition, its hydrogen fuelling station in Amsterdam has had a very good availability and safety performance. Overall, Shell has played a leading role in promoting hydrogen fuel Research and Development and is sharing invaluable first-hand data with government and regulatory agencies to develop the standards for integrated commercial/retail multi-fuel facilities in the U.S and elsewhere.

The evolution to the Hydrogen economy

Shell believes that the evolution towards an embryonic Hydrogen Economy can be realised gradually within the next 20 years. This may sound fanciful, but already governments around the world are making commitments to promote hydrogen FCVs or even create a carbon free economy.

- Iceland is aiming to have its cars, buses and fishing fleet run off hydrogen fuel cells by 2025.
- California, which already has around 30 hydrogen stations, has adopted the so-called ZEV (Zero Emission Vehicle) mandate, which requires the six largest automotive companies present in California to collectively deploy tens of thousands of hydrogen FCVs by 2017.
- In Europe, the EU commission launched its "HyWays Hydrogen Roadmap" whose aim is to develop a validated, well-accepted roadmap for the introduction of hydrogen in the energy system. It predicts that hydrogen vehicles will make up as much as 3.3% of the total vehicle fleet by 2020, and 23.7% by 2030.
- In Japan, the government (METI) plans to extend the existing network of 12 hydrogen refuelling stations in Tokyo/Yokohama to Osaka and Nagoya with a view to having 50,000 FCVs on the road by 2020.

However, this evolution will be gradual, with no dramatic overnight changes in the cars or infrastructure: we won't be required - or expected - to switch to the new cars or construct an infrastructure of dedicated hydrogen filling stations and distribution networks all at once. It is also undoubtedly true that different countries - and even different regions within a single country - will embrace this future at different speeds. A reputable international body has recently estimated that, provided certain conditions are satisfied, hydrogen vehicles could represent up to 30% of the worldwide vehicle fleet by 2050.

So, how do we get there? Through the close coordination and cooperation of car manufacturers, energy companies and governments and by all of us doing what we can to help them in their efforts. While we can't accurately predict the future, we can paint a broad picture of how the Hydrogen Economy may develop.

Timeline

2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

Shell's Vision for the First Ten Years

The technology and infrastructure to support the future are being put in place today. The world's leading car companies are undertaking the research to create practical hydrogen vehicles. And the stations that will fuel these prototype vehicles are being built.

Shell's vision is that the next decade will see the creation of hydrogen mini-networks by bringing together: hundreds of vehicles from different car companies; clusters of four or more integrated hydrogen and gasoline refuelling stations; and two or more energy companies and fleet owners. These will play a crucial role in bridging the gap between today's projects and a commercial infrastructure roll-out. The retail cost of hydrogen will also be much closer to that of conventional fuels on an equivalent cost-per-kilometre basis. Together with intermediate technologies - such as hybrid hydrogen fuel cell/ICE vehicles - this will enable consumers to choose hydrogen solutions in ever-greater numbers and enable the fulfilment of a mass market for FCVs.

For example, California could have a network of 50-100 hydrogen stations with around 2,000 hydrogen vehicles driven on the roads. Shell will have built another hydrogen refuelling station between Washington, D.C. and New York to create the foundation for an "East Coast Corridor". Canada could have a network of hydrogen stations linking communities in British Columbia. Norway could have a hydrogen infrastructure linking Oslo with other Norwegian cities. Other mini-networks in Europe and Japan could also have been completed.

Automotive manufacturers will have started serial production of hydrogen-burning ICE cars, and some will have begun leasing them to corporate customers. Others will have introduced environmentally-friendly hybrid-powered and fuel cell cars to China. In public transport, car companies will have launched buses with hydrogen combustion engines and hybrid hydrogen buses.

2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

Shell's Vision for the Following Ten Years

There is a good chance that, in around ten years' time, the cost of fuel cell vehicles will be an order of magnitude cheaper than they are today and that hydrogen FCVs will be a common sight in car dealerships - and increasingly on the road. By this point, the major urban centres in Europe, North America and the Far East and the corridors between them will be well served by filling stations for hydrogen and other alternative fuels.

Shell believes that after 2020, hydrogen vehicles will be in an increasingly affordable alternative to petrol-burning cars and there will be perhaps thousands of filling stations for alternatively-fuelled cars in the key markets of North America, Europe and Asia. An increasing number of vehicles offered for sale will be fuelled by hydrogen or a bi-fuel solution which includes hydrogen. Iceland will be well on the way to becoming the first country to have eliminated hydrocarbon vehicles from its energy chain. The advancement of carbon sequestration will have brought truly clean hydrogen much closer to reality. Government incentives and scale efficiencies will mean that hydrogen-powered vehicles will be more commonly used in urban areas, particularly for public transportation.

Perhaps not all of these plans will be fulfilled, but they point the way to the future by showing that hydrogen offers a real alternative to conventionally-fuelled vehicles.

The Role of Shell

As a leading provider of energy solutions - for today and tomorrow - one of the Shell Group's most important responsibilities is to explore and exploit the potential for new energy and fuels such as hydrogen as part of our overall energy portfolio. However, the evolution to the Hydrogen Economy is a marathon, not a sprint and Shell Hydrogen's strength lies in being an integral part of the Shell Group - being able to draw on world class international experience in developing and introducing new fuels and sharing a vision of the future.

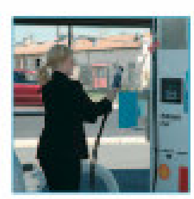
The Shell Group brings the power of its production capacity and infrastructure to benefit the Shell Hydrogen business and already has a platform of potential hydrogen production nodes all over the world. Industry-wide, 50 million tonnes are produced and consumed every year. And Shell's global retail infrastructure - the largest in the world - provides the framework for the future supply of hydrogen to millions of consumers.

Real Technology

Shell has already shown it is serious about hydrogen - Shell Hydrogen has just celebrated its seventh birthday. We are the only major energy company to have participated in fuel cell vehicle projects in the three major hydrogen markets - the United States, Europe and Japan. These include Tokyo's first hydrogen refuelling station and the first combined hydrogen and gasoline station in North America; we also provided funding and project management assistance for the first hydrogen refuelling stations in Luxembourg and Amsterdam. Additionally, Shell announced that it will work with Tongji University to build Shanghai's first hydrogen filling station. In 2006, we embarked on the next stage - creating economically viable hydrogen mini-networks in those key markets.

Shell is also investing significant resources in greener, more efficient production of hydrogen. Its leadership in CO_2 management - both capture and sequestration - can provide clean hydrogen and is an important stepping stone to the production of truly green hydrogen from renewable energy sources.

In those seven years, a lot has happened to demonstrate that Shell is delivering on its business objective to lead the drive towards the Hydrogen Economy. Keep watching this space.



Real Rewards

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Iceland

Towards a carbon-free economy

The Icelandic government has publicly committed to becoming the first economy powered purely by renewable energy sources. Shell has been closely involved with the island's ECTOS (Ecological City Transport System) Project which has demonstrated the feasibility of using hydrogen to power its public transport fleet.

Project Aims:
To test the practical, safe production and distribution of hydrogen and its use on three fuel cell buses operating on normal routes in Iceland's extreme weather conditions. Overall, ECTOS aims to evaluate the socio-economic consequences of transforming the energy base of a modern society as part of Iceland's overall objective of being entirely self-sufficient for its energy resources.

Project Partners:
Icelandic New Energy Ltd. (INE), a Joint Venture of the following companies: VistOrka hf EcoEnergy Ltd. (a public Icelandic company); DaimlerChrysler AG; Norsk Hydro Produksjon A/S; and Shell Hydrogen B.V.

Hydrogen Source:
The hydrogen is produced on-site by the electrolysis of water using 'green' electricity produced from renewable energy sources. It is then compressed and stored to provide daily fuelling for each of the buses.

The Role of Shell:
The ECTOS Project centres on a hydrogen retail filling station at an existing Shell forecourt in Reykjavík - the first Shell-branded hydrogen station in the world.

Shell Hydrogen

A Sustainable Energy Environment

With abundant hydro and geo-thermal energy resources, Iceland powers all stationary applications using renewable energy: already it meets 71% of its energy requirements from these sources. By evaluating the role of hydrogen in its transport fleet, the ECTOS Project is laying the groundwork for the world's first truly green economy.

Real Lives

Educational materials were created by INE specifically for 10-15 year old children and provided to every school in Iceland and there has also been a concerted educational outreach to the media. As a result, the public approval rating for the use of hydrogen over fossil fuels is over 90%.

Real Business

"My hope is that, if we continue to progress at the same rate, we can make hydrogen technology viable sometime around the 2012 or 2015 time frame - that would be a major step forward for the global environment. We can get to this point faster than many other countries as we have only 300,000 people in Iceland of whom 70% live in the Greater Reykjavík area: we would only need about 15 filling stations to reach 90% of the population. This is a much less complicated picture than in Europe or the US but if the infrastructure is going to be ready for consumers by 2015, we really need to move fairly fast in the next few years."

Jón Björn Skúlason,
General Manager, Icelandic New Energy

Real Technology

In Iceland, the fuel-cells and storage tanks are mounted on the roof of an otherwise standard-design low-floor Mercedes-Benz Citaro bus. The compressed hydrogen tanks, pressurised to 350 bar, were supplied by Dynatek. Depending on the number of passengers (up to approximately 80), the twelve metre long Citaro can travel more than 200km at a maximum speed of approximately 80 kilometres an hour.

"When we started this project, fuel cells cost ten thousand dollars per kilowatt: now the 2008 series of PEM fuel cells cost only 120 dollars per kilowatt. Also, the original fuel cells could not tolerate frost or any temperatures below zero and we had to keep them warm at night. Now they can withstand temperatures of as low as -20°. This is beautiful news for us as the combustion engine has had 100 years of development, so I am happy to say that even in six years we have seen enormous progress that will speed our evolution to the Hydrogen Economy."

Thorsteinn I Sigfusson,
Professor, University of Iceland and
Co-Chair of the International Partnership
for the Hydrogen Economy, ILC

"Shell has taught us a lot about how to operate the refuelling station and I think that the station has taught them a lot about how to manage hydrogen in the future - particularly the safety aspects that are always linked to a new energy carrier."

Thorsteinn I Sigfusson,
Professor, University of Iceland and Co-Chair of the International Partnership for the Hydrogen Economy, ILC

Real Rewards

"I think people have looked at us as a test bed for the world. If we can use hydrogen to power vehicles or ships then, because of our existing hydro and geo-thermal energy resources, our energy supply can become more or less 99% clean or renewable and we won't have to rely on fossil fuel imports. In the long run, I think the world will try to do what Iceland can do more speedily - use hydrogen to help power the world on a zero emission cycle."

Jón Björn Skúlason,
General Manager, Icelandic New Energy

"The media has been very positive, the public has been very positive: in general we are working in a very sympathetic environment. Most of the public connects using hydrogen with clean fuel, with clean energy and views it as a beautiful thing for the future. They are saying, 'we would love to power Iceland with renewable energy' and in a sense that is what we are all aiming for."

Jón Björn Skúlason, *General Manager, Icelandic New Energy*

Washington, D.C.

Rehearsal for commercial

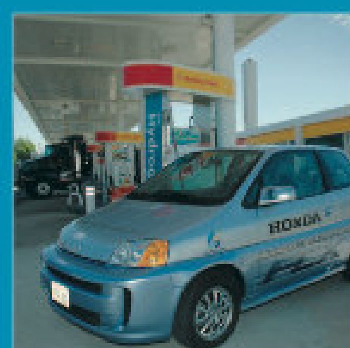
The creation of a commercial environment for hydrogen Fuel Cell Vehicles (FCVs) will require the simultaneous arrival of both the cars and the infrastructure necessary to refuel them. Shell Hydrogen opened its Washington, D.C. fuelling station to further that goal and is now supporting major automotive suppliers in their efforts to jump-start the Hydrogen Economy.

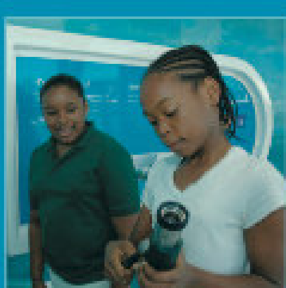
Project Aims:
To demonstrate the viability of hydrogen FCVs as a practical means of transport and to learn about marketing hydrogen in a retail environment.

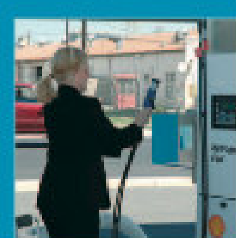
Project Partners:
General Motors, Shell Hydrogen.

Hydrogen Source:
Delivered to the station in liquid form via truck.

The Role of Shell:
Shell constructed the hydrogen storage and fuelling facilities at an existing service station on Benning Road, Washington, D.C. - the first integrated hydrogen and gasoline retail fuelling station in North America.







Shell Hydrogen

Energy Security

Hydrogen can be produced from a variety of different processes and will form a significant part of the energy diversification strategy of many nations.
President George W. Bush, who visited Benning Road in May 2005, is sponsoring the Hydrogen Fuel Initiative which is developing hydrogen energy as one means of addressing the energy security needs of the U.S.A.

Real Lives

"Shell works with members of Congress and their staff and different agencies within the administration to raise their awareness of hydrogen as a transportation fuel. We also work with GM to demonstrate vehicle refuelings: they understand that Shell will have stations ready for drivers when the cars are ready."
Kristin Whitman, Manager, Government and External Affairs, Shell

Real Business

"GM has shown its commitment to hydrogen technology by producing a series of fuel cell vehicles that we have driven on three continents over the last several years - we drive them every day, they perform like real vehicles. Our engineers are working day in and day out to improve the reliability and durability of these vehicles while at the same time reducing their cost. And we have made tremendous strides towards our stretch target of being able to deliver - in mass production quantities - an FCV that could be commercialised by the end of the decade or shortly thereafter.

"We want to avoid the risk of stranded investment and so by bringing hydrogen fuel cell vehicles and retail refuelling forward at comparable paces in key strategic markets, we can go a long away towards commercialising FCVs and making them something that the average customer will one day have in his or her driveway."
Raj Choudhury, Manager, General Motors

Real Technology

One of the major technical challenges of the Benning Road site was a liquid hydrogen storage tank installed below ground - the first of its kind in the U.S. Shell worked with the Washington, D.C. Fire Department and other regulators to settle on a design that was incorporated into the site. So far, the station has safely and successfully performed over 300 gaseous hydrogen vehicle fills and close to 100 liquid hydrogen fills.

The U.S. Postal Service has been using a GM HydroGen3 FCV to deliver mail in the greater Washington, D.C. area. Over an 18 month period, it delivered approximately 500,000 pieces of mail and achieved 99.5% reliability - in the heat of the summer and the cold of the winter. In addition, the Benning Road station has also refuelled FCVs of all major automotive companies - DaimlerChrysler, Ford, Honda, Toyota and Nissan, as well as fuel-cell buses.

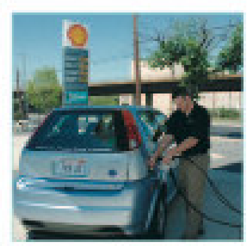
"I think that, in the short to mid term, an array of technologies is going to be deployed to address transportation needs; but each of these vehicles is an important building block towards hydrogen FCVs. So, for example, natural gas vehicles such as our Civic GX have taught us how to handle compressed gases which is terribly important for hydrogen vehicles. With the gasoline/electric hybrid, we've learned a lot about electric drive which is essentially what a fuel cell vehicle is. So, I think that the near to mid term technologies are pathways to the hydrogen future."
Edward B. Cohen, VP, Government and Industry Affairs, Honda North America

"The hydrogen FCV projects that GM and our energy partner Shell are involved in around the world show the general public that this is not something which exists purely within the laboratory or in the realm of Research & Development - this is real."

Raj Choudhury,
Manager, General Motors

Real Rewards

"In the next ten to twenty years we are going to see an increase in the number of hydrogen vehicles on the road - our kids are really going to benefit from a whole new economy.
We know that gasoline has literally fuelled the economy over the last century so I look forward to the possibilities that hydrogen-based economy can bring with it."
Donnell R. Peterson, Assistant Principal, River Terrace Elementary School, Washington, D.C.



"Some in the community around the Benning Road site did have initial concerns about locating a hydrogen station in the heart of the community. We overcame those concerns through a continuing presence in town hall meetings and following through on everything we said we would do. What we've shown through being open since 2004 is that we have been able to run everything in a safe manner. The project here on Benning Road is very important for bringing about the awareness that hydrogen is safe and viable for transportation."

Kristin Whitman, *Manager, Government and External Affairs, Shell*

Amsterdam

Towards zero-emission public transport

For the last three years, some of the one million passengers of Amsterdam's municipal transport company GVB have been travelling around the city on hydrogen-powered buses. Shell Hydrogen has been working closely with GVB to help them realise their vision of making all Amsterdam's urban buses emission-free in the next ten to fifteen years.

Project Aims:
To test the design, construction and operation of a hydrogen fuelling site and its use with three fuel cell buses operating on normal routes in dense urban traffic. Along with Projects in eight other European cities, Amsterdam is part of the European Commission-sponsored CUTE (Clean Urban Transport for Europe) programme.

CUTE aims to provide an ecological, technical and economical analysis of the entire life-cycle of hydrogen vehicles and a comparison with conventional alternatives. Originally planned to finish in 2005, the Project has been extended for a year. Comprehensive data collected from Amsterdam and the other CUTE cities will be applied to further development of both fuel cells and the hydrogen refuelling infrastructure with a long-term view to move towards mass production.

Project Partners:
GVB (municipal transport company), Dienst Milieu en Bouwtoezicht (Environmental Service Department), Hoek Loos BV (contractor for hydrogen refuelling station), EvoBus GmbH (supplier of the buses),Nuon (power company) and Shell Hydrogen.

Hydrogen Source:
The hydrogen is produced on-site by the electrolysis of water using 'green' electricity generated from renewable energy sources. The hydrogen is compressed and stored to provide daily fuelling for each of the buses.

The Role of Shell:
Shell Hydrogen is assisting GVB in: system design, operating procedures and construction; safety management of the hydrogen refuelling station; project engineering, project management and consultancy around the tender process and contract evaluation.

Shell Hydrogen

Zero Emission Technology

The hydrogen used in Amsterdam's fuel-cell buses is manufactured from the electrolysis of water - a process whose only by-product is oxygen. This process is powered by green energy from Nuon and the only vehicle emission is water vapour, meaning Amsterdam is a completely green project.

Real Lives

The general public has reacted positively to the CUTE Project and by the end of the second year over 90% of the passengers and over 80% of the neighbouring community expressed their wish to see more hydrogen-powered public transport in Amsterdam.

Real Business

"We are now in the demonstration phase, with projects scattered around the world, so this is really all about technology validation. The next step is to go to the larger so-called 'lighthouse' projects, with four or five hydrogen refuelling sites in a particular city or region. So we will go from demonstration projects to mini-networks and then we will build up the whole infra-structure. That will take time but the next step is being taken now. This is something Shell is actively pursuing today."

Frank Schnitzeler, Business Development Manager, Shell Hydrogen

Real Technology

Shell has applied the project and safety management expertise derived from 50 years' safe handling of hydrogen to this venture. This has contributed to the Amsterdam fuelling station - with one of the highest availability and safety performance ratings - being cited as best practice for the entire CUTE Project.

In Amsterdam, the fuel-cells and storage tanks are mounted on the roof of an otherwise standard-design low-floor Mercedes-Benz Citaro bus. The compressed hydrogen tanks, pressurised to 350 bar, were supplied by Dynatek. Depending on the number of passengers (up to approximately 80), the twelve metre long Citaro can travel more than 200km at a maximum speed of approximately 80 kilometres an hour.

"The buses have been operating very successfully over the course of the project: we have put nearly 120,000 kilometres on the clock with far fewer technical problems than we anticipated. As a result, we decided to extend the project for an extra year. We think that electrical traction is a major step forward from a number of different perspectives. Of course, as a zero-emission technology, it is much better for air quality in urban environments; but also it is better for the city environment as there is less rumble and noise and the buses are more comfortable for driver and passengers."

Gertjan Kraan, CEO, GVB

"We were looking for partners that had knowledge of hydrogen and one of them was Shell Hydrogen. So we asked them to join the project and bring in their knowledge of hydrogen and safety regulations."

Frits van Drunen, *Project Manager, GVB*

Real Rewards

"The public have been fantastic. The passengers like the buses because they hear hardly any sound. And the people on the roadside are enthusiastic because there is no pollution. We have proven fuel cells are reliable in public transport and so they see that the future is nearby. Developing zero-emission buses is a challenge but the future is secured by these kinds of buses. In 15 years - no longer - diesel buses will be obsolete in Amsterdam's public transport. I'm convinced about that."

Frits van Drunen, Project Manager, GVB

"In the beginning, the public were very curious to try out the bus. They were waiting at the bus stop and they saw a fuel cell bus coming and they said, 'I want to get on that bus'. Now they are used to it in the northern part of Amsterdam because they have been using it for two years. My family and friends have a lot of interest in what I am doing and they all like to hear how it is going. I think it's exceptional to do things like this in my work and I like it."

Peter Pape, *bus driver, GVB*

Luxembourg

Improving urban air quality

With a long track-record of alternative fuel use, a strong desire to improve urban air quality and a hilly terrain that is unusual for a capital city, Luxembourg was a natural location for one of the EU's hydrogen bus trial projects. Shell has been working closely with the transit authority of Luxembourg to help introduce their citizens to the 'fuel of the future'.

Project Aims:
To test the practical, safe production and distribution of hydrogen and its use on three fuel cell buses operating on normal routes on hilly terrain. Along with eight other European cities, Luxembourg is part of the European Union-sponsored CUTE (Clean Urban Transport for Europe) programme.

CUTE aims to provide an ecological, technical and economical analysis of the entire life-cycle of hydrogen vehicles and a comparison with conventional alternatives. Originally planned to finish in 2005, the Project has been extended for a year. Comprehensive data collected from Luxembourg and the other CUTE cities will be applied to further development of both the fuel cells and the infrastructure with a long-term view to mass production.

Project Partners:
Autobus Ville de Luxembourg (municipal transport company), DaimlerChrysler (supplier of the buses), Air Liquide (supplier of the hydrogen) and Shell Hydrogen.

Hydrogen Source:
The hydrogen is produced off-site and transported to the fuelling station.

The Role of Shell:
Drawing on its experience with similar activities in the US, Japan and other European cities, Shell Hydrogen provided technical advice on the construction of the refuelling station and also funding. Shell Hydrogen has considerable expertise in reformer technology for the production of hydrogen, particularly on a small scale for domestic or vehicular use.

Shell Hydrogen

A Track-record of Alternatively Fuelled Vehicles

Bio fuel buses were introduced into Luxembourg's urban passenger vehicle fleet about 10 years ago and hybrid gasoline/electric buses were trialled around five years later. With Hydrogen Fuel Cell buses in operation for three years, Luxembourg is a vivid testimony to the role that alternatively fuelled vehicles might play in the future - particularly in public transport.

Real Lives

"If it was up to me, I would probably choose to drive hydrogen buses all the time because of the environmental issues they address. I prefer to drive a clean bus, so people in a car behind me don't have to close the windows to keep out the pollution and those on bicycles or simply on the street are better off. If any young people ask me about these buses, I say this is their future because if all vehicles were using fuel cell technology, they could breathe in peace."

Christian Cordier,
bus driver, Autobus Ville de Luxembourg

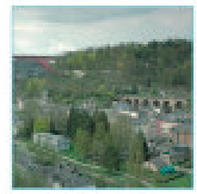
Real Business

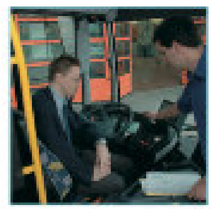
"We are now in the demonstration phase, with projects scattered around the world, so this is really all about technology validation. The next step is to go to the larger so-called 'light-house' projects, with four or five retail sites in a particular city or region. So we will go from these demonstration projects to mini-networks and then we will build up the whole infrastructure. That will take some time but the next step is being taken now. This is something Shell is actively pursuing today."

Frank Schnitzeler, Shell Hydrogen

"Hydrogen was new to us, the bus manufacturers and the builders of the fuelling station: we involved Shell from the beginning to provide their knowledge of safety issues around refuelling."

Georges Feltz, *Autobus Ville de Luxembourg*





Real Technology

Safety is one of the paramount considerations in each of the CUTE projects. Shell's project and safety management expertise derives from over 50 years' safe handling of hydrogen.

In Luxembourg, the fuel-cells and storage tanks are mounted on the roof of an otherwise standard-design low-floor Mercedes-Benz Citaro bus. The compressed hydrogen tanks, pressurised to 350 bar, were supplied by Dynatek. Depending on the number of passengers (up to approximately 80), the twelve metre long Citaro can travel more than 200km at a maximum speed of approximately 80 kilometres an hour.

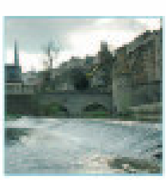
Real Rewards

"I think the potential of fuel cell buses is really very important. These buses meet the challenge of eliminating vehicle emissions in the city centres. They are also very flexible as to how the available power is put onto the wheel, much more so than with conventional buses. If one considers the availability of petrol or natural gas, I think that hydrogen really is the fuel of the future."

Georges Feltz, Autobus Ville de Luxembourg

"Luxembourg has a very special topography: it has a varied terrain with lots of hills in the centre and flat areas around the city so this presents a real challenge for the Hydrogen Fuel Cell buses we are using in this project. The target for the research was and is to test the reliability of the fuel cell system: the performance was excellent and so far the buses have been in operation for more than 9000 hours. We got outstanding results and we gained valuable experience - not only regarding emissions but also noise reduction. This project has definitely been one of the building blocks for future alternatively-fuelled public transport systems."

Philipp Beitzel, *CUTE Project Technician*



Tokyo

Driving towards the Hydrogen Economy

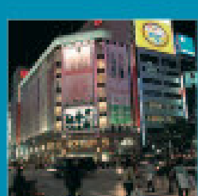
Japan intends to put five million Fuel Cell Vehicles (FCVs) on the road by 2020. As part of the Japan Hydrogen and Fuel Cell (JHFC) Project, Shell is collaborating with all FCV manufacturers to put hydrogen-powered vehicles through their paces in Tokyo and the surrounding areas.

Project Aims:
To test the safe production and distribution of hydrogen and its practical application to safe and efficient hydrogen refuelling systems: the overall objective is to demonstrate the sustainability of the Hydrogen Economy. The JHFC Project also aims to provide several car manufacturers with an opportunity to address the hydrogen challenge, while raising public awareness and creating a demand for hydrogen in the Japanese market.

Project Partners:
DaimlerChrysler, General Motors, Hino, Honda, Mitsubishi, Nissan, Suzuki and Toyota (FCV manufacturers).

Hydrogen Source:
The hydrogen is generated off-site by capturing the by-products of industry processes in manufacturing plants owned by Iwatani and Nippon Steel. It is then liquefied and trucked to the refuelling station.

The Role of Shell:
Shell's primary role in the Project was to design, construct and operate the Ariake station - the first and, so far, only liquid hydrogen station in Japan. Ariake can provide both liquid and compressed hydrogen at 350 Bar.



Shell Hydrogen

On the Road

With only 4% of its energy produced indigenously, Japan wants to balance a steady supply of energy with demands for environmental protection. As a result, it intends to be among the first countries with significant numbers of alternatively-fuelled vehicles and has set a target of introducing five million FCVs by 2020.

Real Lives

Built in co-operation with Iwatani, the station is one of the 12 hydrogen fuelling facilities in the Tokyo area. Since starting operations in June, 2003, the site has refilled over 1700 vehicles making it the most utilised hydrogen refuelling station in the Eastern hemisphere.

"We feel it is important for people to experience the "merits" and the "joys" of fuel cell vehicles. We'd also like to learn how FCVs would be accepted into society. Without facing the passengers directly, we'll never find out.[1]"
Takashi Kato of the FC System Development Division, Toyota Motor Corporation

Real Business

DaimlerChrysler, General Motors, Hino, Honda, Mitsubishi, Nissan, Suzuki and Toyota have been simultaneously testing their fuel cell vehicles on public roads to acquire and analyse data on running performance, reliability, environmental characteristics, fuel economy and the use of hydrogen fuelling stations.

"When we look at Asia, we need to realise that this is a marathon and not a sprint and different countries run at different speeds. Japan is clearly a leader - it is best equipped through its phenomenal car companies. It also has a country strategy that is well-thought through and has the backing of the entire industry. Shell tries to align its strategy to the country strategy and we try to help shape it by sharing knowledge and know-how acquired globally: we are involved in manufacturing projects, stationary projects using residential fuel cells to determine Shell's role in distributed power generation and transportation projects such as with JHFC."
Gabriel de Scheemaker, General Manager Hydrogen, Asia Pacific, Shell Hydrogen

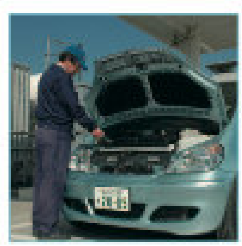
"Our hope is to commercialize the FCX as soon as possible in order to allow the users to share the feeling of the ride. I'm sure this is a thought shared by the various manufacturers.[2]"
Yuji Kawaguchi, head researcher, Honda Technical Research Institute

1 http://www.jhfc.jp/e/column/front/01/03.html
2 http://www.jhfc.jp/e/column/front/03/03.html
3 http://www.jhfc.jp/e/column/front/02/02.html

Real Technology

"We have been very successful in terms of safety - there has been no incident or accident in the Ariake station. Safety is always a top priority."
Toshio Imahama, Station Manager, Shell Hydrogen Tokyo

"Our future goal is to realise the commercialisation of FCVs, priced for easy purchase. However, our immediate aim, first and foremost, is the fundamental establishment of technology. This means that we have to handle one problem at a time. There's no magic potion that can resolve all the problems at once. I can't say exactly when our new model FCV will next be introduced, but I think it will be soon.[3]"
Taro Hagiwara, Director, FCV Development Division, Nissan Motor Co.



"In terms of energy security and also air quality in the urban environment in Japan, hydrogen energy is the ultimate option."

Hiroshi Matsumoto,
Concept Projects,
Technology Compliance,
DaimlerChrysler Japan

Real Rewards

"Hydrogen technology has great potential as here in Japan we don't have natural resources and most energy has to be imported.
But hydrogen can be produced from anything from anywhere using local resources.
In this context using hydrogen energy is very useful for the future in an economic sense and for energy security."
Katsumi Yoshida, Business Development Manager, Shell Hydrogen Tokyo

Real Results; Real Rewards

Hydrogen energy is already making measurable differences to the lives of millions. Today, Hydrogen powers buses in Luxembourg and Amsterdam, cars in Washington and Tokyo and is a critical part of Iceland's plans to be a carbon-free economy. At the heart of each of these projects is Shell.

Shell believes Hydrogen - an abundant, cleaner energy source - will be a key part of the world's future energy mix. So, it is collaborating with key stakeholders - governments, the car industry, academia and customers - to make Hydrogen a practical, safe and globally accessible fuel. It is also applying its technology leadership to building the foundations of the Hydrogen economy - helping to ensure Hydrogen energy will be a valuable, viable part of the future of our planet.

Shell Hydrogen

Experience Choice

Please contact Shell Hydrogen for further information:
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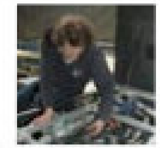
PO Box 162
2501 AN
The Hague, The Netherlands

Email: hydrogen-info@shell.com
URL: www.shell.com/hydrogen

Shell Hydrogen







Real Lives

Today, societies are choosing zero-emission Hydrogen-powered vehicles for cleaner transportation and to meet agreed environmental targets. They are making Hydrogen part of plans to deliver cleaner, competitive energy solutions in the next twenty years.

Already, drivers and passengers in Amsterdam and Luxemburg notice how quiet and clean their Hydrogen-powered buses are. Schoolchildren at Shell's Washington, DC Hydrogen station learn how safe the technology is. People in Tokyo recognise Hydrogen vehicles offer the same - or better - performance as traditional vehicles. And Iceland's citizens are learning how to eliminate their dependence on carbon fuels entirely.

Efforts to produce Hydrogen with a low carbon footprint are ongoing. But tomorrow's challenges can be overcome by making the right choices about Hydrogen today.

Real Business

Shell Hydrogen - established in 1999 to address concerns about climate change, energy security and diminishing reserves of traditional fuel supplies - is the only energy company building Hydrogen infrastructure in all three key markets: the US, Europe and Japan. It draws on Shell Group's extensive experience of Hydrogen production and distribution and is now linking this global capability to bring Hydrogen into a retail setting.

Shell is building new Hydrogen stations - or adapting existing locations - to safely fuel private and public vehicles. Connected in mini networks, these will enable consumers to choose Hydrogen solutions in ever-greater numbers. Urban mini-networks will be the next stage of development, forming the basis of the Hydrogen economy.

Real Technology

Shell is investing significant resources in greener, more efficient production of Hydrogen. Its leadership in Carbon Dioxide (CO2) management – both capture and sequestration – can provide clean Hydrogen and is an important stepping stone to the production of truly green Hydrogen from renewable energy sources.

Shell is applying its unique expertise - in close partnership with a wide range of experts - to a range of significant investments in other areas of the Hydrogen value chain. It has created scientific partnerships with world-leading academic institutions such as MIT in the US, Imperial College in the UK and Tongji University in China. It also has commercial partnerships with the world's leading car manufacturers to advance fuel cell technology and align the commercial roll-out of vehicles with the fuelling infrastructure. And it is an investor in two venture capital funds, supporting early and latter stage companies in order to help develop the Hydrogen economy.