HyWays

FIRST PHASE OF THE PROJECT

ACTOR ANALYSIS REPORT

(DELIVERABLE D3.10)

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CONTENTS

0. Executive summary

This Phase 1 Actor Analysis Report addresses the requirements of Deliverable 3.10.

Actor Analysis is one of the principal planks of the socio-economic modeling component of HyWays. Its main aim is to identify and assess required *Key Changes* which are required for the successful realization of selected hydrogen supply chains on a Generic and Member State specific basis. Furthermore, it aims to directly connect hydrogen supply chains and Key Changes with associated *Broad Actor Groups* which might play a role in overcoming or positively affecting the realization of Key Changes and therefore also of selected hydrogen supply chains. It is hoped that this feature will be of practical use to policy makers by affording them the ability to target policy measures towards facilitating organizations.

Actor Analysis builds upon previous international hydrogen roadmapping efforts which have been almost exclusively quantitative in nature by focusing on primarily qualitative data which are not best captured by quantitative computational modeling efforts. The practical application of Actor Analysis, *Key Changes and Actor Mapping* (KCAM), borrows concepts from theories of general systems development and translates them into a practical tool for the investigation of hydrogen systems development.

The results gathered and compiled within Actor Analysis are intended to provide an additional layer of (qualitative) information to MS representatives for use in the assessment of their selected hydrogen supply chains and in the construction of their national hydrogen roadmaps. This information is used in support of the principal computational modeling elements of the HyWays 'hybrid' approach.

The centerpiece of Actor Analysis is an Access-based tool intended for use by Member States themselves. This tool allows for the systematic and structured input and treatment of largely qualitative information associated with selected hydrogen supply chains, required Key Changes and Broad Actor Groups. Relationships between distinct parameters can be explored and report sheets automatically generated. The design and informational structure of the tool is deliberately systematic and transparent so that data or metadata can be updated or altered as required. It is hoped that the KCAM Access tool might be of enduring use for future roadmapping efforts.

This Report focuses on methodological aspects of this component of HyWays. At this stage, KCAM mapping has not yet been validated by all 6 Phase I Member States. However preliminary MS specific validation has been carried out by stakeholders from the Netherlands, and these results are included in the annexes to give an impression of how results will be presented and treated once mapping has been carried out for all Member States. It should be noted that the final Actor Analysis report at the conclusion of Phase 2 will not contain detailed MS Specific Key Change descriptions – these will be presented in individual MS Specific Actor Analysis Reports.

The complete structure of the Actor Analysis Report is present here, but discussion and analysis sections are largely incomplete as they necessarily rely upon the full set of MS Actor Analysis results. Also, sections concerning input from Actor Analysis to the HyWays toolbox and roadmaps are speculative to a significant extent as the structure and content of the toolbox and roadmaps are still in the process of being defined.

1. Introduction

This Report constitutes ***Deliverable D.10 Actor Analysis Report Phase I***.

The broad objectives of this Report are to:

- Present the broad aims of the Actor Analysis (AA) process.
- Present the conceptual background to the Actor Analysis process.
- Outline the Key Changes and Actor Mapping (KCAM) methodology developed for Actor Analysis.
- Present summary KCAM results for the Netherlands - a pilot test of the methodology - including preliminary cross-cutting analyses of notable trends and findings.
- Highlight information flows between Actor Analysis and other areas of work within HyWays.
- Present a summary of lessons learned and potential inputs for the HyWays toolbox.

In total, the constituent parts of Actor Analysis are:

- ***Actor Analysis Report***
  - Methodology, MS KCAM results summarised, descriptions of generic Key Changes and KCAM guidelines, inputs for the HyWays toolbox, Actor Analysis 'messages'.
- ***MS Specific Actor Analysis Reports***
  - Individual reports for each Member State, including detailed MS Specific Key Change descriptions.
- ***MS Specific KCAM Access tools***
  - Individual Access databases for each Member State with detailed mapping and variable parameter reporting included.
- ***Template KCAM Access tool***
  - Empty and operational KCAM Access tool for direct use in HyWays Phase II as well as potential external applications.

1.1 Aims of Actor Analysis

The primary goal of Actor Analysis is to provide a systematic and qualitative assessment of aspects of Transition Analysis (TA), focusing on:

- The identification and description of *Key Changes* (KCs), which are distinct changes necessary for the realisation of individual hydrogen chains as chosen by each MS. These changes can be related to specific hydrogen chain components.
- The identification of corresponding *Broad Actor Groups* which might influence the realization or not of Key Changes.

Actor Analysis is intended to introduce an additional layer of information (i.e. additional to the quantitative information used by / generated by the main computational modeling and Infrastructure Analysis activities) for use in subsequent roadmapping. This information is:

- Largely qualitative
- Hydrogen chain component-specific
- Member State specific
- Generic

HyWays Member States selected a number of hydrogen supply chains which are investigated quantitatively in the MARKAL, GEM-E3, ISIS and COPERT modeling activities. The work of Actor Analysis is an attempt to provide another perspective for MS representatives to consider when evaluating the (largely quantitative) results of the principal modeling rounds and also to provide structured qualitative input for the construction of MS hydrogen roadmaps.

A conceptual diagram of the process of reaching *end visions* from a common *current profile,* by following selected *hydrogen supply chains* is presented in Figure 1. The Key Changes investigated in Actor Analysis are represented by the horizontal hurdles present on each vertical hydrogen supply chain:

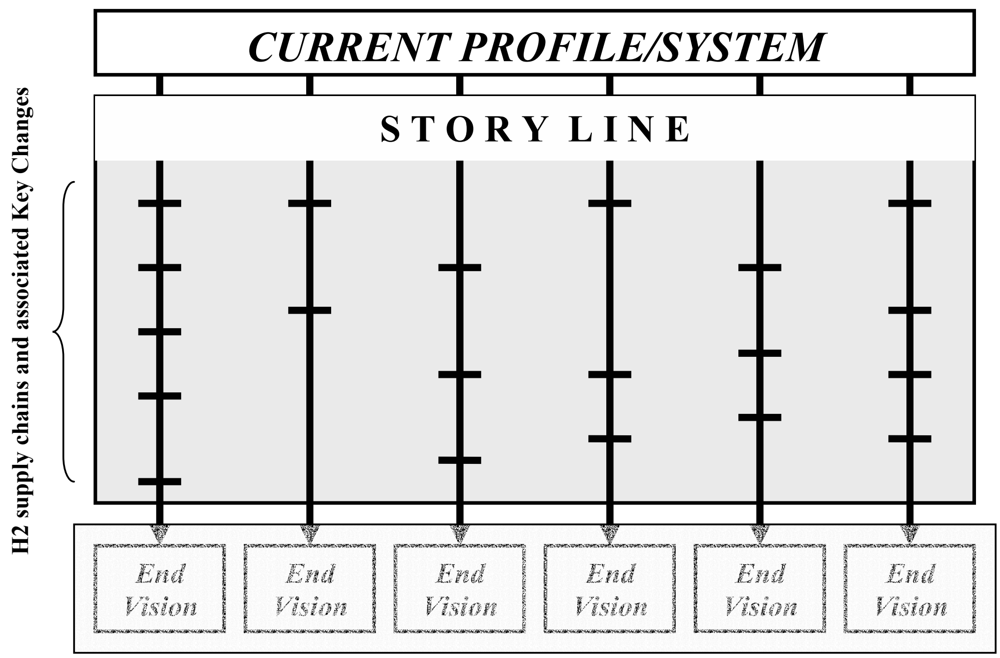


Figure 1 Developing End Visions from Current Profiles, by means of the analysis of Key Changes.

1.2 Manipulation and analysis of qualitative and standardised information

The different hydrogen chains selected by each MS may be regarded as a number of different permutations of a limited number of hydrogen chain component options. They are thus essentially a number of different permutations of a limited number of distinct Key Changes, and this is how Actor Analysis approaches the task of assessing each selected hydrogen chain.

The KCAM methodology, as with Hughes' general systems development model, views hydrogen chains as an advancing, but uneven, 'front' (a concept borrowed from general systems development theory). The unevenness is produced by different states of 'advancement' of each hydrogen chain component. The action required to bring a hydrogen chain component into a state of equilibrium and harmony with the advancing front is described as a Key Change.

This is achieved in Actor Analysis by the construction of a MS- and industry-validated data set which can be systematically, transparently and rapidly manipulated to examine all possible hydrogen chain permutations by a number of different parameters. This flexibility is essential for a process which is to cope with unforeseen changes such as new hydrogen chain selections, the emergence of new broad actor groups, advances in technological maturity, or changing political or social scenarios.

1.3 Construction of a flexible computer tool

KCAM is intended to provide a practical tool which can be used directly by Member State stakeholders during the project and also by policy makers beyond the duration of the HyWays project. For this reason a user friendly MS Access-based tool has been developed which allows users to input and update mapping information and perform various data manipulations and analyses themselves, without the assistance of the KCAM methodology developers. The Access tool has the ability to perform multi-criteria database searches and produce results reporting sheets automatically. This provides the flexibility required to efficiently update and renew the multi-criteria analysis of selected hydrogen chains. It also provides a systematic and transparent means of presenting analysis, and thereby allows for the systematic updating of the model in the light of future developments.

It is hoped that the Actor Analysis 'mapping' spreadsheet is sufficiently flexible and adaptable that it can be applied not only to HyWays Phase II but also to other roadmapping efforts after the end of the HyWays project.

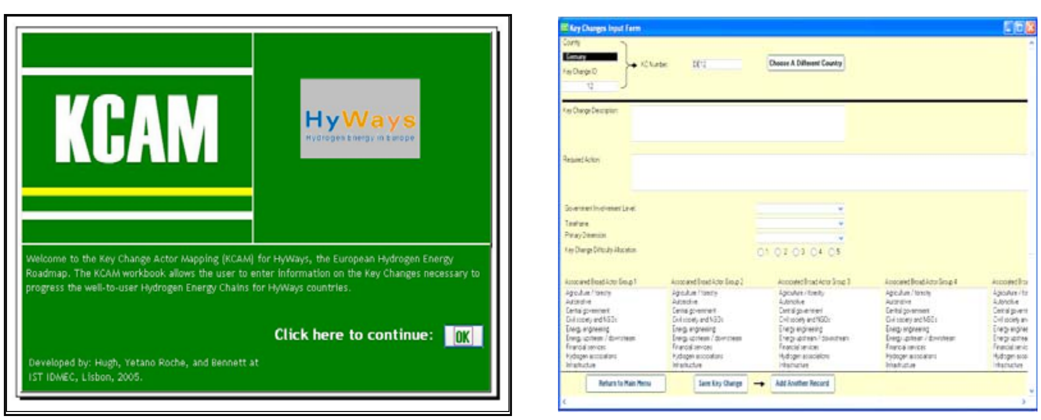


Figure 2 Access KCAM tool screen captures.

2. Methodological approach

2.1 Systems development model

Key Change and Actor Mapping constitutes a practical and widely applicable methodology for defining and analysing specific hydrogen transitions – the shift from a defined 'current profile' to a defined 'end vision' or set of end visions. The methodology builds upon the general systems development model presented by Hughes (1992)[1] and applies many of the concepts and visual analyses of technological change in a pragmatic way, specifically to national European hydrogen systems.

The KCAM methodology envisages hydrogen 'end visions' as defined systems, exhibiting a range of qualitative attributes or 'components', which describe the complete hydrogen path from feedstock source to end-use application, as well as the market development components and infrastructure requirements. The qualitative approach affords the model a high degree of flexibility, and system components might be techno-economic, political, or otherwise in nature. In order for the system to progress from the current state to a more advanced state (the 'end vision') all system components must be broadly in harmony across the advancing *'front'* with no components lagging behind. A significant part of the KCAM methodology is concerned with 'positioning' the relative states of development of each system component along a common scale of progress. Where system components are found to lag behind the advancing front, there is a consequential need to identify a Key Change which would remove the *reverse salient* and restore harmony to the evolving system:

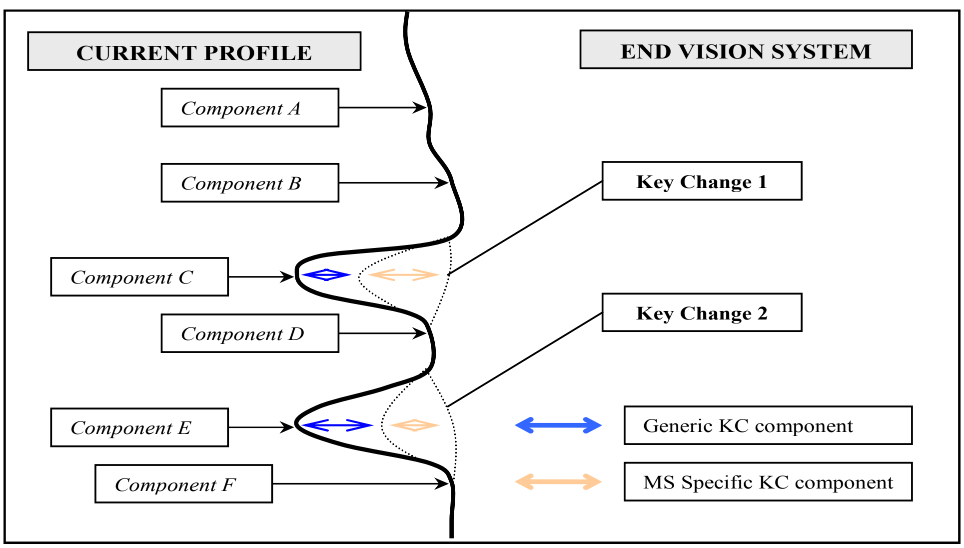


Figure 3 Conceptual diagram illustrating subdivided Key Changes along an advancing system 'front'.

[1] In **Desi, G.** (ed.) *Technology and Enterprise in a Historical Perspective.* Clarendon Press (1992); and also **Hughes, T. P.** *Networks of Power – Electrification in Western Society, 1880-1930.* The Johns Hopkins University Press, Baltimore and London (1983).

2.2 The KCAM methodology applied

The practical application of the KCAM methodology is divided into four distinct stages: Key Change identification and description; Key Change quantification; Broad Actor Group mapping; and Key Change validation.

- Key Change identification and description

KCAM differentiates between two types of Key Changes, namely *Generic Key Changes* and *Member State Specific Key Changes*.

  - Generic Key Changes apply to all Member States. They describe the ambient conditions which are true in all instances. They are therefore predominantly related to basic technological parameters (such as the commercial development status of steam methane reforming (SMR), or of fuel cell vehicles).

  - Member State Specific Key Changes are applicable only within the confines of individual Member State contexts. They relate to Member State specific energy supply and demand trends, energy infrastructure, political disposition and policies, and national societal knowledge and technology acceptance levels.

Member State Specific Key Changes are derived following consideration of specific hydrogen chain component choices made by Member States. They are linked to individual hydrogen chain component choices rather than the chains themselves. They can therefore be applied to *any* chain where the associated chain component choice arises. Under this system hydrogen supply chains thus can be rapidly and systematically analysed as different permutations of one total set of chain component choices.

The *resolution* of defined Key Changes is an important consideration. As Key Changes are subjectively-defined entities, there is consequentially some scope for different interpretations of what any individual Key Change constitutes. It will frequently be possible to differentiate between different focuses within the context of a single Key Change, and it is therefore possible to argue for the identification of ever increasing numbers of more narrowly defined Key Changes. However, practical considerations (namely the limits of time and resources) mean that there will always be a degree of aggregation of Key Change focuses. Finding an optimal balance between aggregation and disaggregation is vital to the success of an application of KCAM in delivering added value to other components of a roadmapping activity in a timely and efficient manner. Stakeholder validation in this matter is therefore essential.

- Key Change classification and quantification

Generic and Member State Specific Key Changes are analysed in very similar ways so that the majority of results can be treated synergistically within the confines of appropriate hydrogen supply chain components. Following their description, each Key Change is classified and analysed along a range of parameters (see Table 1). This process allows for subsequent determination of trends as well as the ability to compare and contrast either individual Key Changes or individual hydrogen supply chains from a range of vectors.

Table 1 Overview of analysis parameters carried out for Generic and Member State Specific Key Changes.

Analysis parameters	Nature of analysis parameter input
Short Key Change	Narrative description
Full Key Change	Narrative description
Envisaged timeframe for Key Change solution	2005-2010 / 2010-2030 / 2030-2050
Difficulty allocation for Key Change solution	1 = very easy… 5 = very difficult
Required action for Key Change solution	Narrative description
Primary dimension allocation	Techno-economic / political / societal / infrastructural
Development goals	Narrative description
Likely level of required government involvement in Key Change solution	EU / national / regional
Possible priority governmental action	Narrative description
Associated Broad Actor Groups	Energy sector upstream or downstream / energy engineering / infrastructure / automotive / supranational government / national government / regional government / research, academia and consultancy / civil society and NGOs / hydrogen associations / transport and logistics / specialist hydrogen equipment manufacturing / agriculture and forestry / media / real estate construction and management / financial services)

Whilst the primary role of KCAM is to describe system advancement requirements in narrative form, it also allows for expert-based quantification of the difficulty envisaged in solving each Key Change by a process referred to as *Difficulty Allocation*. The Difficulty Allocation system grades each Key Change on a 1-5 scale, where ‘1’ signifies that marginal additional effort beyond ‘business as usual’ is required, and ‘5’ signifies that extensive and significant additional effort is required (see Annex 3).

The use of Difficulty Allocations allows a conceptualised ‘advancing system front’ along the lines of those proposed by Hughes to be constructed for any hydrogen supply chain under investigation. This takes the form of summary KCAM charts (see Figure 4). KCAM Summary charts are intended to provide a visual impression only of the relative outstanding difficulties of system development requirements. They are an ancillary aspect of KCAM and are intended to be used in addition to Key Change descriptions and not in place of them.

- Broad Actor Group mapping

Further to the generation of KCAM summary charts, the association made between specific Key Changes and Broad Actor Groups allows for composite Broad Actor Group association charts to be constructed (see Figure 5). As with the KCAM summary charts, these are intended as ancillary policy tools deployed in conjunction with Key Change descriptions only. Broad Actor Group maps take the form of 'heat' charts which denote the number of Broad Actor Group associations with specific hydrogen supply chains as chosen by Member States. 'Hot spots' on these charts indicate a high number of occurrences between Broad Actor Group associations made with individual chosen hydrogen supply chains. With the link made between hydrogen supply chains and Broad Actor Groups it is then possible to conduct subsequent analyses from the perspective of chains or indeed of Broad Actor Groups.

The purpose of Broad Actor Group mapping is to afford policy makers a greater degree of strategic insight into the nature of the barriers which face hydrogen systems development, as well as the ability to 'target' actor groups when formulating policy responses. KCAM users have the option of populating Broad Actor Groups with actual market actors in order to further tailor policy responses, but this stage is not included within the KCAM methodology because the unpredictability of the fortunes of market players means any list of individual actors compiled at the time of mapping would rapidly become outdated.

- Key Change validation

Expert validation is an integral part of each stage of KCAM as it introduces the vital element of negotiated positions, thus minimising the risks of inexpert or bias mapping input. It also ensures a high degree of stakeholder 'ownership' and endorsement of the mapping product. Expert input is sought for Key Change descriptions, classifications and difficulty allocations. Generic Key Change descriptions and difficulty allocations are validated by an industry-based expert panel. Member State Specific Key Changes are validated by Member State representatives and stakeholders. The validation process is carried out in practice by means of workshops and teleconferences. This aspect of the KCAM methodology might be viewed as both a strength and as a potential weakness; whilst such a high level of stakeholder / expert input serves to enhance the credibility and rigour of the mapping process, it also makes it highly dependent upon the efforts of the stakeholder / expert groups.

The provision of a comprehensive set of user guidelines is another integral feature of KCAM (these guidelines, validated by the Actor Analysis Task Force, are presented in Annex 3). The methodology was designed with the intention of being deployed at the national level, and as such the provision of guidelines for carrying out KCAM was viewed as essential not only for increasing the ease of methodological understanding amongst KCAM users but also to instill a common understanding of the extent and limits of assessment categories. In order for subsequent analysis to review, for example, Key Changes which are categorised as belonging to the "political dimension" there must be a clear and common understanding of the adopted definition of the "political dimension".

Both generic descriptions and MS-specific descriptions can be replicated for different chains in the same MS contexts. This is an essential feature of Actor Analysis as it affords a standardised treatment of Key Changes and therefore the possibility of systematic and consistent subsequent analysis of hydrogen chains. From a pragmatic perspective, it also allows for a relatively rapid treatment of the high number of possible permutations of hydrogen chain permutations.

2.2.1 Generic Key Changes

Generic Key Changes can be reproduced in every MS context. They describe the ambient conditions which are true in all instances. They are therefore predominantly related to basic technological parameters. The text for descriptions of Generic Key Changes is agreed/validated by an expert group (see Annex 1).

Generic descriptions briefly cover:

- Current status of the technology
- Development goals
- Generic Key Change difficulty allocation

The 'Generic Key Change difficulty allocation' describes the 'depth' of this component of a Key Change, and is denominated by a number on a scale of 1 (least difficult allocation) to 5 (most difficult allocation) (see Annex 3). Again, this was decided by the expert group.

It should be noted that such qualitative hydrogen technology development sketches are not included explicitly at any other stage of the HyWays process. Such descriptions therefore have an intrinsic worth to the HyWays project which extends beyond the confines of Actor Analysis.

2.2.2 MS Specific Key Changes

MS Specific Key Changes are applicable only within the confines of MS specific contexts. They describe Key Changes which are specific to the MS in question and avoid describing Key Changes which are more widely applicable such as the technological status of hydrogen technologies. They are related to MS specific energy supply and demand trends, energy transportation infrastructure, political disposition and policies, and national societal knowledge and technology acceptance levels. MS Specific Key Changes are replicable within the MS specific context.

As with Generic Key Changes, MS Specific Key Changes are assigned a 'difficulty allocation' on an identical 1-5 scale. These allocations are decided by MS representatives and stakeholders.

MS Specific Key Changes are often directly associated with Generic Key Changes – as such they are linked together to form one Key Change composing of the two distinct parts (see Figure 4).

2.2.3 Practical aspects of the work

Actor Analysis involved a number of distinct steps and participants. The majority of the work was carried out by IDMEC, but other groups involved included an 'Actor Analysis Task Force' (AATF) and MS representatives and stakeholders for each of the 6 MS involved in Phase I of the HyWays project.

The AATF was established early on in the Actor Analysis procedure, and was composed of a number of industry and other representatives from a broad range of Phase I MS. The AATF is comprised of representatives from: SenterNovem, DENA, Hexion, Total, Air

Products, FHG/ISI, LBST, and Imperial College London. The AATF fulfill a number of key roles:

- Providing guidance in the development of Actor Analysis concepts and general approach.
- Providing guidance in the development of the KCAM Access tool.
- Providing expert review and input of Generic Key Change descriptions, and providing associated 'difficulty allocations'.

Actor Analysis follows a sequential series of steps in order to achieve its goals. In summary, these steps are:

- Establishment of an industry-based Actor Analysis Task Force (AATF).
- Development of KCAM methodology and Access tool.
- Generic Key Changes descriptions and difficulty allocation carried out by IDMEC and AATF.
- Preliminary KCAM carried out by IDMEC.
- MS specific KCAM carried out by relevant MS representatives and stakeholders.
- Results compilation and analysis by IDMEC.
- Actor Analysis Report written by IDMEC.

The development of the general KCAM approach, and specifically the development of the KCAM Access tool, accounted for the majority of the total time allocation. The KCAM Access tool underwent a number of refinements before the final version was reached. Whilst this was a time consuming process, it is thought that in Phase II of the HyWays project, a comparatively short amount of time will be required to update the KCAM methodology and Access tool in the light of the Phase I Actor Analysis experience; further refinements and development, instituting 'lessons learned' etc. will inevitably involve some dedicated time before the actual mapping of Phase II MS can begin, but it is anticipated that the majority of time spent in methodology development can be circumvented.

Gaining feedback from the AATF and was achieved by email correspondence and teleconferences.

3. Input data and scenario assumptions

- A brief literature review was carried in order to assess potential practical applications from previous work on systems development, new technology diffusion, and transition theory.
- The literature was also consulted to provide an up-to-date description of the status of hydrogen technologies in the development of Generic Key Change descriptions.
- MS inputs to the HyWays MARKAL model were used in the MS Specific Key Changes descriptions to provide background context concerning specified technology penetration timeframes. This is especially pertinent for the process of deciding ‘difficulty allocations’.
- MARKAL technology definitions and other HyWays assumptions as to various technology formats or energy system characteristics were applied to the construction of Generic Key Change descriptions.
- The HyWays MID was used to provide updated MS hydrogen chain selections for the KCAM procedure.
- MS Profiling Reports were used as a source of background information for MS Specific Key Changes mapping.
- Generic Key Change descriptions and difficulty allocations were provided by an Actor Analysis Task Force.
- Member State Specific Key Change descriptions and difficulty allocations were provided by relevant MS representatives and stakeholders.

4. Results

4.1 Explanation of the results format

This section presents a KCAM graphical representation of the Key Changes and relative difficulty allocations for each selected Key Change for each MS. Results for each MS are presented in consecutive sections. Each MS section follows a standardized format:

- Chain selection table
- MS Specific Key Change short descriptions and difficulty allocations
- KCAM Summary charts
- Associated Broad Actor Group summary charts

Detailed MS Specific Key Change descriptions are presented in dedicated MS Specific Actor Analysis Reports. KCAM Access tools for each Phase I MS, with all detailed mapping, will be available as separate files.

KCAM results are summarised as charts showing the Generic Key Changes, Member State Key Changes, and their difficulty allocations – for each hydrogen chain selected by Member States. These maps are intended to present a graphical approximation of an advancing 'front', migrating from the *current profile* towards the *end vision*. Note that these KCAM maps present only a summary of the results: detailed MS Specific Key Change descriptions will not be included in the final Actor Analysis Report (although descriptions for the Netherlands are included in this Phase 1 Report – see **Annex 2**), but will be presented in separate MS Specific Actor Analysis Reports. Generic Key Change descriptions are presented in **Annex 1**.

The following diagram explains how KCAM summary charts should be interpreted:

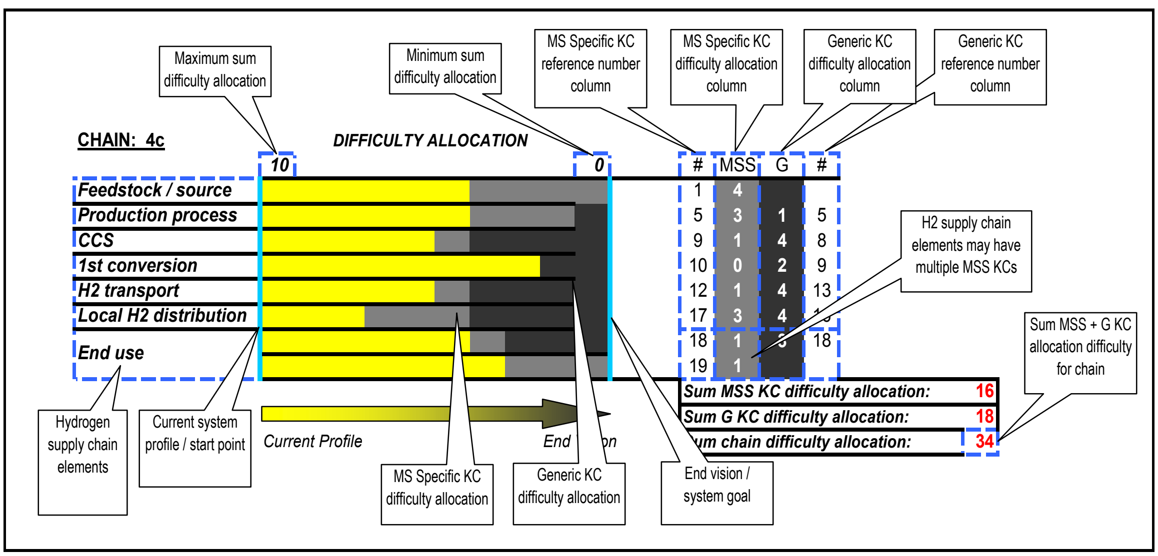


Figure 4 Explanation of KCAM summary chart layout.

4.2 Netherlands KCAM results

4.2.1 Chain selection table

Table 2 Netherlands hydrogen supply chain choices.

No.	Feedstock production	H2 production	Conversion	H2 Transport	Distribution	End-use
1a	NG	De-central SMR[0]	-	-	CGH2 FS	Vehicle (FC/ICE)
1b	NG	De-central SMR[0]	-	-	Local GH2 grid	CHP FC[3]
2a	Off shore wind elec.	Central electrolysis	-	Pipeline	CGH2 FS	Vehicle (FC/ICE)
2b	Off shore wind elec.	Central electrolysis	-	Pipeline	DC + mini grid	CHP FC[3]
3a	Hard coal	Central gasification[1]	-	Pipeline	CGH2 FS	Vehicle (FC/ICE)
3b	Hard coal	Central gasification[1]	-	Pipeline	DC + mini grid	CHP FC[3]
4a	NG	Central SMR[1]	-	Pipeline	CGH2 FS	Vehicle (FC/ICE)
4b	NG	Central SMR[1]	-	Pipeline	DC + mini grid	CHP FC[3]
4c	NG	Central SMR[1]	Liquefaction[4]	LH2 truck	LH2 FS	Vehicle (FC/ICE)
5a	Biomass	Central gasification	-	Pipeline	CGH2 FS	Vehicle (FC/ICE)
5b	Biomass	Central gasification	-	Pipeline	DC + mini grid	CHP FC[3]
6a	NG	Central SMR[0]	-	Pipeline	CGH2 FS	Vehicle (FC/ICE)
6b	NG	Central SMR[0]	-	Pipeline	DC + mini grid	CHP FC[3]

[0] Without CCS [1] With CCS [3] Cogeneration heat and power in collective residential, tertiary and small industry [4] H2 liquefaction with Dutch mix. Cells with "-": not applicable.

4.2.2 MS Specific Key Changes short descriptions and difficulty allocation.

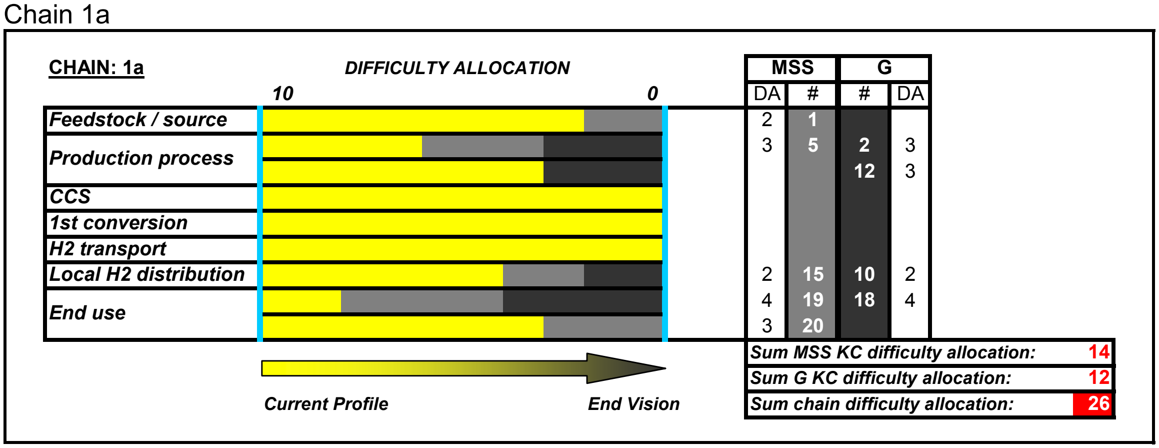
Table 3 List of Netherlands MS Specific Key Changes and Difficulty Allocations.

MS S KC #	NETHERLANDS MS Specific KC short description	KC Difficulty Allocation
	FEEDSTOCK / SOURCE	
1	Long term supplies of NG must be secured for domestic use.	**2**
2	Long term supplies of hard coal must be secured for domestic use	**3**
3	Significant increase in contribution of offshore wind power for electricity generation must be realized and surplus electricity made available for hydrogen production.	**4**
4	Adequate and economic supplies of biomass must be secured for domestic power production purposes.	**3**

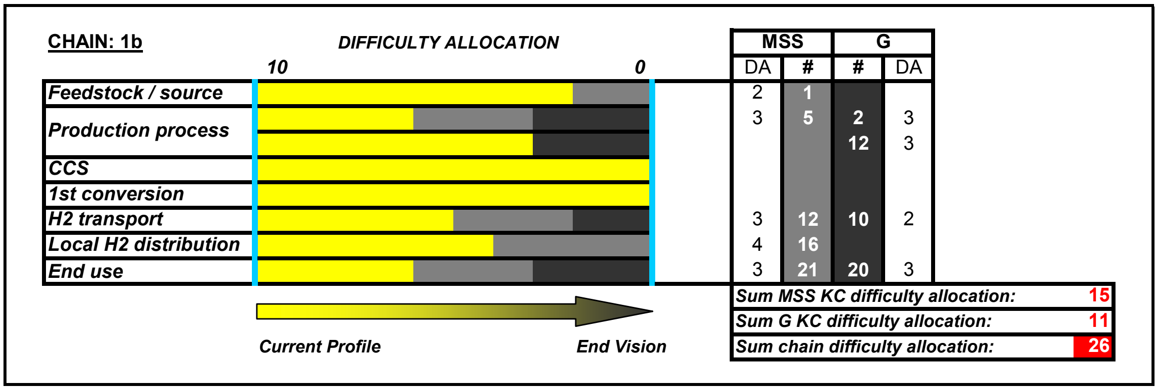
	PRODUCTION PROCESS	
5	Lack of NG decentralized SMR plants must be overcome.	**3**
6	Lack of NG central SMR plants must be overcome.	**2**
7	Lack of centralized electrolysis plant must be overcome.	**2**
8	Lack of hard coal SMR plants must be overcome.	**3**
9	Lack of biomass gasification plants must be overcome.	**3**
	CARBON CAPTURE AND STORAGE	
10	Lack of commercial CCS experience and tested facilities must be overcome.	**5**
	FIRST CONVERSION	
11	Lack of liquefaction plants must be overcome.	**1**
	HYDROGEN TRANSPORT	
12	Lack of sufficient G-H2 transport pipelines must be overcome.	**3**
13	Lack of required L-H2 trucks must be overcome.	**1**
14	Lack of experience and investment in H2-NG admixing and separation technology must be overcome.	**4**
	LOCAL HYDROGEN DISTRIBUTION SYSTEM	
15	Lack of G-H2 fuelling stations must be overcome.	**2**
16	Lack of local G-H2 grids must be overcome.	**4**
17	Lack of distribution centres and connected mini grids must be overcome.	**3**
18	Lack of L-H2 fuelling stations must be overcome.	**2**
	END USE APPLICATION	
19	Market penetration of FC/ICE vehicles must be achieved	**4**
20	Potential public resistance to owning/operating H2-fuelled FC/ICE vehicles on the grounds of safety or other non-techno-economic grounds must be overcome.	**3**
21	Lack of decentralised H2 CHP plant must be overcome.	**3**

4.2.3 KCAM summary charts - Netherlands

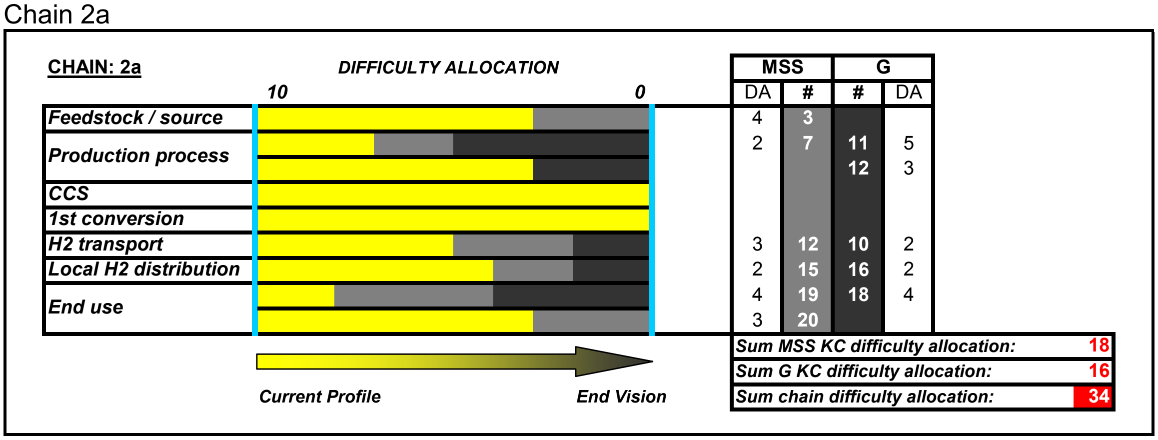
Chain 1a



Chain 1b



Chain 2a



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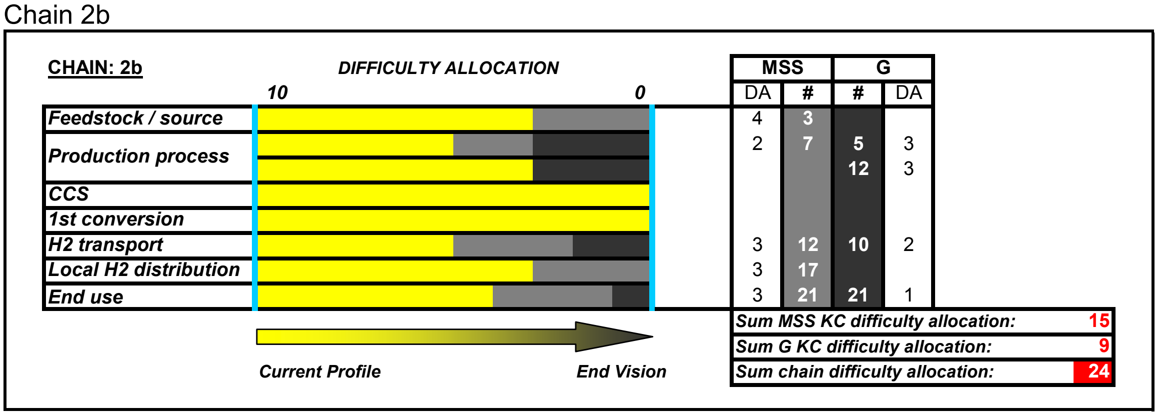
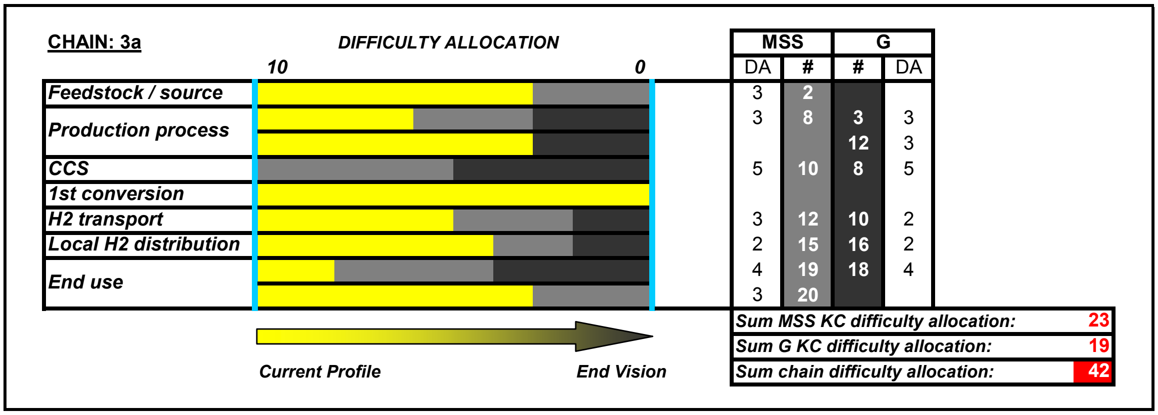


Chain 3a



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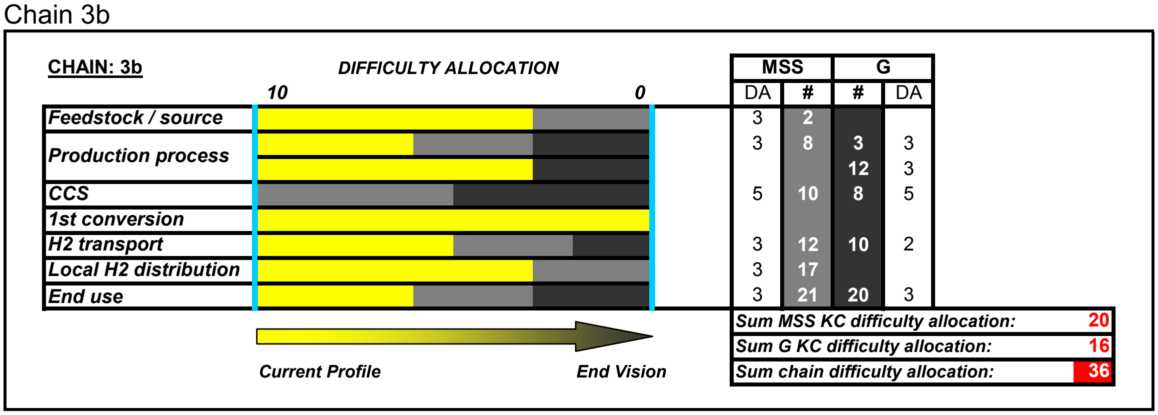

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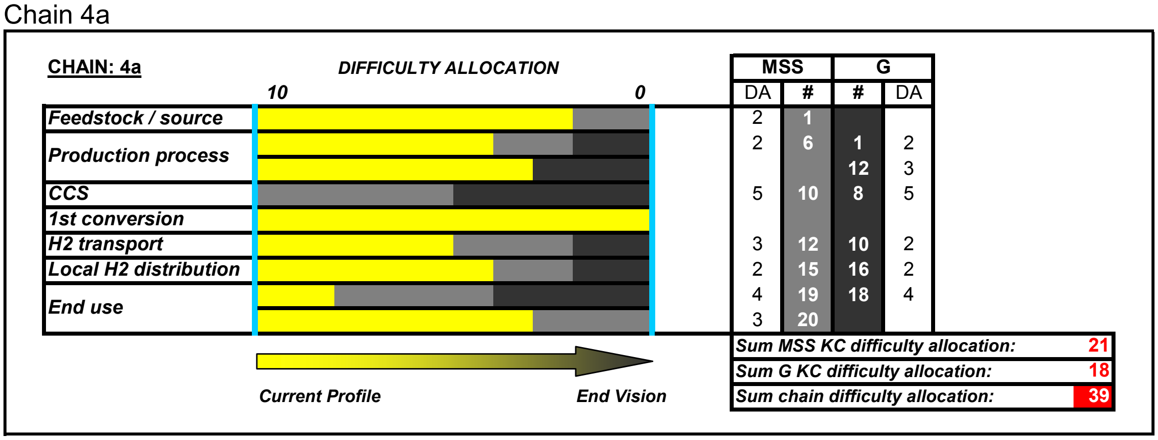
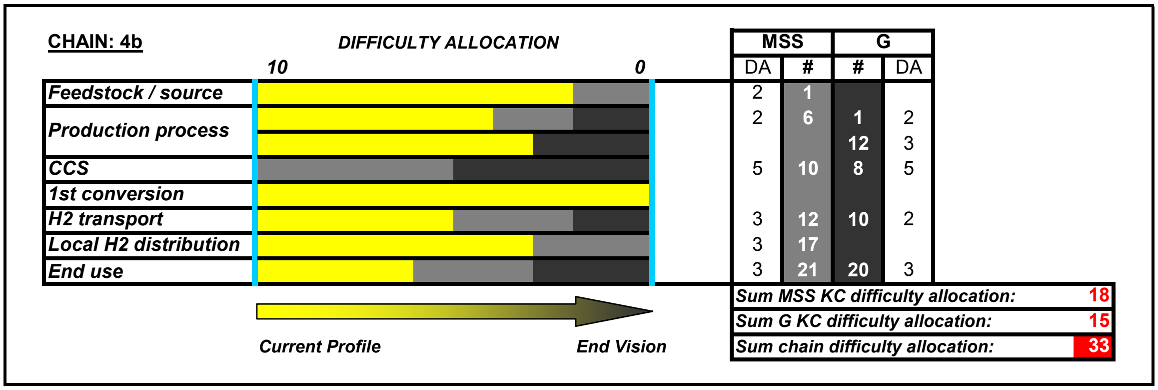
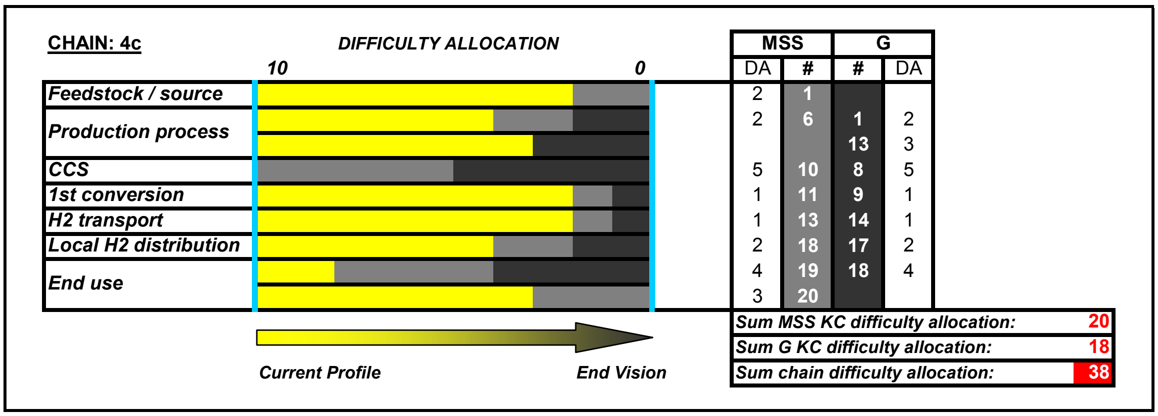


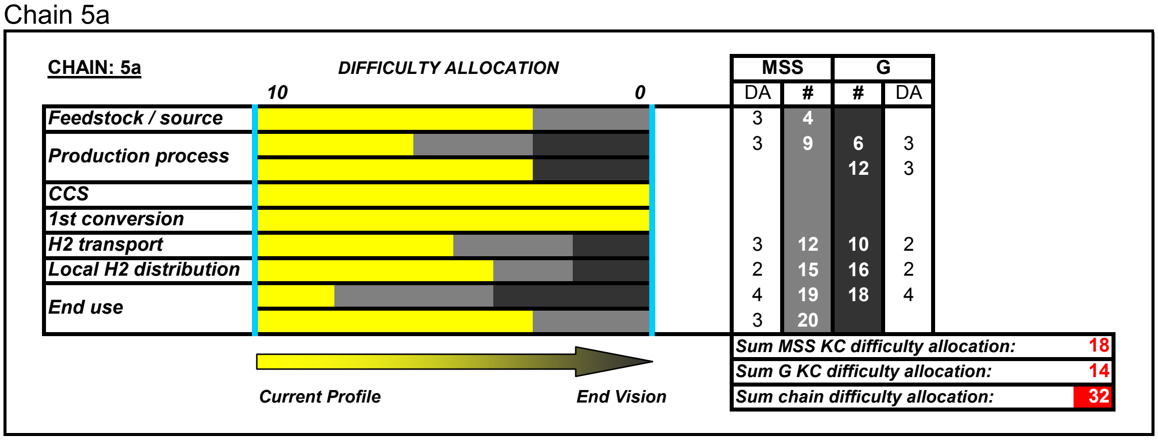
Chain 4b



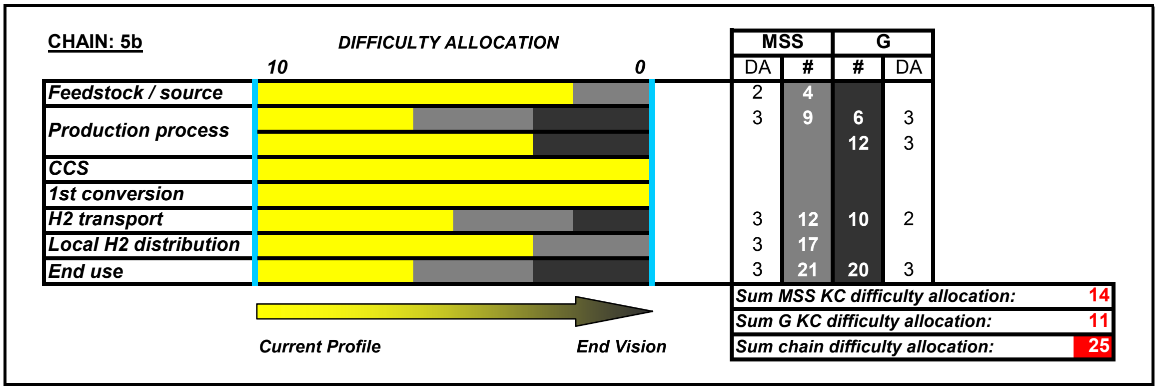
Chain 4c



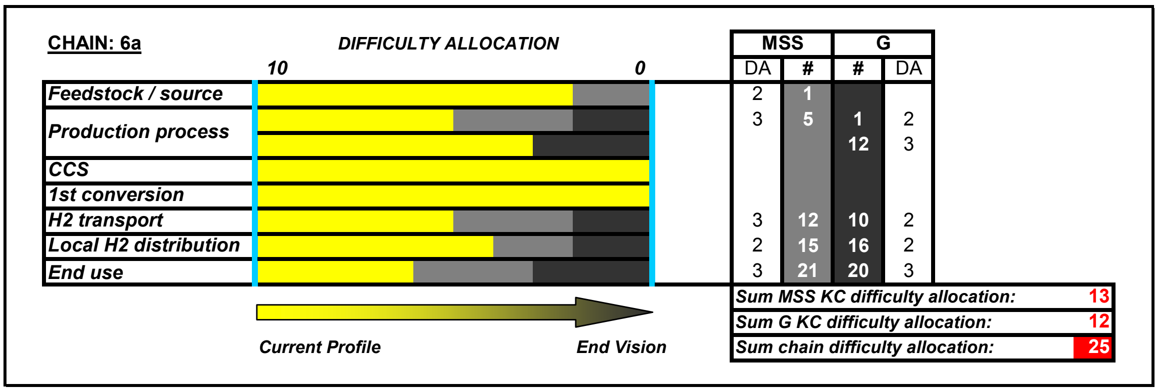
Chain 5a



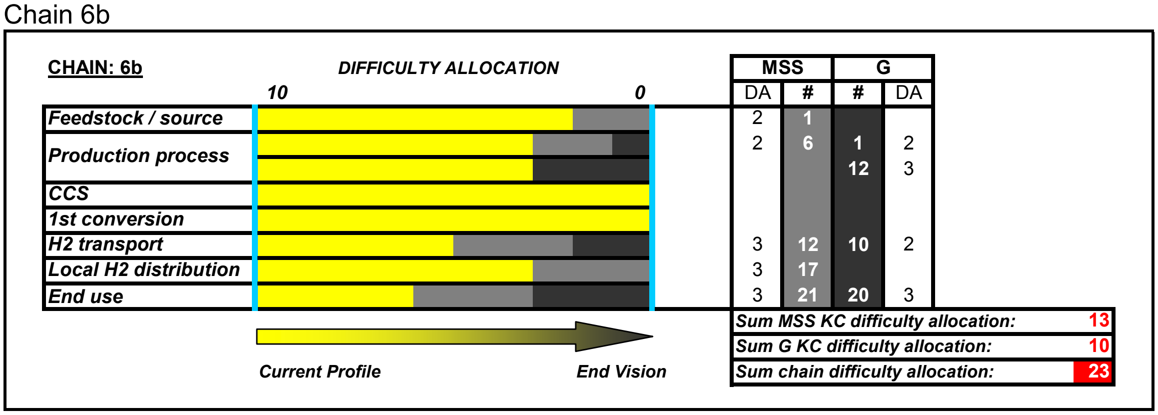
Chain 5b



Chain 6a



Chain 6b



4.2.4 Associated Broad Actor Groups - Netherlands

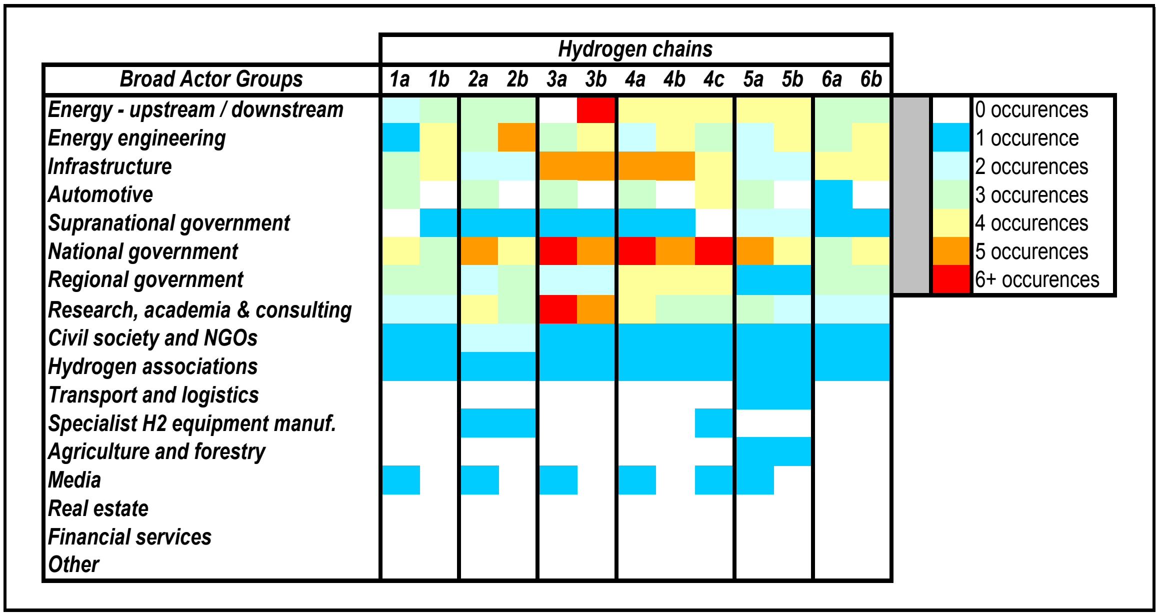


Figure 5 Netherlands Broad Actor Group summary chart.

5. Feedbacks and links between Actor Analysis and other HyWays work

5.1 Integration of Actor Analysis in HyWays methodology

Actor Analysis in Phase 1 of the HyWays project has focused on the development of the Key Changes and Actor Mapping (KCAM) methodology. As such, limited validation of Member State Specific mapping has taken place so far.

However preliminary mapping has been carried out for the 6 Member States involved in Phase 1 of the project, so validation by the relevant stakeholders is now anticipated. Because of the qualitative nature of Actor Analysis, a relatively high degree of MS stakeholder input is essential for the process. For this reason the whole process of AA and the use of the Access tool will be presented to all stakeholders at the start of Phase 2 in order to impart to them the concepts behind AA and the value of it, and ultimately also to secure their commitment to the process.

With the methodology finalized, Generic Key Changes validated and the Access tool in place, in Phase 2 it will be possible to carry out validated MS Specific mapping at a very early stage. Member States will be able to use the structured qualitative information provided by AA in the consideration of hydrogen chain formats before successive model runs in an iterative fashion, bringing AA in line with the other components of the hybrid methodology.

6. Lessons learned, the HyWays toolbox and potential value to roadmapping

6.1 Value of Actor Analysis for the HyWays toolbox

The HyWays 'toolbox' is a document with 2 principal aims:

1. Highlight 'lessons learned' from the HyWays Phase I experience with the aim initially of improving the various procedures for HyWays Phase II. This aim will be updated towards the end of Phase II to suggest potential improvements for any future roadmapping efforts in the light of the HyWays experience in its entirety.

2. Record the methodologies adopted by the various areas of work carried out for the HyWays project. It is to be hoped that this record will be of enduring use and will constitute a widely applicable method for other hydrogen roadmapping efforts.

Inputs for the HyWays toolbox arising from Phase I Actor Analysis focusing on lessons learned include:

- The content of the MS Profiling Reports (WP3) should be guided partially by the qualitative informational demands of Actor Analysis. This would increase the efficiency of primary MS specific research demands synergistically.
- More active engagement of the AATF and earlier engagement of MS representatives would be beneficial.
- Actor Analysis should be carried out at an earlier corresponding stage of Phase II than was the case in Phase I. This would mean more time is available for MS specific primary research into MS Specific Key Changes. It would also allow for a significantly increased level of integration of AA results into the process of chain selection and evaluation by MS representatives, thereby reducing the extent to which AA might be regarded as a 'stand alone' component of the HyWays process (albeit one with an important potential contribution to roadmap construction). It is thought that a correspondingly earlier completion of AA is an achievable aim for Phase II as the conceptual framework and development of the KCAM Access tool (which accounted for the majority of the total time expended on AA) are now already established. It is hoped that only relatively minor 'fine tuning' of these components will be required for AA in Phase II.
- Methods of integrating the results of AA into MS hydrogen chain considerations should be investigated in closer detail.

Inputs for the HyWays toolbox arising from Phase I Actor Analysis focusing on methodology include:

- An assessment of the value added to largely quantitative roadmapping efforts (which account for the majority of international roadmapping activities to date) of a structured and systematic treatment of qualitative socio-economic information on a 'tailored' country-specific basis.

- The practical application of general theories of systems development specifically to hydrogen systems development.
- An operational KCAM Access tool, which can be used directly or adapted to future roadmapping efforts. The use of the KCAM method will assist in:
    - Identifying and evaluating required Generic and nation-specific Key Changes for defined future hydrogen systems.
    - Enabling treatment of KCAM results according to a number of desired primary parameters.
    - Matching selected hydrogen supply chains or Key Changes with Broad Actor Groups, which will assist policy makers in 'targeting' influential bodies with measures aimed at furthering progress towards the practical realization of selected hydrogen supply chains.
    - Automatic generation of tailored reporting sheets within the KCAM Access tool.

6.2 Value of Actor Analysis to the construction of HyWays roadmaps

Inputs for the construction of roadmaps arising from Actor Analysis include:

- MS Specific and Generic KC descriptions – provision of an additional layer of qualitative information on chain-by-chain basis for use by stakeholders in construction of their roadmaps.
- MS Specific KCAM summary charts – provide a validated overview of relative difficulty allocations for each chain.
- MS Specific Broad Actor Group charts – for use in policy 'targeting' by policy makers.
- Provision of flexible KCAM Access tool for use by MS stakeholders in the qualitative consideration of further possible hydrogen supply chains or variations on existing chains.

7. Conclusions

Actor Analysis is the principal qualitative plank of the HyWays hybrid roadmapping approach. There is a raft of pertinent information which is vital to the quality of any roadmap but which is not easily captured by primarily numerical modeling approaches. Examples of such qualitative information include national policy priorities; social awareness and acceptance of hydrogen technologies; energy market characteristics; codes and standards; and local planning considerations. The *ad hoc* treatment of such roadmap inputs in previous roadmapping efforts has adverse implications for the rigour and objectivity of the roadmap product and therefore potentially on subsequent policy responses.

The KCAM methodology, which constitutes the practical application of Actor Analysis, has been developed to strengthen the treatment of important non-numerical information in the hydrogen transition roadmapping process, and is employed in support of the main computational modeling components. The basic units of investigation in the KCAM methodology are 'Key Changes', or distinct system development requirements. These are described, classified and quantified by expert panels, ensuring not only high quality definition and evaluation of inputs but also enhancing stakeholder consensus and ownership of the product. Although this requires securing the active involvement of stakeholder participation in the process, any potential associated difficulties are outweighed by the benefits of achieving genuinely negotiated positions in what is essentially a political endeavour. Without this level of active stakeholder involvement and validation the risk that roadmapping products might not ultimately be accepted by their intended recipients is increased.

The KCAM approach is derived from a general systems development model which has strong conceptual parallels with the compartmentalised hydrogen supply chain structure adopted by HyWays. This allows for efficient data manipulation and results comparison across a range of analysis vectors. A user-friendly Access based KCAM computer tool has been developed to allow users to conduct their own analyses of prospective hydrogen supply chains. Whilst the KCAM methodology has been developed specifically for HyWays, it has been designed as a generic and stand-alone tool which can be of use in other national contexts.

This Phase 1 Actor Analysis Report has focused on the development of the KCAM methodology, as well as presenting validated Generic Key Change descriptions and preliminary validated MS Specific mapping for the Netherlands. Preliminary mapping has been carried out by IDMEC-IST for the 6 Phase 1 countries, and the next stage is for all Member States to be presented with the concepts, methods (including the Access KCAM tool) and benefits of the process in order to secure their commitment and active participation in the validation of the mapping for their own MS contexts.

8. Annexes

Annex 1: List of Generic Key Change descriptions and difficulty allocation

Annex 2: List of Member State Specific Key Change descriptions: Netherlands

Annex 3: Guidelines for KCAM allocation

Annex 1: List of Generic Key Change descriptions and difficulty allocation

(DELIVERABLE 3.10 ACTOR ANALYSIS)

DESCRIPTIONS OF GENERIC KEY CHANGES

This document *'Descriptions of Generic Key Changes'* is one element of Actor Analysis and Transition Analysis. It summarises *Generic Key Changes*, i.e. required Key Changes that are consistently true for all MS contexts in realising selected hydrogen chains. Generic Key Change Descriptions are made for each *Hydrogen Chain Component* and focus in particular on the techno-economic competitiveness of hydrogen production, transport and end-use technologies.

These *Descriptions* aim to capture key information for each set of technologies, including:

- Relevant HyWays assumptions associated with hydrogen energy technologies or processes
- Current development status of the technologies
- Key technology development goals
- Broad Actor Groups involved
- Generic Key Change solution difficulty assessment by chain component

In subsequent MS-specific mapping activities, the *Generic Key Changes* will be analysed in conjunction with their corresponding *MS Specific Key Changes* (which focus in particular on the political/institutional, social and infrastructural aspects) and overall, aggregated Key Change solution difficulty assessments by chain component will be derived.

The comments are based on a variety of sources and are linked to the techno-economic assumptions that are used in HyWays project to date, as summarised in the WP1/2 Final Report.

Wherever possible, partners are asked to input relevant assumptions from the E3 database, HyWays task force findings, and HyNet technology. Partners are asked to review and provide input in five areas for each Generic Key Change description:

1. HyWays assumptions – please include any improvements to the summary of the WP1/2 Final Report.
2. Current State-of-the-art – description of the technology and state of maturity.
3. Development Goals – concise changes that are expected or needed.
4. Overall difficulty and timeframe for 'overcoming' Generic Key Changes (1 = Lowest difficulty allocation; 5 = Highest difficulty allocation). This is intended to be a subjective indication only. Considerations related to timeframes should be indicated if not already in the description. Note that the difficulty allocation describes the change needed for the technology in question to

A. HYDROGEN PRODUCTION PROCESS

1. STEAM METHANE REFORMING (Large scale)

1. HyWays Assumptions

Hydrogen produced from Natural gas is studied in HyWays under the following assumptions:

- *Natural Gas is imported as a European mix, mainly from Russia, Norway and the Netherlands (except in the case of Norway) via major European pipelines, and distributed to centralized plants. However the Netherlands export will decrease and the Netherlands may become a net importer for the period after 2030.*
- *The characteristics of extraction and processing vary slightly across countries.*
- *The techno-economic characteristics of two centralised SMR plants are assumed: Linde 1992 (without CCS) and Foster Wheeler 1996 (with CCS).*

2. Current state of the art – description

Large scale Steam Methane Reforming of natural gas is a mature technology and is currently the most widely used method of producing hydrogen. SMR technology is widely used in the production of hydrogen for ammonia synthesis and methanol and also for hydrogen supply in oil refineries (for methanol synthesis partial oxidation or a combination of steam reforming and partial oxidation is used for syngas generation to achieve a suitable hydrogen-to-carbon ratio which should be about 2 to 1). A typical plant can produce as much as 1.5 million Nm^3 (normal cubic metres) per day with a conversion efficiency of between 75 and 76% related to the lower heating value and between 80 and 82% related o the HHV, and an average operating capacity factor of 90%. Most hydrogen plants are situated where the hydrogen is consumed as demand loads are usually of a sufficient size to justify a dedicated SMR plant.[i]

Large scale reformers are developed by plant engineering in a case by case scenario. This leads to a typical construction incorporating separated chemical reactors and heat exchangers. The processes are typically optimized for full load, introducing high mass, leading to thermal slowness and efficiency losses when operated below the design load. For this reason large scale reformers must be operated in steady state load (at the design point) to avoid serious efficiency losses. Large scale steam reforming has the advantage of the lowest capital investment requirement per m^3 of hydrogen produced compared to any other hydrogen production technology including small scale on-site reforming. As slow incremental growth is expected, pipeline transportation or truck transportation will be required for some decades. Studies have shown that incurred trucking transportation costs make the cost advantage of large scale reforming disappear at a distance of around 50 km of the plant, depending on the chosen pressure and scale of the on-site reforming competitor; thereafter, on-site reforming is more cost-competitive. Pipeline transportation, however, will become cost efficient when a certain critical mass is reached.

A disadvantage of existing large scale reformers is that in most cases the quality of hydrogen produced is not sufficient for fuel cells. Fuel cells typically require 99.999%

purity of hydrogen (quality 5.0 with max 100 ppm CO), whilst large scale reformers mostly don't produce this quality (and in the EU as a whole there are just 3 liquid plants which produce high purity hydrogen of 5.0 quality, based in Germany, the Netherlands and France).

3. Development goals

- Lower cost (e.g. by engineering out components or the introduction of alternative solutions such as membrane separation).
- Other fuels (e.g. diesel, kerosene).
- Modulation of 1:10 (which is not possible in large scale plants which usually are run at base load) (Haldor Topsoe, 1998).

4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals".*

2010	2020	2030	2050
x			

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?*
(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)

1	2	3	4	5
	x			

5. Broad Actor Group(s) involved

- Energy engineering
- Energy upstream / downstream (NG)

6. Additional References

2. NATURAL GAS REFORMING (SMR) Small Scale / On-site (OSR)

1. HyWays Assumptions
Distribution of natural gas to de-centralised plants occurs through local pipeline grids. The techno-economic characteristics of one de-centralised SMR plants are assumed (Haldor Topsoe, 1998).
2. Current state of the art – description
The greatest difference between large scale SMR and small scale / on-site reforming (OSR) is that in OSR the chemical processes and the heat exchange processes are fully integrated. Furthermore a burner is integrated in the reformer reactor using the off-gas of the PSA. Thus heat losses to the environment are reduced and efficiencies are improved. Given the dimensions (shorter reaction times due to less mass slowness) higher modulation is possible (latest designs specify 1:5 modulation, without serious efficiency losses). Therefore small-scale reformers in some instances have more flexible operability. The basis for state of the art designs is the principle used in the Heat Exchange Reformer (HER), developed in the 1980s by Haldor Topsoe. This technology is based on a combination of co-current and counter current heat exchange between the flue gas and the catalyst bed(s). Current state-of-the-art designs (Hexion, Carbotech etc.) have a reformer reactor including an integrated burner. Also a HTS (high temperature shift) reactor is integrated. The syngas produced in the reforming process is partially shifted in the HTS section, thus getting a higher hydrogen yield. This first stage of the process typically is operated in the 10-25 bar range, because the PSA process requires that pressure. The PSA (pressure swing adsorption) process separates the hydrogen from all other gases. A purity of 99.999% represents the state-of-the-art. In recent years the U.S. company H2-GEN has announced that it will develop very low cost small reformers for on-site reforming. The German group W.S. Schmidt (in Renningen) has developed a thermally fully integrated FLUX reformer which will lead to increased efficiencies and lower volume. Several other companies are also considering a commercialization of this technology and have presented early products. Linear downscaling of the large scale reforming process leads to a small scale version with low efficiencies as the effects of heat losses are getting worse exponentially (surface versus mass). For this reason, chemical reactors and heat exchangers are integrated in small scale reformers, creating the possibility to modulate whilst maintaining high efficiency. The costs of small-scale reformers are today at a level of around €6000 per Nm^3 capacity installed in the scale of 50 Nm^3 per hour. Significant cost savings for small, scale reformers are thought to be possible by factory production of small to medium series. However, current specific reformer costs (€/installed capacity) are still substantially higher than those for large scale reformers. When transportation costs are included an advantage occurs starting at a distance of 50 km from the large scale reformer. The modulation opportunity of OSR offers advantages in the roll out phase of the hydrogen fed fuel cell cars as hydrogen production can be adapted to a growing need within certain limits with negligible influences on efficiencies.

Since not all fuelling stations have natural gas available, fuel flexibility is desired. In the EU call of December 2004 a reservation was made to develop multi-fuel processing technology for on-site production of hydrogen. This would enable the on-site reforming of diesel and gasoline, thus opening the possibility of producing hydrogen at any European fuelling station.

On-site reforming is considered primarily as an interim solution for hydrogen production as the GHG issue is not adequately tackled.

3. Development goals

- Cost reduction through increased sales volumes.
- Cost reduction through engineering out components and the introduction of alternative solutions such as membrane separation.
- Durability and reliability to be improved.
- Other fuels (e.g. diesel and gasoline).
- Modulation of 1 : 10 (which is not possible in large scale plants which usually are operated at base load).
- Duogen (duel generation of hydrogen and electricity by an integrated fuel cell).
- Operating range to be extended in order to accommodate with fluctuating hydrogen demand (and especially with low demand).
- The US DOE's goal for 2013 is to reduce the cost of hydrogen production from natural gas by 25% from the 2004 figure. The goal for distributed production of hydrogen from natural gas is US$ 1.50-kg (delivered, untaxed) at the pump (without CCS), though recent projections suggest that US$ 2.00 is perhaps more valid.

4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals".*

2010	2020	2030	2050
	x		

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?*
(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)

1	2	3	4	5
		x		

5. Broad Actor Group(s) involved

- Energy engineering
- Energy upstream / downstream (NG)
- Research, academia and consulting
- Specialist hydrogen equipment manufacturing

6. Additional References

Thomas, Sandy
Schmidt, W.S.

3. HARD COAL GASIFICATION

1. HyWays Assumptions
Typical European Coal mixes are specified for the four MS which have selected this option (Germany, Italy, Greece, and the Netherlands). Hydrogen is generated via large scale gasification (with CO_2 capture and storage). Long-distance transport of coal (and hence energy use) is necessary in Greece and the Netherlands.
2. Current state of the art – description
Coal gasification produces a gas with around 60% hydrogen and also large amounts of CO and CO_2 as well as sulphur and nitrogen compounds. Different types of coal gasifiers exist, but the entrained flow gasifier is considered the best option for hydrogen production. This method can accommodate a number of different types of coal. The high reaction temperature leads to a high carbon conversion. However, to achieve these high operational temperatures a relatively high amount of oxygen is required. The syngas produced is composed of CO, H_2, CO_2 and N_2. H_2 is subsequently separated from the syngas. Hydrogen production from coal is a well-developed commercial technology. However, high investments costs put it at a disadvantage in the face of SMR.[ii] Placement of coal plants at coastal locations would reduce CO2 transport costs in CCS schemes, and increase the availability of off shore CO2 storage opportunities such as depleted NG fields. Such opportunities are partly governed, however, by the geographical location of coal fields as primary resource transport costs are high.
3. Development goals
• Technological development is focusing on separation and purification using hydrogen separation membranes and other technologies including integrated ceramics, water gas shift membrane reactors, defect free thin films, and inorganic membranes. • Significant worldwide research is currently being conducted around the world with the aim of utilizing abundant and cheap coal resources, notably in the US, Australia, Germany and Spain.[iii]
4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals".*

2010	2020	2030	2050
	x		

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame? (1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)*

1	2	*3*	4	*5*
		x		

5. Broad Actor Group(s) involved

• Energy engineering • Energy upstream / downstream (coal) • Transport and logistics sector (barge, sea, ship, port handling, storage) • Research, academia and consulting • Specialist hydrogen equipment manufacturing
6. Additional References

4. ELECTROLYSIS WITH ELECTRICITY MIX (Central and on-site)

1. HyWays Assumptions
The electricity mix assumed for 2020 in the six HyWays MS varies widely, with NG, hard coal and nuclear dominating to different extents. Greenhouse-gas emissions and costs vary widely as well. Please refer to WP1/2 report for details. *Electrolysers have different capacities according to the central or de-central nature: four electrolysers (two of each nature) are characterised in HyWays. Whilst France and Germany consider both central and de-central options for electrolysis with electricity mix, Italy and Norway consider solely de-centralised electrolysis.*
2. Current state of the art – description
At the present time electrolysis provides only a small percentage of the world's hydrogen, most of which is supplied to industrial applications which require small volumes of high purity hydrogen. Industrial electrolysis systems currently have hydrogen production capacities of up to 5 tons per hour and net system efficiencies up to 62-70% based on the LHV (HHV: 74-82%) including all auxiliaries such as AC/DC converter, pumps, blowers etc.. Such systems operate with a net power consumption of around 48-53 kWh per kg of hydrogen produced (Source: *AccaGen* 2005; *GHW* 2004; *Norsk Hydro* 1997; *Stuart Energy Europe* 2004).[iii] Electrolysis is a commercially available technology, and most systems use alkaline technology. State-of-the-art technologies achieve 4.3-4.8 kWh/Nm^3 hydrogen including all auxiliaries, which corresponds to efficiencies between 62 and 70% related to the HHV. The system is highly modular and requires a minimum of auxiliary components.[ii]
3. Development goals
• Current R&D efforts are aimed at improving net system efficiencies of commercial electrolysis towards 95% (HHV). • Efforts are currently focusing on pressurized operation, which eliminates the use of a hydrogen compressor and has favourable characteristics as a result of lower losses in the electrochemical reaction. • Cost reduction through increased sales volumes. It is estimated that prices as low as €400 per kg of H2 produced might be achieved by 2010.
4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*

2010	2020	2030	2050
	x		

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame? (1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)*

1	2	3	4	5

		x		

5. Broad Actor Group(s) involved
• Energy engineering • Power industry • Energy upstream / downstream (NG, coal, nuclear energy) • Transport and logistics sector (barge, sea ship, port handling, storage) • Research academia and consulting
6. Additional References

5. DEDICATED WIND ELECTROLYSIS (Central and on-site)

1. HyWays Assumptions
The techno-economic characteristics of two wind turbines (on-shore: 2MW, off-shore 4.5 MW) are assumed for 2020 in HyWays. *Electrolysers have different capacities according to the central or de-central nature: four electrolysers are characterised in HyWays (see 4a).* *Greece has prioritized the study of on-shore wind in large and small electrolysers. Italy and Norway consider solely de-centralised on-shore wind hydrogen production, Whilst France, Germany and the Netherlands consider solely off-shore wind.*
2. Current state of the art – description
Electrolysis with on-shore wind: A number of wind-based hydrogen production demonstration projects are already up and running, notably the Utsira demonstration project sponsored by the Norwegian government. In the EU the Greek Centre for Renewable Energy Sources (CRES) is focusing on hydrogen production from RES, and other European partners are collaborating in the development of two test sites in Spain and Greece for the exploitation of wind energy for self-sufficient production, storage and use.[iii] Such stand-alone systems are currently a relatively expensive energy solution compared to standard grid supply, but the hydrogen storage component affords peak shaving and also minimizes the required total capacity of the RES source to meet a defined demand.[iv] Electrolysis with off-shore wind: Wind turbines in Northern Europe produce about 700MW of clean energy[2]. In the next ten years a capacity of several thousand MW is planned offshore in Denmark, the U.K., Germany, the Netherlands and Ireland. There are also early plans for the integration of off-shore wind electricity production with hydrogen storage.
3. Development goals
• Unit cost reduction mainly through increased sales volumes is the major goal for the wind power industry. • Control mechanisms for integration of wind with hydrogen storage (as opposed other storage mechanisms: heat pumps, pumped storage) and cost-efficient peak-shaving are being developed worldwide. • In cases where only surplus electricity is used for hydrogen production the investment costs in the electrolysers needs to be justified by the amount of hydrogen that can be produced. This requires careful dimensioning and unit cost reduction of electrolysers.

[2] Off shore wind power capacity installed or under construction end 2004: Denmark: 409.15 MW; Germany 4.5 MW; Netherlands: 18.8 MW; Sweden: 23.25 MW; UK: 214 MW (Source: Bundesverband Windenergie e.v. (BWE) 2004).

4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*			
2010	**2020**	**2030**	**2050**
	x		

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame? (1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)*				
1	**2**	***3***	**4**	***5***
		x		

5. Broad Actor Group(s) involved

- Energy and civil engineering
- Power industry
- Research, academia and consulting

6. Additional References

6. RESIDUAL AND FARMED WOOD GASIFICATION

1. HyWays Assumptions
The techno-economic assumptions for hydrogen generation from biomass in HyWays are based on the use of two different degrees of dealing with plant data: one plant where the production of syngas via gasification, the CO shift and the purification via PSA is presented separately, and one plant where only data for the complete plant including syngas generation, CO shift and PSA are available. For all countries except the Netherlands, the wood is chipped at the source and then transported to the gasification plant by trucks (average distance 50 km). Assumptions on future trends of waste and farmed wood availability have not been found.
2. Current state of the art – description
Biomass gasification relies on technology that has been developed for other applications. Thermo-chemical processes can be applied to bio-resources such as agricultural residues and wastes or biomass grown as an energy crop to produce hydrogen through pyrolysis and gasification. This process generates a carbon-rich syngas that is reformed into H_2 using thermal processing techniques similar to fossil fuels reformation. Biomass gasification for hydrogen production has been under development over the last two decades and a number of units are currently in commercial operation, though the majority are demonstration projects only. In the EU, the Netherlands has a Bio-hydrogen Platform, which concentrates on pyrolysis and supercritical water gasification. At the EU level the CHRISGAS consortium aims to develop a large-scale biomass gasification process to produce a clean, H_2-rich gas which it intends to use in the production of liquid vehicle fuel. In the US there is a target for 2010 to develop and demonstrate technology to supply purified H_2 for PEMFC from biomass at US$2.6/kg (projected at the commercial scale of 75,000 kg/day), and for this to be competitive with gasoline by 2015. There is also a "Hydrogen Production from Biomass program" funded at US$1.2m, which includes pyrolysis, gasification and fermentation.[iii] As biomass can also be used in cofiring and for producing liquid biofuels, there will be competition for biomass which may drive up the price. Governments may leave the biomass price to the market or interfere by developing a strategy for optimal allocation of biomass to the three options (cofiring, biofuels, hydrogen) based on maximum CO2 reduction.
3. Development goals
• Improving cost competitiveness and environmental performance in relation to conventional use of biomass for energy
4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*

2010	2020	2030	2050

	x		

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?*
(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)

1	2	*3*	4	*5*
		x		

5. Broad Actor Group(s) involved

- Energy engineering
- Agriculture/forestry
- Transport and logistics sector (barge, sea ship, port handling, storage)
- Research, academia and consulting

6. Additional References

7. MUNICIPAL WASTE GASIFICATION

1. HyWays Assumptions
Only Italy studies this feedstock within HyWays, assuming the availability of waste on-site and its pre-treatment (municipal waste has to be collected from the households and transported to a waste treatment facility in any case independent on the kind of waste treatment) and gasification in a plant with 20 MW of GH_2 output. Assumptions on trends of waste availability have not been found. *Another possible production path is anaerobic digestion of the municipal waste followed by reformation and clean-up processing.*

2. Current state of the art – description
The strengths of using waste for hydrogen production are: • Reduced CO_2 emissions: waste materials are considered a renewable and easily available energy source with a neutral impact on atmospheric CO_2 concentration. • Possible material recovering (glass and metal). • Waste volume reduction after thermal treatment. Gasification/pyrolysis technology is one of the most well-established and used processes that convert any solid materials, biomass or waste (containing carbon) into a synthesis gas rich in hydrogen. The greatest problems in using thermal process wastes for hydrogen generation is the transfer of environmental pollutants present in the waste itself, whether in the flue gas or by means of the different solid streams that are generated in the processes. For this reason it becomes necessary to have, first of all, a waste screening system in order to have a homogeneous material to feed a gassifier/pyrolyzer, a good gas treatment process, and a good solid stream treatment and storage system. One of the most interesting technologies for producing hydrogen from plastics includes two steps: pyrolysis of plastics and catalytic steam reforming of pyrolysis gases and vapors. Pyrolysis of plastics to produce hydrocarbons has been demonstrated and it uses almost the same technology for biomass pyrolysis. The product composition depends on the feedstock as well as on the process conditions. For example, pyrolysis of polyethylene at 700ºC generates over 50% gaseous, non-condensable hydrocarbons and 40% condensable (liquid) hydrocarbons. Increasing the process temperature results in higher gas yields. In most cases the product is a mixture of a large number of compounds and isolating specific monomers is not practical. However, the mixed hydrocarbon product can be used as a feedstock for the catalytic steam reformer: to produce hydrogen. It is important to note that CO_2 from waste is considered "neutral" with respect to greenhouse gases, as it does not increase the CO_2 concentration in the atmosphere. Another possible process uses heating from electrically conducting gas (a plasma) in a

special gasification system to convert wastes to valuable products (Electrofusion Electrodissociation System -SEED-). This kind of system is highly effective in processing a wide variety of waste streams, including hazardous, medical, radioactive, industrial, municipal and tire wastes. The system is also highly capable at producing a syngas rich in hydrogen and useful solid byproducts (roofing tiles, insulating panels, sand-blasting media and other construction-related products). The environmental attractiveness results from nearly total destruction of organic materials (high volume and weight reduction) and very low emission of hazardous air pollutants.

The SEED process was originated to feed engines for electric power generation but it is possible to use it even for hydrogen production and fuel cell uses. Under this configuration, the process becomes a source of distributed hydrogen with a purity greater than 99.999% using a PSA (pressure swing adsorption) unit. The remaining carbon monoxide from the PSA tail gas can be used in an appropriately sized genset for power production.

In addition to providing cost effective, environmentally responsible treatment and extraction of value from waste, this system can be used as part of a distributed hydrogen/power production system. Depending on the waste stream, it can produce considerably more power than they consume. Such combined systems can be installed in a variety of locations to provide local power and eliminate service interruptions and at stable cost. Because a portion of the fuel is waste, costs can be contained and kept competitive.

3. Development goals

- Unknown

4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*

2010	2020	2030	2050
	x		

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?*
(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)

1	2	3	4	5
	x			

5. Broad Actor Group(s) involved

- Energy engineering
- Regional / local government
- Waste industry
- Transport and logistics sector (handling, storage)
- Research, academia and consulting

6. Additional References

B. CARBON CAPTURE AND STORAGE (CCS)

8. CARBON CAPTURE AND STORAGE (CCS)

1. HyWays Assumptions

CCS is assumed for one of the large-scale SMR plants included in HyWays calculations (Foster Wheeler 1996), and for coal gasification (which is in all cases large scale).

2. Current state of the art – description

CCS methods currently used to separate (capture) CO_2 from other gases are physical scrubbing processes (e.g. SELEXOL) or chemical scrubbing processes (e.g. using a MDEA as a scrubbing agent). Both methods require energy input to recover CO_2. Research is focusing on increasing the efficiency and lowering the cost of separation techniques.

Potential storage options which are being considered include depleted oil and gas reservoirs, deep un-mineable coal beds, and deep porous formations containing salt water. The storage in depleted oil reservoirs is currently the best and safest solution especially when combined to EOR (enhanced oil recovery).

Countries involved in significant research endeavours include the US, Canada, Japan, Norway, the Netherlands and Australia. The EU is also funding a number of projects.[iii] Several demonstration projects of CCS within coal fuelled power plants have been announced and should be running before 2010.

There are currently no commercial electricity generation plants using carbon capture and storage technologies. However a number of carbon capture processes have been deployed in other industrial activities (e.g. to remove the CO2 from syngas upstream in the FT synthesis).

The permitting procedure for operating CCS programmes may prove extremely lengthy. Currently the CO2 trading emissions regulation does not consider CCS. This needs to be addressed in the future.

Amine scrubbing, a method of pre-combustion CO_2 capture, has been used for over 60 years for the removal of hydrogen sulphide and CO_2 from hydrocarbon gas streams. However most of this experience is with reducing gas streams rather than oxygen-containing flue gases, and at a smaller scale than for many power plants. The largest operating unit, at Trona, California, captures 800t CO_2 per day – less than 10% of the capacity needed for a 500MW coal-fired power station.

Post-combustion scrubbing is a commercial method of CO_2 capture in ammonia plant which is also available for use at utility-scale – for example, the Great Plains Synfuels Plant in the USA. However there is thought to be significant opportunities for cost reduction and efficiency improvement.[v]

3. Development goals

- There are significant costs involved in CCS, with capture representing 70-80% of total costs. A primary RTD objective for the EU is to reduce the costs from €50-60 to €20-30 per tonne of CO_2 captured, whilst aiming to achieve capture rates above 90%.
- There is also a strong need to assess both the reliability and long-term stability of CO_2 storage in order to map geological storage potential, determine safety aspects and to build public confidence and ensure acceptability.[vi]
- The current knowledge base is insufficient to support reliable assessments of the integrity of long-term geological storage. Further research is required to support the development of models to provide greater assurance on this issue. There is also a need for a greater knowledge base to support environmental impact assessments of the consequences of CO_2 releases to the terrestrial and marine environments.[v]
- There is thought to be significant scope for reducing the energy demand of CO_2 capture processes.
- There is a need to scale up CO_2 capture technologies in order for efficient CO_2 capture in large plant. CO_2 capture will be deployed in tandem with CO_2 transport systems (for delivery to storage sites), and this will frequently necessitate investment in dedicated pipeline systems. Capture systems will therefore need to be of a sufficient scale to justify the investment in a dedicated CO_2 transport system.
- In the case of hydrogen production by SMR or gasification, CO_2 capture requires pure oxygen and the O_2-N_2 separation technologies need to be improved in terms of efficiency and cost.
- The quality of CO_2 (residual contents in SO_2, N_2 and O_2) is an important issue. Standards need to be developed especially in the context of gas collection networks.
- Social acceptance is critical. The viability of storage must be demonstrated (through R&D efforts) while public communication actions must be organized.

4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*

2010	2020	2030	2050
		x	

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?*
(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)

1	2	3	4	5
				x

5. Broad Actor Group(s) involved

- Energy engineering
- Central government
- Infrastructure
- Research, academia and consulting
- Civil society and NGOs

• Regional government
6. Additional References

C. CONVERSION

9. HYDROGEN LIQUEFACTION

1. HyWays Assumptions
Three countries use liquefaction of the gaseous hydrogen produced for applications, whilst France uses liquefaction for truck transport solely. Two liquefiers of different capacities are used in the calculations. Different energy sources (NG, electricity mix) are used for the energy requirements for liquefactions, vaporization and LH_2 tank storage.
2. Current state of the art – description
Hydrogen liquefaction uses a significant percentage of hydrogen's energy content (as much as 30% based on the LHV of the hydrogen, although this figure is strongly dependent on the process scale of hydrogen liquefaction plants and is likely to drop to 21% in the 2020-2030 timeframe) and requires special materials and handling.[iii] There are presently several small liquefiers with daily output of 200 kg in service mainly for research purposes. In the USA, construction of the first five large scale industrial liquefaction plants began in the mid fifties. These plants had capacities between 15,000 - 35,000 l/h (approx. 25 - 60 t/d). Around the same time, Linde AG installed a plant in India with 10,000 l/h (16 t/d) capacity. Today there are about 10 medium sized plants with production capacities of 10 - 60 t/d in operation around the world. Newer are liquefaction plants in USA, Japan and Europe with capacities in the range 2000 to 8000 l/h (3 - 12 t/d). In 1991 a liquefaction plant was constructed in Ingolstadt in Germany by Linde AG, which has a capacity of 4.4 t/d [vii] and supplies the semiconductor industry with high-purity hydrogen. A second plant in Eastern Germany is under consideration (HyWeb, 2005).
3. Development goals
• Increase process efficiency.
4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*

2010	2020	2030	2050
x			

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?* *(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)*

1	2	3	4	5
x				

5. Broad Actor Group(s) involved
• Energy engineering (industrial gases companies)

6. Additional References

D. HYDROGEN TRANSPORT

10. G-H2 PIPELINES

1. HyWays Assumptions
Transport through pipelines is made by land except for Norway which uses a 1600 km sea pipeline (which consists of two 800 km pipelines and an intermediate compressor for pressure drop compensation between the two pipelines). The techno-economic data assumed for hydrogen pipelines is summarised in the WP1/2 report.

2. Current state of the art – description
Current hydrogen delivery infrastructure exists only for limited industrial hydrogen markets for chemical and refining industries in Europe and the United States. There are currently about 1000 km of hydrogen transmission pipelines in the U.S. and more than 1300 km in Europe. These are limited systems and they lack the scope or scale needed to deliver hydrogen outside of a few industrial areas to potential large-volume end-user applications. Therefore it is likely that significant capital investment in dedicated hydrogen delivery infrastructure will be required before a hydrogen economy can be realised.[iii]

3. Development goals
• Several technology issues need to be resolved and significant cost reductions are required for effective hydrogen pipeline transmission and distribution. These issues include: o a better fundamental understanding of hydrogen embrittlement and diffusion to enable the development of lower cost metal alloys, plastics, or composites for hydrogen pipelines; o improved metal welding or other joining techniques to reduce the material and labour costs associated with pipeline construction and repair; o improved seals to reduce hydrogen leakage in fittings and other components. o interior or exterior coatings could be retrofitted on existing or new pipelines to achieve compatibility with hydrogen service.[viii]

4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*

2010	2020	2030	2050
	x		

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame? (1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)*

1	2	3	4	5
	x			

5. Broad Actor Group(s) involved
• Infrastructure • Central government • Regional government • Research, academia and consulting
6. Additional References

11. G-H2/NG PIPELINES

1. HyWays Assumptions
Admixture of 5% of hydrogen into NG is studied in Greece and the Netherlands (NB: HyWays awaits to exchange information with NaturalHy project). The assumed costs for transports are 0.0253 €/kWh for 5 km and 0.0004 €/kWh for 250 km (WP1/2 report).
2. Current state of the art – description
An alternative approach to dedicated H_2 pipelines is the use of the existing natural gas delivery infrastructure. However these systems would require significant modification for use in the delivery and distribution of hydrogen as difficulties such as the embrittlement of some high-strength steel piping materials and components (e.g. compressors and valves) currently used for natural gas, would have to be overcome.[iii] The FP6 NATURALHY project currently studies these modifications. A preliminary conclusion from the Dutch Greening of Gas project (which dealt with admixture) is that modifications would not be needed in case of low percentages of hydrogen admixed to natural gas. The natural gas network could be used as a 'dump' for surplus hydrogen in the absence of sufficient hydrogen storage capacity (e.g. in the early days of a hydrogen economy), as the hydrogen could be burned with the natural gas in industrial burners and household stoves.
3. Development goals
• Development of new membrane materials for efficient separation of hydrogen from G-H_2/NG mixtures (FCV applications for example). • Development goals are largely unknown. Identifying development goals is one of the aims of the NATURALHY project.
4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*

2010	2020	2030	2050
	x		

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?* *(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)*

1	2	3	4	5
			x	

5. Broad Actor Group(s) involved
• Energy upstream / downstream (NG) • Infrastructure • Central government • Research, academia and consulting

6. Additional References

NB: HyWays has not explicitly dealt with the issue of hydrogen storage from the quantitative modeling perspective, but it is useful nonetheless to acknowledge the different forms of storage technologies available. It is possible to differentiate broadly between 4 kinds of storage: large scale, small scale, on board (vehicle) storage, and solid state storage:

- **Large scale storage:** expected to be mainly pressurized gas. This format is dealt with here in Generic Key Change 12.
- **Small scale storage:** mainly cryogenic liquid. This format is dealt with here in Generic Key Change 13.
- **On board (vehicle) storage:** usually pressurized gas. This format is not dealt with specifically but is considered integral with Generic Key Changes 18 and 19 which focus on FC and ICE vehicles.
- **Solid state storage:** usually in the form of metal hydrides and used in portable applications. This format is not considered within the HyWays project context.

12. HYDROGEN STORAGE (Large Scale)

1. HyWays Assumptions			
Large scale storage has NOT been envisaged specifically by MS in HyWays. However for the purposes of Actor Analysis, it is assumed that all instances of central or decentral (but not on-site) CGH_2 production incorporate large scale storage facilities at the production site.			
2. Current state of the art – description			
Storage within the hydrogen delivery infrastructure will be important to provide surge capacity for daily and seasonal demand variations. Storage at the large scale is best achieved by pressurized gaseous hydrogen methods because the cost of cooling (required to maintain hydrogen in a liquid state) is prohibitive. The most common pressure vessels for gaseous hydrogen are steel tubes or tubes made of composite material. They can be used to store hydrogen at 6,000 psi or higher. Research in the field of compressed hydrogen storage centres on the development of advanced composite tank materials to achieve lighter, stronger tanks. The pressure vessels are often manifolded together allowing for larger storage capacity. Geologic storage is routinely used to provide seasonal surge capacity in the natural gas delivery infrastructure. Very large volumes of natural gas are stored in natural geologic formations such as salt caverns under modest pressure (typically about 2000 psi or less). The hydrogen infrastructure will likely require similar bulk storage capability. Besides naturally-occurring geologic formations, storing hydrogen in specially engineered rock caverns, referred to as lined rock caverns (LRC), offers another possibility. Research into the suitability of geologic storage is needed. Containment within geologic storage may be more challenging and potential environmental impacts need to be investigated.[ix] The main envisaged applications for large scale hydrogen (gaseous) storage are centralised applications such as large scale production sites where hydrogen is generated for load leveling purposes.			
3. Development goals			
• High pressure distribution and storage systems in line with the needs of the auto industry.			
4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*			
2010	**2020**	**2030**	**2050**
		x	
4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?*			

(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)				
1	**2**	***3***	**4**	***5***
		x		

5. Broad Actor Group(s) involved
• Energy engineering • Energy upstream / downstream (gas industry for geological storage)

6. Additional References

13. HYDROGEN STORAGE (Small scale)

1. HyWays Assumptions
Germany, Italy and the Netherlands assume the storage of liquid hydrogen in vessels (NB: other forms of storage are not mentioned), which requires electricity obtained from the mix. For the purposes of Actor Analysis, small scale storage facilities are envisaged at the H2 production point of the supply chain.
2. Current state of the art – description
Hydrogen is also stored as a cryogenic liquid due to its higher volumetric energy density and thus smaller footprint. Liquid hydrogen storage tanks are insulated, to preserve temperatures of below -253 degrees Celsius, and to minimize heat transfer into the tank. Liquid hydrogen storage technology has disadvantages - mainly the energy required to liquefy the gas and the strict controls needed to maintain temperature stability and to avoid the risk of overpressure. The cost of the tanks, combined with the cost of the liquefaction process makes this an expensive option. On the other hand liquid storage has some advantages – its footprint can be integrated in today's filling station layout, and it is a common method of delivery within the gas industry for larger amounts of hydrogen. Continuously evaporated hydrogen may be catalytically burnt with air in overpressure safety systems or even collected again in a metal hydride.[x] The main envisaged applications for small scale hydrogen (liquid) storage are on-site applications such as hydrogen fuelling station forecourts.
3. Development goals
• [Yet to be determined]
4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*

2010	2020	2030	2050
		x	

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?* *(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)*

1	2	3	4	5
		x		

5. Broad Actor Group(s) involved
• Energy engineering • Energy upstream / downstream (gas industry for geological storage)
6. Additional References

14. LH2 truck

1. HyWays Assumptions
Hyways assumes truck transport of liquid hydrogen in France, Italy the Netherlands and Germany. Transport by truck is for 150 km or 300 km.
2. Current state of the art – description
Transport of liquid hydrogen by road over short and medium distances is seen as an important means of meeting small demands prior to developing infrastructure (e.g. for supplying distribution centres and fuelling stations prior to pipeline construction). Indeed demonstration projects such as CUTE make use of this means of hydrogen delivery. The competitiveness of this option depends on a number of factors including trucking distance, loading/unloading infrastructure and duration, the nature of the delivery (multi-stop vs. one-stop), as well as on the requirements of the filling station (for example whether liquid hydrogen is offered, or whether strongly fluctuating demand is expected, in which case liquid supply secures flexibility). Typical truck capacity can range from 3000 kg H_2 to 4000 kg LH_2/truck. It takes around 3 hours to load and 3.5 hours to unload a LH_2 truck. LH_2 boil-off losses are 6% during loading and unloading[xi], although cold boil-off gas lost during loading can be captured and redirected into the production/liquefaction process. Further losses are incurred during transport. For a 400 kg truck around 10-30% of the stored energy is lost depending on the distance of travel. For the larger trucks the losses are less due to a better truck to stored energy ratio. However, losses from superinsulated vessels are minimal.
3. Development goals
• Liquid hydrogen pumps to be fitted to all trailers
4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*

2010	2020	2030	2050
x			

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?* *(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)*

1	2	3	4	5
x				

5. Broad Actor Group(s) involved
• Energy engineering • Transport and logistics sector
6. Additional References

15. CG-H2 TRUCK

1. HyWays Assumptions				
Hyways assumes truck transport of gaseous hydrogen (for 50 km) in Norway only.				
2. Current state of the art – description				
Although storage of compressed gaseous hydrogen is feasible for stationary applications which are not usually bound by size and weight restrictions for storage containers, it is less practical for transportation because the conventional pressurized metal tanks are heavy and expensive.[iii] Nevertheless they are seen as an option in the early market development phases. The compressed gas tube trailer hydrogen truck capacity is of around 500 kg H_2/truck (Source: Worthington-Heiser 2000, Messer 1998). It takes around 3 hours to load a compressed gas trailer. Dropping the trailer off at a filling station and collecting an empty trailer takes around one hour [xi]. The average weight of the required tube trailer is 15,000 kg. Assuming a distance of 50 km of transport, the tube trailer has to travel 100 km per fill (to fuelling station and back). Transporting the tube trailer truck consumes 10% of the transported fuel. Compared to liquid transport transportation, losses are higher due to greater weight. For that reason CG H_2 trucking can be cost competitive for distances of up to 50 km.				
3. Development goals				
• Weight reduction and further development of composite tanks • Higher pressure storage would help to increase the efficiency of this method of distribution. Also a higher pressure storage system would help in meeting the needs of the onboard storage pressure desired by the automotive companies without having to invest in additional local compression facilities.				
4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*				

2010	2020	2030	2050
x			

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame? (1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)*				
1	**2**	***3***	**4**	***5***
x				
5. Broad Actor Group(s) involved				
• Energy engineering • Transport and logistics sector				
6. Additional References				

E. LOCAL HYDROGEN DISTRIBUTION

16. CG-H2 FUELLING STATION

1. HyWays Assumptions

The techno-economic data for the CGH2 filling stations for 2020 under HyWays varies according to the suction pressure of the pump (ranging from 1.5 Mpa to 10 Mpa).

2. Current state of the art – description

Compression, storage and dispenser technologies are under extensive testing in demonstration projects across Europe and the world.

Compression: Compressors are primarily used for the filling of high pressure (20 – 30 Mpa) and low pressure (1 – 5 Mpa) storage tanks. Typical pressure levels are 3 – 4 Mpa for pre-compression stages for filling of collecting tanks, and 25 – 30 Mpa for storage tanks in fast fill applications. Almost all common natural gas compressors can relatively easily be modified to be suitable for hydrogen[vii]. In HyWays the hydrogen at first is compressed to 30 MPa which is the pressure of the stationary hydrogen storage at the filling station. For refuelling in a vehicle the hydrogen is compressed to the required pressure via booster compression (85 MPa to provide a full 70 MPa vehicle tank at 15^{o}C in any case). Alternative ways of hydrogen compression such as metal hydride thermal cyle compression are under study. As they have no moving parts they may be favourable, especially when excess heat is taken from the reforming process.

Dispenser: The fast fill process is achieved by an overpressure above the pressure level in the vehicle tank being filled (35 or even 70 Mpa). The choice of the highest pressure level is primarily dependent on the maximum permitted pressure that the storage tank can withstand (modern tanks constructed from composite materials are rated for up to 70 Mpa). Because of the logarithmic relationship between pressure and work required for compression, the increased energy required for a higher filling pressure is not great. Thus the compression from 0.1 to 30 Mpa needs only 10% more energy than the compression from 0.1 to 20 Mpa.

3. Development goals

- Improvement of compression efficiency, for example through a) use of cryogenic pumps compressing LH2 via high-pressure evaporators into CG-H2; or b) use of hydraulic compressors such as pioneered by Linde.
- Development of alternative and integrated hydrogen compression technologies such as metal hydride thermal cycle compression.
- Improved design and energy recovery techniques will lower operating and maintenance costs and reduce the amount of energy required to compress hydrogen.[iii]
- Further decreases in fuelling time.
- Improved gas cooling systems.

- For both CGH_2 and LH_2 refuelling stations, additional goals include:

- Development of solid codes and standards (safety issues).
- Development of common rules for permitting and siting of HRS (e.g. FP6 HyApproval project: Handbook for Hydrogen Refuelling Station in Europe).

4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*

2010	2020	2030	2050
	x		

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?*
(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)

1	2	3	4	5
	x			

5. Broad Actor Group(s) involved

- Energy upstream / downstream
- Energy engineering
- Central government
- Regional / local government
- Specialist hydrogen equipment manufacturers

6. Additional References

17. L-H2 FUELLING STATION

1. HyWays Assumptions

The techno-economic data for the LH_2 filling stations for 2020 under HyWays (Linde LH_2 filling station selected for assumptions) is specified in the WP1/2 report.

2. Current state of the art – description

Low temperature liquid hydrogen must be handled very differently to compressed gaseous hydrogen. Liquid hydrogen storage at filling stations allows both LH2 and CGH2 vehicles to be fuelled from one source and its practicality for use in vehicles with liquid hydrogen tanks makes it common in demonstration projects (though GH_2 is more commonly used in OEMs than LH_2). Today the common Linde LH_2 – Filling Stations allow to fill the -254°C cold liquid into the vehicle tank without icing and to fuel several vehicles in immediate succession. The fueling itself is nearly as fast as today's filling stations for gas or diesel[xii].

3. Development goals

- Further decreases in fuelling time.

4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*

2010	2020	2030	2050
	x		

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?*
(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)

1	2	3	4	5
	x			

5. Broad Actor Group(s) involved

- Energy upstream / downstream
- Energy engineering

6. Additional References

F. END-USES

NB: HyWays assumes trends and bounds derived from institutes, automotive industry's and member states' expectations for market development in transport and stationary applications.

Generic key changes for the end-use segment must be expressed in relation to the penetration rates and cost trends set for the different scenarios (differently to the above sections, where key generic changes are expressed in relation to the global perceptions of technology status). A summary of the penetration rates for transport and stationary applications, and their different divisions between technologies for the HyWays High and Low scenarios are given in Contestabile (2005).

Basic R&D on fuel cells is not covered in detail.

18. HYDROGEN FUEL CELL VEHICLES (FCVs) AND FC HYBRID VEHICLES

1. HyWays Assumptions
Fuel Cell and FC Hybrid passenger cars, light commercial vehicles and buses considered in HyWays are divided into two categories according to the form of hydrogen that is used (liquid or gaseous). Their fuel consumptions and greenhouse-gas emissions are specified in the WP1/2 report.
2. Current state of the art – description
Predictions vary widely on the timing and penetration of FCVs into the market. Most automakers are predicting sometime after 2010, with the market requiring at least 5 to 8 years to develop after the introduction of the first commercial vehicle. PEM fuel cells in particular have emerged as the option with most potential for powering motor vehicles with hydrogen (whether stored as a liquid or gas). Technological improvements in the PEM fuel cell system are fast but low-cost, easy-to-manufacture stack designs and ancillary stystems are still a challenge. It is expected that it will take several production cycles to gain experience, establish reliability and achieve maturity. Demonstrations in North America (Canada, USA, California), Japan, the EU (in particular CUTE buses), Korea, Australia will lead to the existence of several hundred FCVs in fleets in the next years. [3] Garages, parking houses and tunnels need to be fitted with hydrogen leakage detectors.
3. Development goals
• Japanese FCV Performance Targets include 55-65% efficiency of stacks and over 500 km cruising distance [3]. This requires improvement of fuel cells and their integration into the vehicles and increased on-board storage capacity. • General fuel cell R&D in the US includes targets for a 60% efficient, durable,

direct hydrogen fuel cell power system for transportation at a cost of $45/kW (including hydrogen storage) by 2010 and $30/kW by 2015.[3]

- High temperature PEMFCs.
- The Strategic Overview Document released by the Hydrogen and Fuel Cell Platform in 2005 sets a cost target for Europe of <€100/kW for 150,000 vehicles/year.
- Cost reductions through engineering and increased sales volumes.

4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*

2010	2020	2030	2050
	x		

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?*
(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)

1	2	3	4	5
			x	

5. Broad Actor Group(s) involved

- Automotive
- Energy engineering
- Central government
- H2 equipment manufacturing

6. Additional References

19. HYDROGEN ICE VEHICLES (ICEVs) AND HYBRID ICEVs

1. HyWays Assumptions

ICE and ICE Hybrid passenger cars, light commercial vehicles and buses considered in HyWays are divided into two categories according to the form of hydrogen that is used (liquid or gaseous). Their fuel consumptions and greenhouse-gas emissions are specified in the WP1/2 report.

2. Current state of the art – description

Modifying gasoline engines to burn hydrogen fuel resulted until recently in lower power output, but optimized engines developed by some auto-makers are now opening the door to the use of hydrogen ICEs and point towards their role as entry vectors in the transition towards FCV penetration.

Various demonstrations of hydrogen ICE and hybrid vehicles (in particular, buses), have taken place in the last decade.

Garages, parking houses and tunnels need to be fitted with hydrogen leakage detectors.

3. Development goals

- Low NOx burning of hydrogen
- Increased on-board storage capacity

4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the “development goals”).*

2010	2020	2030	2050
	x		

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?*
(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)

1	2	*3*	4	*5*
		x		

5. Broad Actor Group(s) involved

- Automotive
- Energy engineering
- Central government

6. Additional References

20. CHP FUEL CELL SYSTEMS

1. HyWays Assumptions
Fuel Cell CHP systems considered in HyWays are divided into three categories according to their combination of outputs and by-products (e.g. electricity as main output and heat as by-product). The systems are connected to the grid or a boiler for exchange of electricity or heat in case of deficiency or excess power. Two capacities (2.5 kW_e and 50 kW_e) for FC CHP with hydrogen-fuelled peak boiler are considered.
2. Current state of the art – description
The major impediment for market penetration of stationary systems (mainly for CHP applications) is cost, especially since fuel cell stacks are still not well-suited to mass production techniques and contain significant quantities of noble metal catalyst 3. High temperature fuel cell types such as molten carbonate fuel cells (MCFCs) and solid oxide fuel cells (SOFCs) offer the potential for CHP generation. When the heat of electrochemical combustion is captured and used, total system overall fuel efficiencies can be as high as 80-85%.[xiii] MCFC systems do not require an external reformer to convert energy-dense fuels to hydrogen; these fuels are converted into hydrogen within the fuel cell itself. Although they are more resistant to impurities than other fuel cell types, future advances have yet to be made focusing on making MCFCs resistant enough to impurities from coal such as sulphur and particulates. The primary disadvantage of current MCFC technology is durability. The high temperatures at which they operate and the corrosivity of the electrolyte used accelerate component breakdown and corrosion, decreasing the cell life.[iii] Small scale CHP is expected to alleviate power draw from the grid rather than replace it. High temperature PEMFCs (operating temperature 160-180°C) offer the advantage of combination into polygeneration. The cooling cycle of the stack is above the minimum of 150°C required for advanced heat pumps. This offers the opportunity to create an efficient machine which provides electricity in combination with cooling and/or heating. Depending on the season (winter/summer) or location (south/north) such a machine can deliver the required mix on demand.
3. Development goals
• Developers are currently exploring corrosion-resistant materials for components as well as fuel cell designs that increase cell life without decreasing performance.[iii] • Development of combinations of fuel cell systems with integrated cooling and heating capabilities.
4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with*

any indications given in the "development goals").

2010	2020	2030	2050
	x		

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame?*
(1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)

1	2	*3*	4	*5*
		x		

5. Broad Actor Group(s) involved

- Energy engineering
- Real estate construction and management
- Specialist hydrogen equipment manufacturers
- Boiler industry

6. Additional References

21. CHP ICE SYSTEMS

1. HyWays Assumptions
Hydrogen ICE CHP systems considered in HyWays produce heat as a by-product.
2. Current state of the art – description
Engines for stationary CHP (from e.g. natural gas) can easily be converted to run on hydrogen. There is no information on projects demonstrating the small or large scale direct use of hydrogen as a fuel in CHP.
3. Development goals
• Low NOx burning of hydrogen
4a. Time frame for bulk of the key change – *Please mark with an X the time frame(s) that are envisaged for overcoming this key change (NB: these should be consistent with any indications given in the "development goals").*

2010	2020	2030	2050
	x		

4b. Generic Key Change solution difficulty assessment – *How would you rate the overall difficulty of achieving the above key change in the desired time-frame? (1 = Lowest difficulty allocation; 5 = Highest difficulty allocation)*

1	2	*3*	4	*5*
x				

5. Broad Actor Group(s) involved
• Energy engineering • Real estate construction and management • Boiler industry
6. Additional References

Annex 2: List of Member State Specific Key Change descriptions: Netherlands

HyWays
European Hydrogen Energy Roadmap

DELIVERABLE 3.10 ACTOR ANALYSIS

THE NETHERLANDS

Key Changes Summary Document

This Key Changes Summary Document describes identified Key Changes by hydrogen chain component. This is a vital step in the **qualitative analysis** of selected hydrogen chains, and is intended to add another layer of information to the process of constructing a national hydrogen roadmap in support of the quantitative input from the various models used in HyWays.

This document presents each Key Change description by chain component; when MS representatives are satisfied that the descriptions are accurate and representative of the MS specific context, the IDMEC team will integrate the revised descriptions into a Key Changes and Actor Mapping (KCAM) Excel spreadsheets.

Please remember that the Key Changes described in this document are Member State Specific Key Changes ONLY. Generic Key Changes (i.e. those relating to the techno-economic maturity of various technologies in general, for example, the techno-economic status of fuel cell cars) are NOT described here. Please also note that the descriptions provided here by the IDMEC team should be regarded as PRELIMINARY only. **We hope MS representatives will use their expert knowledge to make improvements. Besides being of practical benefit to the KCAM process, this activity also provides vital MS validation.**

For guidelines on how to make various allocations (e.g. Difficulty Allocation, associated Broad Actor Groups; primary dimension allocation etc.) please refer to the *MS Specific Key Changes Allocation Guidelines Document*. Brief instructions on filling in this document are provided throughout *in italics*.

We would ask you to carefully consider **DIFFICULTY ALLOCATIONS** for each Key Change. In the right hand column in the tables in Section D, please allocate an overall difficulty rating for 'overcoming' the Key Change (1 = Lowest difficulty; 5 = Highest difficulty). This is intended to be a subjective indication only. For further guidelines on Difficulty Allocations please refer to the *MS Specific Key Changes Allocation Guidelines Document.*

FEEDSTOCK / SOURCE

A. CHAIN COMPONENT DESCRIPTION

Natural gas

B. KEY CHANGE SHORT DESCRIPTION

Long term supplies of NG must be secured for domestic use.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER

1

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
1a					2
1b					
4a					
4b					
4c					
4d	-	-	-	-	
6a					
6b					

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

The Netherlands possesses the second largest share of Europe's natural gas reserves (34% of total reserves). Careful gas field exploitation management ("small fields" policy) will help ensure that domestic resources are likely to provide a significant contribution of supply until at least until 2030. Significant gas network connectivity between the Netherlands and Norway, the UK, Belgium, Germany and Russia will help ensure a smooth transition to a state of greater gas import dependency after 2030. The density of gas pipeline networks in the Netherlands is the highest in Europe, so primary fuel distribution is unlikely to be a limiting factor.

As the gas industries liberalise (with the exception of transport, which since the 1st January 2005 is under the direct control of the Netherlands government), the challenge will be to maintain the discipline and careful management of gas resources of the previous system but under full competition. It remains to be seen if competition will result in gas resource competition by efficiency increases and supply diversification. Other factors will be whether gas from the Groningen field is exploited for the benefit of domestic gas demand or used for export purposes, and also the long term impact of the liberalisation of the gas market. Competition effects and increases in production efficiency may produce low prices, which in turn might slow the development of small gas fields. Conversely, growth in demand (from the transport as well as industry sectors) together with the depletion of gas reserves after 2030 might produce rising prices which in turn might stimulate small gas field development.

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

The traditional careful approach to gas resource exploitation in the Netherlands should continue in order to lengthen the life of reserves. Policy measures will need to be put in place to ensure that the private sector does not sacrifice long term national supply security for short term export revenues. Next to this the exploration for new fields should continue, even if importing gas entails a smaller investment risk for gas companies. Gas prices should be carefully regulated to ensure that prices do not drop so low that small gas field exploitation becomes economically unattractive for developers. Geopolitical efforts to secure diverse supplies of gas from overseas should be maintained and expanded.

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
x			

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- Policy measures will need to be put in place to ensure that the private sector does not sacrifice long term national supply security for short term export revenues.
- When resources become shorter, regulatory policy may have to be developed for optimal allocation to electricity production, use as feedstock for chemical processes among others hydrogen production, use as transport fuel and use for heating in industry and households.

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	x
Energy engineering	
Infrastructure	x
Automotive	
Supranational government	
Central government	x
Regional government	x
Research, academia and consultancy	
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

IEA (2000) *Energy Policies of IEA Countries: The Netherlands 2000 Review*. Available Online at: http://www.iea.org/textbase/nppdf/free/2000/nether2000.pdf (accessed June 14th 2005).

FEEDSTOCK / SOURCE

A. CHAIN COMPONENT DESCRIPTION

Hard Coal

B. KEY CHANGE SHORT DESCRIPTION

Long term supplies of hard coal must be secured for domestic use.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER

2

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
3a					3
3b					

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

The Netherlands has no domestic hard coal production capacity, but imports around 18 Mtoe annually. This is achieved very inexpensively largely because of excellent harbour logistics (especially the harbours of Rotterdam and Amsterdam, which have large sites for stockpiling and blending). Coal firing power stations in the Netherlands have been retrofitted so that they are able to burn a wide range of coal qualities while maintaining relatively high environmental standards. The “Battle coal” programme, launched in 1994, promotes the blending of coal of inferior quality with that of higher quality to produce an acceptable blend. This policy, combined with a well-managed buying policy, has produced the lowest coal prices in Europe despite the lack of domestic supplies.

However the prospects for the coal firing power industry are limited by the high capital cost component of delivering new projects. Whilst existing stations are able to produce fairly clean energy at a low price, the newly-liberalised market favours smaller-scale, modular production options with smaller capital requirements, namely gas-based technologies such as CCGT. A further factor adversely influencing the economics of coal firing are taxes levied on CO_2 emissions, which differentiate between feedstock types and which penalise coal use the most. Coal-based capacity, currently representing below 40% of TPES, is thought to have already reached its maximum under the prevailing economic climate.

Whilst the Netherlands has been very successful in maintaining, despite the lack of exploitable domestic coal reserves, a cost competitive base-load coal firing ability, the long term prospects for coal are uncertain. The liberalisation of the power industry and arising forces such as the need to minimise capital expenditure on new plant, combined with the pressures exerted by CO_2-oriented policies, means that the commissioning of a new generation of coal firing stations is increasingly unlikely. Whilst it cannot be discounted (positive government intervention on the grounds of supply security, improvements in clean coal technology or CCS to alleviate the CO_2 tax burden, and rises in the price of natural gas are all possible opportunities the coal lobby might benefit from), the emergent free market structure appears to be bias against coal and so there may be shortages in coal supply for the purposes of hydrogen production from coal gasification from 2030 onwards unless remedial measures are taken.

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

The coal firing electricity industry is unlikely to face serious shortages in supply at least in the short term. The critical factor is that in the Netherlands, because of the very low coal prices and the stability of supply sources, supply itself is not a limiting factor, but demand is. Whilst coal firing plant remains profitable there will be no supply bottleneck. A more serious constriction to the future of coal firing is the cost of building new plant. In the short-medium term, existing plant can be retrofitted and adapted to keep step with evolving CO_2-oriented tax burdens. Building a new generation of coal firing plant will prove a greater challenge because of the economic models favoured by the private sector which favour formats which yield shorter payback periods. However, when the older coal fired plant reaches decommissioning age, there may be a shortfall in base load capacity, or a base load capacity based on CCGT technology which is subject to comparatively volatile gas markets. Policies to ensure the long term survival of some coal firing capacity is likely to necessitate governmental involvement as the private sector's priorities are different and not necessarily as closely aligned with the best national interest. The coal lobby itself must play a part in promoting the performance and image of coal firing technologies, as well as investigating a new role for coal – namely that of stimulating the initial take-up of hydrogen infrastructures.

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
	x		

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- The successful policies which have yielded a very low cost of coal should be maintained.
- RD&D into clean coal production methods, as well as integrated CCS schemes, should be pursued with the intention of minimising the CO_2 tax burden on coal firing plant.
- Capital allowances, feed-in tariffs and similar financial mechanisms should be extended to the commissioning of new coal plants which operate within specified environmental performance parameters.
- Policy and market mechanisms should increasingly reflect the intrinsic worth of sources which provide a greater degree of national energy supply security. The same is true of technologies which might provide, in the short term, a cheap 'kick start' for the development of hydrogen infrastructures, even if they do not produce electricity with the lowest emissions.
- Social acceptance and 'image problems' associated with coal firing should be targeted.

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	x

Energy engineering	x
Infrastructure	x
Automotive	
Supranational government	
Central government	x
Regional government	
Research, academia and consultancy	x
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

IEA (2000) *Energy Policies of IEA Countries: The Netherlands 2000 Review*. Available Online at: http://www.iea.org/textbase/nppdf/free/2000/nether2000.pdf (accessed June 14th 2005).

FEEDSTOCK / SOURCE

A. CHAIN COMPONENT DESCRIPTION

Off shore wind electricity

B. KEY CHANGE SHORT DESCRIPTION

Significant increase in contribution of offshore wind power for electricity generation must be realised and surplus electricity must be made available for hydrogen production.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER | 3 |

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
2a					4
2b					

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT
Please describe below the nature of the identified MS Specific Key Change:

An investigation into off shore wind potential in the Netherlands Exclusive Economic Zone (EEZ) in the North Sea estimates that for the 56,000 Km_2 of the Dutch EEZ, more than 30,000 are potentially available for offshore wind exploitation. This would, in theory, suffice for 4-5 times the national electricity of the Netherlands. Furthermore it was estimated that some 10% of the electricity consumption of the Netherlands can be generated by off shore wind energy at a cost price of 10 euro cents or less. The Netherlands currently has a target for installed off shore wind capacity of 6 GW for offshore wind capacity by 2020. Several feasibility / environmental studies are currently underway or have been carried out. Two wind farms have been developed in Ijsselmeer (Lely [2 MW] and Dronten I [16.8 MW]). A 100 MW demonstration wind farm is planned at Egmond an Zee.

The Dutch government is currently investing in off shore demonstration projects, has established an energy tax on fossil electricity (REB) from which RES is exempted and a subsidy scheme for clean electricity generation (MEP), and has also initiated the “BLOW” covenant agreed in 2001 by the 12 provinces to make a greater commitment to on shore wind power and overcome problems with installing capacity linked to integration and spatial planning. The success of these schemes will make a significant impact on the prospects for wind power in the Netherlands. In 2005 the Dutch government froze the MEP subsidy scheme for RES because its success made it too expensive, meaning a set-back for the off shore wind initiatives which were counting on these subsidies. Some kind of new subsidy scheme is likely to be implemented. It remains to be seen if how the balance between on shore and off shore wind investment will develop.

The power produced by the wind is fed into the national grid as this will yield the highest CO2 cost effectiveness. But surplus electricity can be made available for hydrogen production by electrolysis.

F. REQUIRED ACTION
Please describe below possible remedial actions to realise the MS Specific Key Change:

The Dutch government has made some progress developing wind power, and the Egmond an Zee farm will constitute a major achievement in off shore wind power. However the government needs to ensure that a balance between on shore wind development and off shore wind development is struck where one does not marginalise the other. Whilst on shore wind is boosted by the BLOW Covenant, off shore wind has no corresponding dedicated policy besides the catch-all REB and the now-frozen MEP. Policy measures should be established which reward off shore wind exploitation specifically (e.g. in a new MEP). Doing nothing until the basic technology reaches favourable cost competitiveness should be avoided; besides supportive market instruments, other activities such as continued assessment of off shore wind exploitation potential should be carried out.

It needs to be ascertained that surplus electricity is actually used for hydrogen production and not used for some form of energy storage.

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
x			

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- Subsidy scheme for RES for electricity
- Quicker planning and licensing processes for developing off shore wind projects

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	x
Energy engineering	x
Infrastructure	
Automotive	
Supranational government	
Central government	x
Regional government	x
Research, academia and consultancy	
Civil society and NGOs	x
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	

Other (please state)

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

IEA (2002) *Energy policies of IEA countries*. Available online at: http://www.iea.org/textbase/nppdf/free/2000/netherl_comp02.pdf (accessed 14th June 2005).

Kooijman, H.J.T., de Noord, M., Volkers, C.H., Machielse, L.A.H., Hagg, F., Eecen, P.J. and Herman, S.A. (2001) *Cost and Potential of Offshore Wind Energy on the Dutch part of the North Sea*, ECN and Stork Product Engineering. Available online at: http://www.ecn.nl/docs/library/report/2001/rx01063.pdf (accessed 14th June 2005)

European Wind Energy Association. Available online at: http://www.ewea.org/documents/0927-Offshore%20WD%20FINAL.pdf (accessed 14th June 2005)

FEEDSTOCK / SOURCE

A. CHAIN COMPONENT DESCRIPTION

Biomass

B. KEY CHANGE SHORT DESCRIPTION

Adequate and economic supplies of biomass must be secured for domestic power production purposes.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER

4

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
5a					3
5b					

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

Biomass currently represents the Netherlands' greatest RES contribution to TPES (constituting around 77% of all inland RES production). Although the share of biomass is expected to remain higher than any other RES until 2030, its annual growth rate is expected to steadily decline from 4.7% annual growth between 2000 and 2010 to just 1.7% annual growth between 2020 and 2030 (European Energy and Transport – trends to 2030). Biomass-based CHP is eligible for the MEP (Environmental Quality of Electricity Production) subsidy scheme.

The Biomass Action Plan (2004) suggested that in principal there would be no shortage of biomass until 2010, but thereafter importing biomass would be unavoidable (though in practice this is already happening).

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

By the envisaged timeframes for biomass gasification, it is likely that biomass supplies will have to be imported. Priority efforts should be made to encourage biomass importation, perhaps by extending pro-RES policy measures to encapsulate the transportation of biomass. Domestic reserves of biomass should also be developed and existing sources of supply should be managed in a sustainable manner. In order to maintain sufficient supplies of biomass, demand side issues will also need to be addressed. Barriers associated with power generation from biomass (related mainly with emissions control) will need to be addressed in order to maintain an adequate level of demand.

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
X			

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC
Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION
Please briefly describe below suggested policy measures which might realise the Key Change:

- As biomass can also be used in cofiring and for producing liquid biofuels, there will be competition for biomass which may drive up the price. Governments may leave the biomass price to the market or interfere by developing a strategy for optimal allocation of biomass to the three options (cofiring, biofuels, hydrogen) based on maximum CO2 reduction.
- Import of biomass from non-EU countries may encounter EU trade thresholds, or EU levies that make the imported biomass more costly. Government action should be aimed at influencing or adapting the EU policies in this respect.

J. ASSOCIATED BROAD ACTOR GROUPS
Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	x
Energy engineering	
Infrastructure	
Automotive	
Supranational government	
Central government	x
Regional government	
Research, academia and consultancy	
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	x
Specialist H2 equipment manufacturing	
Agriculture and forestry	x
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES
Please list any used / recommended relevant references or sources:

Renewable Energy Policy Review (2004) *The Netherlands*, Altener, European Renewable Energy Council, Brussels, Belgium. Available online at:
http://www.erec-renewables.org/documents/RES_in_EUandCC/Policy_reviews/EU_15/Netherlands_policy_final.pdf (accessed 14th June 2005).

Raats, M. (2004) *Biomass CHP and district heating: evaluation of the policy and legal frameworks and barriers of biomass CHP/CHP in the Netherlands*, OPET, SenterNovem, Netherlands. Available online at:
www.opet-chp.net/download/wp3/wp3biomasschpsurveynetherlands.pdf (accessed 14th June 2005).

PRODUCTION PROCESS

A. CHAIN COMPONENT DESCRIPTION

NG SMR decentral

B. KEY CHANGE SHORT DESCRIPTION

Lack of NG decentralised SMR plants must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER

5

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
1a	■	■			3
1b		■	■		

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

Netherlands has a highly dense NG distribution infrastructure and plentiful domestic gas reserves at least until 2030 so supplying SMR plant with NG will not be problematic at least until the longer term.

The Netherlands has considerable experience of hydrogen production by means of NG SMR, and existing capacity is centred in the Rijnmond/Botlek industrial areas. Hydrogen produced from NG SMR processes cater to a number of industrial applications, including chemical feedstocks, hydrogenation processes, high temperature flames and furnace atmospheres. Existing capacity currently includes both centralised and decentralised NG SMR, with decentralized capacity predominantly on-site production for dedicated industrial consumption. The development of more decentralised NG SMR capacity which supplies local grids is perhaps dependent upon investment in grids rather than on the availability of the production capacity itself.

Decentralised gas-based power generation as a general format is very well established in the Netherlands, and around one-third of domestic electricity generation is produced in this way. So, the development of further decentralised NG SMR capacity will not be hindered by the lack of decentralised electricity generation capacity.

Despite the fact that efficiency of production depends upon scale, the influence of scale on efficiency is smaller in the case of the production of hydrogen then in the case of electricity production. It has been asserted that on-site production will predominate in the less densely populated areas, whilst the more densely populated areas in the western part of the country will see a mix of both central and decentral formats. (MoM - MS Workshop I).

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

The Netherlands already has a significant proportion of its electricity generated by decentralised NG-fed plant. It also has (relatively) considerable experience at decentralised NG SMR. It is likely that decentralised SMR capacity could be increased by retrofitting existing NG plant with

SMR equipment. Policy efforts should be made to reward hydrogen production, perhaps in the same way that conventional NG CHP was successfully encouraged in the Netherlands in the 1990s. Another important area will be ensuring that codes and standards are in place to facilitate an expansion of hydrogen production and storage.

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
	x		

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
x			

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- Quicker planning and licensing processes for developing projects
- The installation of so called "hydrogen try out regions" to introduce and test hydrogen applications. These regions also function to test hydrogen regulations and standards, and to discover remaining gaps in the field. Assessment and monitoring are therefore key elements in such regions.

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	
Energy engineering	x
Infrastructure	x
Automotive	
Supranational government	
Central government	
Regional government	x
Research, academia and consultancy	
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

Hemmes, K., de Groot, A. and den Uil, H. (2003) *Bio-H2: Application potential of biomass related hydrogen production technologies of the Dutch energy infrastructure of 2020-2050*, ECN, Petten, Netherlands.

PRODUCTION PROCESS

A. CHAIN COMPONENT DESCRIPTION

NG SMR central

B. KEY CHANGE SHORT DESCRIPTION

Lack of NG central SMR plants must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER

6

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
4a			■	■	2
4b			■	■	
4c		■			
4d	-	-	-	-	
6a	■	■			
6b	■				

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

Netherlands has a highly dense NG distribution infrastructure and plentiful domestic gas reserves at least until 2030 so supplying SMR plant with NG will not be problematic at least until the longer term.

The Netherlands has considerable experience of hydrogen production by means of NG SMR, and existing capacity is centred in the Rijnmond/Botlek industrial areas. Hydrogen produced from NG SMR processes cater to a number of industrial applications, including chemical feedstocks, hydrogenation processes, high temperature flames and furnace atmospheres. Existing capacity currently includes both centralised and decentralised NG SMR. Nominally centralised production exists, supplying bulk quantities (e.g. 50,000 Nm^3/hour) of low purity (99%) hydrogen to industrial consumers via two dedicated pipelines (one connecting industries in the Rijnmond region, and one connecting the Netherlands to the north of France). NG SMR production of a capacity suitable in scale for centralised generation is already in place in the area, though there remains an absence of an extensive hydrogen pipeline network to make true centralised generation possible and widespread.

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

Large scale NG SMR is already a well established method of hydrogen production in the Netherlands. Steps must be taken to ensure that adequate hydrogen is available for domestic use rather than for export revenue. Market instruments might be established by government to stimulate investment in hydrogen production by industry, though this should happen in proportion to rising demand in any case. The concentration of large scale NG SMR plant in the Rijnmond industrial area might be further expanded but growth is perhaps limited mostly by pipeline capacity and geographic reach of the network.

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
	x		

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- Market instruments established by government to stimulate investment in hydrogen production by industry
- Quicker planning and licensing processes for developing projects
- The installation of so called "hydrogen try out regions" to introduce and test hydrogen applications. These regions also function to test hydrogen regulations and standards, and to discover remaining gaps in the field. Assessment and monitoring are therefore key elements in such regions.

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	
Energy engineering	x
Infrastructure	x
Automotive	
Supranational government	
Central government	x
Regional government	x
Research, academia and consultancy	
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

Hemmes, K., de Groot, A. and den Uil, H. (2003) *Bio-H2: Application potential of biomass related hydrogen production technologies of the Dutch energy infrastructure of 2020-2050*, ECN, Petten, Netherlands.

PRODUCTION PROCESS

A. CHAIN COMPONENT DESCRIPTION

Electrolysis

B. KEY CHANGE SHORT DESCRIPTION

Lack of centralised electrolysis plant must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER 7

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
2a		■	■		2
2b		■	■		

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT
Please describe below the nature of the identified MS Specific Key Change:

The Netherlands has significant practical and commercial experience with industrial-based electrolysis. Commercial wind-based electrolysis has yet to be deployed but the Netherlands is in a good position to adapt previously tested methods of electrolysis to wind RES. Achieving cost-competitive hydrogen production compared to fossil-based methods such as natural gas SMR is likely to depend upon legislative intervention which rewards no carbon production over fossil-based low-carbon production.

There is a strong consensus amongst MS stakeholders that hydrogen will only be produced from wind-RES if electricity cannot be supplied to the grid either because the grid is too weak (unlikely, at least in the short-medium term) or because demand is too low. It was asserted that hydrogen production would be used as a way to manage wind-generated electricity (e.g. load levelling), and not vice-versa. ((MoM – MS Workshop I). If hydrogen production is dependent upon wind electricity production and policy (and not wind production being dependent upon hydrogen production and policy), there will be an inherent degree of uncertainty built into this hydrogen supply chain; hydrogen production would be a secondary concern only and this might deter investors in production plant and potential hydrogen customers alike.

F. REQUIRED ACTION
Please describe below possible remedial actions to realise the MS Specific Key Change:

Research into integrating wind electricity, electrolysis plant and hydrogen storage into local electricity networks to optimise the efficiency of such systems could provide potential investors with greater confidence in their cost effectiveness. If hydrogen production is a secondary concern in such systems (and electricity put straight onto the electricity distribution / transmission system is the primary concern) then investors will need reassurance that electrolysis plant will be operational for sufficient periods to justify the investment. Further research and demonstration into optimising wind/electrolysis hybrid systems will help provide potential investors with this reassurance.

G. PRIMARY DIMENSION ALLOCATION
Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
	x		

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- Facilitate off shore wind parks and stimulate solutions for load levelling (by hydrogen production) as a measure to ' protect' investements in the wind parks

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	
Energy engineering	x
Infrastructure	
Automotive	
Supranational government	
Central government	x
Regional government	x
Research, academia and consultancy	x
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	x
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

PRODUCTION PROCESS

A. CHAIN COMPONENT DESCRIPTION

Hard coal gasification

B. KEY CHANGE SHORT DESCRIPTION

Lack of hard coal SMR plants must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER

8

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
3a			■	■	3
3b				■	

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

The attractiveness of using coal as a feedstock for hydrogen production (with CC&S) in the mid-term is limited by the availability of commercial technologies that allow a roll-out of gasification plants. A strategy must be drawn from existing plants and experience. One coal gasification plant is already in place in the Netherlands, but there is no information on any activities related to hydrogen production, nor to integration of CC&S. The Demkolec plant in Buggenum is one of the world's longest-standing projects. The plant is a 253 MW (net) IGCC utilizing a Shell gasifier to gasify 2,000 metric tons of coal per day. The plant served as an EU demonstration plant during initial years of operation and was used to test different operating conditions and various feedstock with commercial scale. This experience is an important asset. Recently, there has been interest in altering the fuel mix at Buggenum to include biomass as well as coal and to possibly produce hydrogen in addition to electricity.

Another key change for the integration of coal gasification plants is the study of their integration into the grid system in an efficient way.

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

RD&D activities into hard coal gasification should continue; a solid base and experience has already been achieved and this should be actively built upon. In addition, RD&D into subsequent hydrogen generation (and CCS) in such plant should be commenced. Government intervention to promote a "flagship" combined hard coal gasification/hydrogen production/CCS project might be valuable in kick-starting industrial commitment to such systems ('Zero Emission Power Plant').

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an 'X':

Political / Institutional	Techno-economic	Social	Infrastructural
	x		

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- Promote a "flagship" combined hard coal gasification/hydrogen production/CCS project might be valuable in kick-starting industrial commitment to such systems ('Zero Emission Power Plant').

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	x
Energy engineering	x
Infrastructure	x
Automotive	
Supranational government	
Central government	x
Regional government	
Research, academia and consultancy	x
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

Nuon Corporate website. Available online at
http://corporate.nuon.com/en/index.jsp?mode=flash
(Accessed 12th Sept 2005).

PRODUCTION PROCESS

A. CHAIN COMPONENT DESCRIPTION

Biomass gasification central

B. KEY CHANGE SHORT DESCRIPTION

Lack of biomass gasification plants must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER | 9 |

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
5a					3
5b					

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

Under its Bio-hydrogen Platform, the Netherlands has a number of hydrogen production from biomass R&D projects already in operation, involving a collaborative effort of 11 Dutch institutes and universities. Activities are currently focusing on pyrolysis and supercritical water gasification.

At the present time there is a significant amount of biomass electricity generation in the Netherlands, though the majority of this is small-scale decentralised CHP plant. Centralised biomass generation is usually carried out in combination with coal-based generation in dual-firing mode. However, there is currently no commercial capacity for the production of hydrogen by means of biomass gasification, and time will be required to build up this capacity.

Achieving centralised (large scale) biomass generation capacity will involve a number of steps, including commissioning large scale biomass plant, adapting such plant for hydrogen production by means of gasification, and installing a supporting hydrogen distribution pipeline network. The Biomass Action Plan (2004) identified a number of problems in initiating bio energy projects, including in the areas of licensing procedures surrounding the commissioning of bio energy plant and administrative action. The main problem was found to be the fact that such projects have to comply with legislation on emissions, waste and fertilizers. These bottlenecks will have to be overcome if large scale biomass gasification is to become a commercial viability.

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

Whilst the Netherlands has considerable experience in conventional biomass electricity generation, the subsequent production of hydrogen from biomass should continue to be a RD&D priority. Subsidised proof-of-concept projects would generate experience and provide confidence for private sector investment. In addition the legislative “bottleneck” identified in the Biomass Action Plan associated with conventional biomass generation need to be satisfactorily addressed, or incentives for biomass generation which outweigh existing disincentives need to be put in place.

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
x			

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- Bottlenecks with compliance with legislation on emissions, waste and fertilizers will have to be overcome

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	x
Energy engineering	x
Infrastructure	
Automotive	
Supranational government	x
Central government	x
Regional government	
Research, academia and consultancy	
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

Hemmes, K., de Groot, A. and den Uil, H. (2003) *Bio-H2: Application potential of biomass related hydrogen production technologies of the Dutch energy infrastructure of 2020-2050*, ECN, Petten, Netherlands.

IEA (2004) Hydrogen and Fuel Cells – Review of National R&D Programs, Paris, France.

CARBON CAPTURE AND STORAGE

A. CHAIN COMPONENT DESCRIPTION

Carbon Capture and Storage is used.

B. KEY CHANGE SHORT DESCRIPTION

Lack of commercial CCS experience and tested facilities must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER **10**

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
3a					5
3b					
4a					
4b					
4c					
4d	-	-	-	-	
5a					
5b					

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

Whilst CCS experience in the Netherlands is as yet limited, the potential is thought to be large. The Netherlands has significant potential for storage in onshore and offshore aquifers, onshore and offshore gas fields, and onshore coal fields. Transport remains a potential barrier, and it is likely that storage sites will not be exploited economically until a central CO_2 grid is constructed. Early transport by boat is possible. Investment in CCS technology development is comparatively low in the Netherlands, however, so technology transfer is perhaps a prime option for introducing CCS technology. Regarding the specific application of CCS technology, however, work has been carried out by Novem on the technical and economic feasibility of enhanced coal-bed methane recovery (ECBM) in the Netherlands.

It was suggested in the 1st HyWays workshop that CCS will require a degree of social acceptance amongst the wider public, and that in turn this represents a political risk. However it is also seen as a relatively long-term option, so it is likely that there is time with which to win over public acceptance of this technology. (MoM – MS Workshop I). Implementing CCS in short term timeframes will certainly be a technical and economic challenge.

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

Continued RD&D into CCS applications in the Netherlands is essential. The Netherlands has significant natural assets which could be used for CCS but further surveys and tests need to be carried out. Government could play a role in encouraging industry (especially those with oil and gas exploitation interests) to invest in research projects. Demonstration projects will be essential to boost industry and public confidence in the technological potential. Gaining social acceptance should also be a priority, especially where on shore storage sites are being considered. Safety codes and standards will need to be in place as soon as possible. It is likely that CCS will be applied mainly to coal burning plant, which is thought to become a viable option after 2030 – CCS technology and experience should aim to be market tested by this timeframe. Potential financial benefits arising from carbon trading should be investigated in detail in the context of specific project financing of CCS projects in the Netherlands.

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
	x		

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- Promote RD&D into CCS applications in the Netherlands to gain experience, develop public acceptance and set safety codes and standards.

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	x
Energy engineering	
Infrastructure	x
Automotive	
Supranational government	
Central government	x
Regional government	x
Research, academia and consultancy	x
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

IEA (2004) Hydrogen and Fuel Cells – Review of National R&D Programs, Paris, France.

More information on Carbon sequestration	Website	Internet	www.cleanfuels.novem.nl	more sources are available , e.g. on website ministry of Economic Affairs
Removal of CO2 by Storage in the Deep Underground, Chemical Utilization and Biofixation. Options for the Netherlands	1999	Novem	downloadable from www.cleanfuels.novem.nl	

FIRST CONVERSION

A. CHAIN COMPONENT DESCRIPTION

Liquid hydrogen production

B. KEY CHANGE SHORT DESCRIPTION

Lack of liquefaction plants must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER **11**

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
4c		■			1

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT
Please describe below the nature of the identified MS Specific Key Change:

Liquefaction is an established technology. While improved energy efficiency of the process is needed, liquefaction is only of temporary importance in the process of hydrogen introduction in the Netherlands, so it does not require massive investments for improvement.

F. REQUIRED ACTION
Please describe below possible remedial actions to realise the MS Specific Key Change:

Improvements in energy efficiency are a priority.

G. PRIMARY DIMENSION ALLOCATION
Please mark ONE box with an 'X':

Political / Institutional	Techno-economic	Social	Infrastructural
	x		

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC
Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
			x

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION
Please briefly describe below suggested policy measures which might realise the Key Change:

None

J. ASSOCIATED BROAD ACTOR GROUPS
Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	
Energy engineering	**x**
Infrastructure	
Automotive	
Supranational government	
Central government	
Regional government	
Research, academia and consultancy	
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	**x**
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

HYDROGEN TRANSPORT

A. CHAIN COMPONENT DESCRIPTION

G-H2 pipeline

B. KEY CHANGE SHORT DESCRIPTION

Lack of sufficient G-H2 transport pipelines must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER

12

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
2a		■	■		3
2b		■	■		
3a			■	■	
3b				■	
4a			■	■	
4b			■	■	
5a			■	■	
5b			■	■	
6a	■	■			
6b	■				

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

The development of pipeline infrastructure is under study in the Infrastructure Analysis section of HyWays (also carried out preliminary by ECN in Dec 2004, indicating that the most densely populated Western region will be more likely to have central production with pipeline distribution). The key economic, regulatory and urban planning changes need to be evaluated on this basis.

The Netherlands have a portion of the 879km hydrogen pipeline network operated by Air Liquide in the Netherlands, France and Belgium. Air Products also operates a 30-mile, 50,000-kg/day pipeline in the Netherlands.

Any key changes in this area need to be analysed in parallel with the needs of GH2-NG pipelines (as explained below, Gasunie Research coordinate Naturalhy, a program to test distribution of hydrogen, mixed with natural gas, in existing natural gas pipelines).

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

Pilot projects demonstrating the practicality and safety of GH2 pipelines in urban areas would increase investor confidence in the technology, though this is perhaps less important (due to the current existence of large-scale GH2 pipes) than gaining widespread public acceptance of the technology and achieving local construction approval. Whilst industry will respond to a future demand for hydrogen if it arises, government could encourage construction by deploying market instruments such as, for example, tax exemptions for hydrogen transport technologies or capital allowances.

G. PRIMARY DIMENSION ALLOCATION
Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
	x		

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC
Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION
Please briefly describe below suggested policy measures which might realise the Key Change:

- Promote pilot projects demonstrating the practicality and safety of GH2 pipelines in urban areas.
- Encourage pipelines construction by deploying market instruments such as, for example, tax exemptions for hydrogen transport technologies or capital allowances.

J. ASSOCIATED BROAD ACTOR GROUPS
Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	x
Energy engineering	x
Infrastructure	x
Automotive	
Supranational government	x
Central government	
Regional government	
Research, academia and consultancy	x
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES
Please list any used / recommended relevant references or sources:

HYDROGEN TRANSPORT

A. CHAIN COMPONENT DESCRIPTION

L-H2 truck

B. KEY CHANGE SHORT DESCRIPTION

Lack of required L-H2 trucks must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER 13

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
4c					1

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT
Please describe below the nature of the identified MS Specific Key Change:

Companies like Air Products use LH2 trucks in the Netherlands. This technology is well established. Delivery by truck is expected to take place to short-distances from production plants, or for isolated remote fuelling stations in motorways. The Infrastructure Analysis study will shed light on the needs for short-distance transport. It is expected that this option is of temporary importance in the process of hydrogen introduction in the Netherlands, so it does not require massive investments for improvement.

It was mentioned in the first MS Workshop that the acceptance of this transport option will depend on the assessment of the amount of truck movements needed (hazardous goods regulation).

F. REQUIRED ACTION
Please describe below possible remedial actions to realise the MS Specific Key Change:

Assessment of the amount of truck movements needed and if necessary come to covenant about safety (ref. LPG covenant 2005).

G. PRIMARY DIMENSION ALLOCATION
Please mark ONE box with an 'X':

Political / Institutional	Techno-economic	Social	Infrastructural
	x		

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC
Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

None.

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	**x**
Energy engineering	**x**
Infrastructure	
Automotive	**x**
Supranational government	
Central government	**x**
Regional government	
Research, academia and consultancy	
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

HYDROGEN TRANSPORT

A. CHAIN COMPONENT DESCRIPTION

G-H2-NG pipeline

B. KEY CHANGE SHORT DESCRIPTION

Lack of experience and investment in H2-NG admixing and separation technology must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER

14

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
4d	-	-	-	-	4

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

The dense nature of the Netherlands' gas supply network is considered to provide a strong future opportunity for admixing, as mentioned in the 1st MS Workshop. Ownership of gas distribution pipelines is with the State, which would reduce potential difficulties presented by multi-party ownership as policies can be applied uniformly, given favourable political will. Research into gas-hydrogen mixing is at an advanced stage in the Netherlands, with the pursuit of projects such as Greening of Gas (VG2) and NATURALHY (Coordinated by Gasunie). There is also governmental interest in the admixture option in the Dutch energy transition project of the Ministry of Economic Affairs.

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

As ownership of the gas distribution network lies with the State, the government is in a position to implement any retrofitting of pipes for the purposes of admixing with hydrogen with a high degree of efficiency. There exists some government support for the admixture option. The challenge is now to establish long term demonstration projects and experience in both adapting existing pipelines as well as in operating them on admixture. Funding for adapting the network to accept admixing in advance of hydrogen demand is vital so that early demand will not be restricted by any lack of admixture capability. Local planning permissions may also be required. Innovative funding initiatives in order to spread the high initial capital costs of retrofitting NG pipes may also be an option – and mechanism such as public-private partnerships should be considered.

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
x			

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION
Please briefly describe below suggested policy measures which might realise the Key Change:

- Establish demonstration projects in adapting existing pipelines and operating them on admixture.
- Funding for adapting the network to accept admixing in advance of hydrogen demand.
- Innovative funding initiatives in order to spread the high initial capital costs of retrofitting NG pipes, e.g. public-private partnerships.

J. ASSOCIATED BROAD ACTOR GROUPS
Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	
Energy engineering	x
Infrastructure	x
Automotive	
Supranational government	
Central government	x
Regional government	x
Research, academia and consultancy	x
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES
Please list any used / recommended relevant references or sources:

IEA (2004) Hydrogen and Fuel Cells – Review of National R&D Programs, Paris, France.

Vergroening Van Gas (VG2)project	Website	Internet	www.vg2.nl	Various downloadables about mixing hydrogen into natural gas grid
(Vergroening Van Gas) VG2 conference 19 January 2005	2005	Copies of presentations	Downloadable from www.vg2.nl	

LOCAL HYDROGEN DISTRIBUTION SYSTEM

A. CHAIN COMPONENT DESCRIPTION

G-H2 Fuelling station

B. KEY CHANGE SHORT DESCRIPTION

Lack of G-H2 fuelling stations must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER

15

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
1a	■	■			2
2a		■	■		
3a			■	■	
4a			■	■	
5a			■	■	
6a	■	■			

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

Gaseous hydrogen fuelling stations will have similar requirements whether they are supplied from on-site or centralised production plants. The form of delivery (liquid or gaseous hydrogen) will influence the need for different compressor and storage equipment at the stations. The approximate needs for fuelling stations will be elucidated from the Infrastructure Analysis study. See LH2 station section for further considerations on developing the network.

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

Potential owner/operators of GH2 fuelling stations should be encouraged to enter the market by favourable licensing conditions supplied by government. License conditions need to be determined in advance and should follow those for “conventional” fuelling stations as much as is possible. Codes, standards and responsibilities need to be developed and clearly communicated to potential owners of GH2 fuelling stations. Planning approval will have to be secured from local authorities. Another priority is gaining public acceptance and increasing their knowledge of the practical aspects of such technology. Responsibility for this can be shared by government as well as private owner/operators of plant, and hydrogen association could also play a role. Close collaboration in the deployment of GH2 fuelling stations with the automobile industry would yield synergistic efficiencies.

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an ‘X’:

Political / institutional	Techno-economic	Social	Infrastructural
	x		

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- Quick licensing and planning approval procedures. Issuing favourable licensing conditions to potential owner/operators of GH2 fuelling stations. Set clear codes and standards.

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	x
Energy engineering	
Infrastructure	x
Automotive	x
Supranational government	
Central government	x
Regional government	x
Research, academia and consultancy	
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

LOCAL HYDROGEN DISTRIBUTION SYSTEM

A. CHAIN COMPONENT DESCRIPTION

Local G-H2 grid

B. KEY CHANGE SHORT DESCRIPTION

Lack of local G-H2 grids must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER **16**

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
1b		■	■		4

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT
Please describe below the nature of the identified MS Specific Key Change:

In the Netherlands, 98 % of the houses have a connection to a gas-grid with a long technical life-time. Since gas and biogas will continue to be dominant in the Dutch energy household during the next decades, the demand for hydrogen in residential or other stationary areas where CHP systems are being developed needs to be determined before evaluating the barriers for hydrogen grids.

F. REQUIRED ACTION
Please describe below possible remedial actions to realise the MS Specific Key Change:

Codes, standards and responsibilities must be settled at central government level. Local planning permissions might be required. Private investors should be encouraged through demonstration projects as well as the deployment of favourable market instruments. Public acceptance will need to be gained if local GH2 grids are installed in residential areas.

G. PRIMARY DIMENSION ALLOCATION
Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
x			

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC
Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
x			

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION
Please briefly describe below suggested policy measures which might realise the Key Change:

- Local planning permissions; codes, standards and responsibilities
- Promotion of demonstration projects
- Deployment of favourable market instruments

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	**x**
Energy engineering	**x**
Infrastructure	**x**
Automotive	
Supranational government	
Central government	**x**
Regional government	**x**
Research, academia and consultancy	
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

Bousardt, R et al (200x) Elements of sustainable energification on a town-district level in the Netherlands. Available online at: http://www.worldenergy.org/wec-geis/publications/default/tech_papers/17th_congress/1_1_21.asp (accessed 16 June 2005).

LOCAL HYDROGEN DISTRIBUTION SYSTEM

A. CHAIN COMPONENT DESCRIPTION

Distribution Centre (DC) + mini grid

B. KEY CHANGE SHORT DESCRIPTION

Lack of distribution centres and connected mini grids must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER

17

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
1b					3
2b					
3b					
4b					
5b					
6b					

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

In the Netherlands, 98 % of the houses have a connection to a gas-grid with a long technical life-time. Since gas and biogas will continue to be dominant in the Dutch energy household during the next decades, the demand for hydrogen in residential or other stationary areas where CHP systems are being developed needs to be determined before evaluating the barriers for hydrogen grids.

In addition, the requirement for distribution centres (DCs) of this format will further entail issues associated with storing relatively large amounts of H2 within or close to population centres. This raises the necessity (beyond techno-economic Generic Key Changes) for further national development of codes and standards, for local planning permissions, and also winning public acceptance of such DCs.

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

Codes, standards and responsibilities must be settled at central government level. Local planning permissions might be required. Private investors should be encouraged through demonstration projects as well as the deployment of favourable market instruments. Public acceptance will need to be gained if distribution centres and mini GH2 grids are installed in residential areas.

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural

x			

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
x			

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- Local planning permissions
- Codes, standards and responsibilities
- Promotion of demonstration projects
- Deployment of favourable market instruments.

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	x
Energy engineering	x
Infrastructure	x
Automotive	
Supranational government	
Central government	x
Regional government	x
Research, academia and consultancy	
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

Bousardt, R et al (200x) Elements of sustainable energification on a town-district level in the Netherlands. Available online at: http://www.worldenergy.org/wec-geis/publications/default/tech_papers/17th_congress/1_1_21.asp (accessed 16 June 2005).

LOCAL HYDROGEN DISTRIBUTION SYSTEM

A. CHAIN COMPONENT DESCRIPTION

L-H2 fuelling station

B. KEY CHANGE SHORT DESCRIPTION

Lack of L-H2 fuelling stations must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER

18

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
4c		■			2

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

The Netherlands has a density of fuelling stations above the EU average, with a total of around 4000 stations. Licenses for fuelling stations are auctioned, with licenses lasting 15 years. Ownership is predominantly in the hands of 4 major oil companies, and it remains to be seen if a future network of hydrogen stations would be owned by oil companies or by new market entrants specifically interested in hydrogen supply. If oil companies decide to resist the spread of hydrogen fuelling stations their deployment may be retarded in an absence of legislative safeguards or pro-hydrogen incentives.

Supply to LH2 fuelling stations would be predominantly by cryo-truck, which are expected to be cost effective before sufficient demand volumes to justify GH2 fuelling stations with connected pipeline networks are installed. The LH2 format is also suitable for remote stations as the costs of cryo-truck resupply are expected to be favourable compared to laying GH2 pipes to isolated locations. Another influencing factor is consumer willingness to invest in hydrogen-fuelled vehicles - studies suggest that as much as 20% of drivers would consider hydrogen if there are 'sufficient' fuelling stations in their local area - a high figure which suggests that 'islands' of hydrogen fuelling stations are a feasible commercial proposition which would allow for a phased introduction of hydrogen fuelling stations rather than a massive, consecutive, nation-wide network investment. The high population concentrations in cities, and the envisaged early development of the area of Rijnmond and Rotterdam as a major hydrogen producing hub, could result in a favourable situation where large numbers of vehicles can be served in geographically compact urban centres.

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

Potential owner/operators of LH2 fuelling stations should be encouraged to enter the market by favourable licensing conditions supplied by government. License conditions need to be determined in advance and should follow those for "conventional" fuelling stations as much as is possible. Codes, standards and responsibilities need to be developed and clearly communicated to potential owners of LH2 fuelling stations. Safety issues concerned with resupplying LH2 fuelling stations with LH2 trucks will require special consideration. Planning approval will have to be secured from local authorities. Another priority is gaining public acceptance and increasing their knowledge of the practical aspects of such technology. Responsibility for this can be shared by government as well as private owner/operators of plant, and hydrogen association could also play a role. Close collaboration in the deployment of LH2 fuelling stations with the automobile industry would yield synergistic efficiencies.

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
	x		

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- Quick licensing and planning approval procedures.
- Issuing favourable licensing conditions to potential owner/operators of GH2 fuelling stations.
- Set clear codes and standards.

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	x
Energy engineering	
Infrastructure	x
Automotive	x
Supranational government	
Central government	x
Regional government	x
Research, academia and consultancy	
Civil society and NGOs	
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

END USE APPLICATION

A. CHAIN COMPONENT DESCRIPTION

FC/ICE vehicles

B. KEY CHANGE SHORT DESCRIPTION

Market penetration of FC/ICE vehicles must be achieved.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER 19

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
1a	■	■			
2a		■	■		
3a			■	■	
4a			■	■	4
4c		■			
5a			■	■	
6a	■	■			

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

The Netherlands is pursuing a number of RD&D projects for fuel cell vehicles, including participation in a number of EU programs. However, funding and research efforts to date have focused predominantly on stationary power applications rather than transport, perhaps a reflection of the lack of an auto industry combined with the presence of a strong energy industry.

Although little effort has yet been made at the national level on identifying or instigating legislative drivers for fuel cell vehicles (as is the case with virtually all nations), the Netherlands has a number of market instruments and other supportive measures targeting transport demand, including fuel and vehicle taxation, energy labelling and information dissemination about “eco-driving”, an air quality directive, spatial planning, and the promotion of modal shift and intermodal changes. The Netherlands is also considering road pricing and the introduction of a CO_2 emissions related purchase tax from which hybrid and electric vehicles would be exempt. There appears to be significant scope for the promotion of H_2 fuel cell/ICE vehicles in existing or considered transport policy measures, be it through exemptions or payment reductions.

It remains to be seen if these policy measures will ease the introduction of H2 fuel cell / ICE vehicles into the Netherlands market when the basic technology approaches a state of techno-economic competitiveness. Policies promoting public awareness will also be important.

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

Aspects related to the purchasing of fuel cell cars must be considered in greater depth than at present, and a campaign to raise general awareness of fuel cell cars amongst the public should be launched in anticipation of the technology reaching the market. Market instruments and incentives such as tax exemptions or capital allowances should be considered relatively soon in order to provide a strong initial push for market penetration. As the national automotive industry in the Netherlands is small, efforts should be made to establish good procedures for the introduction of fuel cell vehicles with foreign automotive companies. More research should be commissioned into how best to integrate the deployment of fuel cell cars into the existing transport systems in the Netherlands.

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
x			

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- Promote general awareness of fuel cell cars amongst the public, a.o. through demonstrations.
- Develop market instruments and incentives such as tax exemptions or capital allowances.
- Engage in discussions with foreign car industry about functioning as early market.

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	
Energy engineering	
Infrastructure	
Automotive	x
Supranational government	
Central government	x
Regional government	
Research, academia and consultancy	x
Civil society and NGOs	
Hydrogen associations	x
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

END USE APPLICATION

A. CHAIN COMPONENT DESCRIPTION

FC/ICE vehicles

B. KEY CHANGE SHORT DESCRIPTION

Potential public resistance to owning/operating H2-fuelled FC/ICE vehicles on the grounds of safety or other non-techno-economic grounds must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER **20**

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
1a	■	■			3
2a		■	■		
3a			■	■	
4a			■	■	
4c		■			
5a			■	■	
6a	■	■			

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT
Please describe below the nature of the identified MS Specific Key Change:

Studies have yet to be found which investigate how strong (potential) support is amongst members of the general public of the Netherlands for ownership of H2 FC/ICE vehicles. There are studies of the general feelings towards hydrogen as an energy carrier which conclude that the public is generally favourable and that safety concerns are within reason.

F. REQUIRED ACTION
Please describe below possible remedial actions to realise the MS Specific Key Change:

A campaign to raise general awareness amongst the public of fuel cell cars, as well as instilling a positive association with them, should be launched by government at all levels. Research into existing knowledge levels and acceptance levels should be carried so that national informational campaigns can be effectively formulated and targeted. Hydrogen associations and the auto industry can also play a strong role in this effort. The mass media should actively be engaged, and high profile demonstration projects might be an effective way of achieving this. The auto industry should also play a strong role in this through advertising campaigns. Collaborative efforts between government and private industry to win public approval of the technologies should be investigated and pursued.

G. PRIMARY DIMENSION ALLOCATION
Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
		X	

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- Promote general awareness of fuel cell cars amongst the public, a.o. through demonstrations.

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	
Energy engineering	
Infrastructure	
Automotive	x
Supranational government	
Central government	x
Regional government	
Research, academia and consultancy	x
Civil society and NGOs	x
Hydrogen associations	
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	x
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

De acceptatie van waterstof als alternatieve energiedrager in Nederland. Een survey	2004	ResCon research & consultancy		Survey of awareness, knowledge and acceptance of hydrogen among the public

END USE APPLICATION

A. CHAIN COMPONENT DESCRIPTION

CHP FC systems

B. KEY CHANGE SHORT DESCRIPTION

Lack of decentralised H2 CHP plant must be overcome.

C. MS SPECIFIC KEY CHANGE REFERENCE NUMBER **21**

D. CHAINS AFFECTED, ENVISAGED TIMEFRAMES AND DIFFICULTY ALLOCATION

Chain	2010	2020	2030	2050	Difficulty Allocation?
1b					
2b					
3b					
4b					3
4d	-	-	-	-	
5b					
6b					

E. KEY CHANGE DESCRIPTION BY CHAIN COMPONENT

Please describe below the nature of the identified MS Specific Key Change:

The Netherlands leads the way in ‘conventional’ cogeneration in Europe. Around forty percent of Dutch electricity is generated by Combined Heat and Power. The wide range of incentives (tax refunds, among other support measures) and increased market opening offer opportunities to harness in promoting the use of CHP in hydrogen energy systems in the mid term. Vigorous investment in CHP by private companies in the past lead to under-utilised capacity and higher unit cost in the 1990’s (IEA, 2003).

There has been one important fuel cell CHP demonstration project that can serve as a stepping stone in this field. The 100kW SOFC CHP test unit at Westervooort (the world’s largest) supplied electricity and hot water to the area from 1998. The test unit has now been transported to Germany. There are other R&D projects related to local generation and CHP on the basis of hydrogen and natural gas (IEA, 2004).

F. REQUIRED ACTION

Please describe below possible remedial actions to realise the MS Specific Key Change:

The sound demonstration base provided by the Westervoort SOFC project should be built upon and followed up with new demonstrations, which should be conducted under increasingly “commercial” conditions in order to be effective at convincing the private sector of the feasibility of the technology. The private sector should be consulted by government over its perceptions of potential market opportunities and barriers concerning the deployment of FC CHP plant so that policy initiatives can be designed in such a way that they achieve the desired results. Different sectors (hospitals, residential, industry, agriculture) and grid integration issues should be studied for initial introduction opportunities. The successful experience of deploying policy instruments for stimulating the take up of conventional CHP should be revisited and examined for potential use in stimulating FC CHP deployment. Government should collaborate with the private sector to examine how to create favourable market conditions for the deployment of FC CHP. In addition, codes, safety and responsibilities need to be established and communicated to potential stakeholders. Public acceptance may be a lesser priority if hydrogen is to be stored on site in or near to residential areas, and planning approval may be required from local authorities.

G. PRIMARY DIMENSION ALLOCATION

Please mark ONE box with an 'X':

Political / institutional	Techno-economic	Social	Infrastructural
x			

H. LIKELY LEVEL OF REQUIRED GOVERNMENT INVOLVEMENT IN SOLUTION OF KC

Please mark ONE box with an 'X':

Local / Regional	Central	EU level	Don't know
	x		

I. POSSIBLE PRIORITY GOVERNMENTAL ACTION

Please briefly describe below suggested policy measures which might realise the Key Change:

- Promotion of demonstration projects.
- Deployment of favourable market instruments.
- Local planning permissions; codes, standards and responsibilities.

J. ASSOCIATED BROAD ACTOR GROUPS

Please mark as many boxes as applicable with 'X's:

Broad Actor Group	Associated?
Energy – upstream / downstream	
Energy engineering	x
Infrastructure	
Automotive	
Supranational government	
Central government	x
Regional government	
Research, academia and consultancy	x
Civil society and NGOs	x
Hydrogen associations	x
Transport and logistics	
Specialist H2 equipment manufacturing	
Agriculture and forestry	
Media	
Real Estate Construction and management	
Financial services	
Other (please state)	

K. ADDITIONAL REFERENCES / SOURCES

Please list any used / recommended relevant references or sources:

IEA (2003) *Energy Efficiency Update – Netherlands.*

IEA (2004) *Hydrogen and Fuel Cells – Review of National R&D Programs*, Paris, France.

de Groot, A and Tillemans, FWA (2003) Hydrogen for Residential Combined Heat and Power

Annex 3: Guidelines for MS Specific Key Changes classification

Key change solution difficulty assessment by chain component

The estimated difficulty of a Key Change to occur by chain component is determined by AATF members. AATF members / MS stakeholders are asked to assign a single difficulty rating according to a sliding scale where 1 indicates that the Key Change by chain component is expected to occur with the least difficulty, and 5 indicates that significant obstacles are present.

- 1= The KC is expected to occur with little or no additional effort by associated Broad Actor Groups; the KC will be realised in the mainstream under *business as usual* conditions.
- 2= The KC will require some (minimal) additional effort/action by associated Broad Actor Groups in order for it to be realised in the mainstream.
- 3= The KC will require fairly substantial additional effort/action by associated Broad Actor Groups in order for it to be realised in the mainstream.
- 4= The KC will require very substantial additional effort/action by associated Broad Actor Groups in order for it to be realised in the mainstream.
- 5= The KC will require massive additional effort/action by associated Broad Actor Groups in order for it to be realised; the KC will be very difficult to realise in the mainstream even given a major increase in efforts.

Primary dimension allocation

- Political / institutional

The political/institutional dimension includes required Key Changes that are directly linked with the policy process, from design to implementation. This includes economic instruments (taxes, subsidies, and direct investment), various forms of regulatory instruments (obligations, codes and standards, permission procedures etc.). The implementing body is central (national), regional (local) or supranational (EU) governmental organizations, or non-governmental institutions such as licensed trades or regulatory bodies. Also, high-level political strategy is included e.g. the establishment of regulatory institutions, and cross-cutting incentive policies (e.g. integrating renewable and H_2 incentives, etc.). The allocation of a Key Change to this dimension suggests that, in the case of technology uptake, the technology is adjudged to be at or very close to commercial cost-competitiveness, and regulatory and market-based incentives rather than more fundamental R D&D or unit cost reduction (which belong the Techno-economic dimension) are the prime factors for a successful Key Change solution. Issues related to public awareness / acceptance are not included in this dimension (they belong to the Social dimension).

- Techno-economic

The techno-economic dimension includes required Key Changes that are associated with basic or applied technological research or development, and commercial development activities which are concerned within the context of the MS in question ONLY. This includes all activities which lead to technological progress for stated applications or reduced unit cost through scientific progress or increased sales volumes. Public funding is not included (this is incorporated within the political / institutional dimension). Fixed physical assets associated with energy or energy carrier transportation are not included (see Infrastructure dimension). Fixed physical assets associated with energy generation or hydrogen production are included if the Key Change focuses on an absence of specific technologies in a particular MS context. The allocation of a specific technology to this dimension suggests that it has not yet reached commercial cost-competitiveness and more fundamental barriers exist to Key Change solution than can reasonably be solved by market-based incentives and other applied policy mechanisms.

- Social

The Social dimension includes required Key Changes that are associated with society in general's concerns, abilities and priorities within the specific MS context ONLY. This includes education, technology acceptance, environmental sensibilities, safety, and demand for the spectrum of energy services. Key Changes associated with this dimension are associated with personal user-level technology applications (e.g. FC vehicles, home boilers etc.) but not higher-level decisions such as planning permission (e.g. for wind turbine deployment).

- Infrastructural

The Infrastructural dimension includes required Key Changes that are associated with stationary physical assets used for the transportation of energy or energy carriers, namely hydrogen (gas and liquid) pipelines, natural gas pipelines, oil pipelines, electricity transmission and distribution systems, and hydrogen fuelling stations. The development/deployment of cryogenic trucks are not included. Relevant activities in this dimension include all technological development, investment and deployment.

Likely level of required governmental involvement

- Supra-national / EU level

The solution of the MS S Key Change by chain component is associated with action most appropriately taken at EU level rather than at national level – because of a need for trans-border standards or normalization of procedures. These might include codes and standards.

- Central

The solution of the specific Key Change by chain component is associated with action most appropriately taken at the level of the MS national government. This might include nationally-instituted taxation or market mechanism schemes, and national strategic planning and goals.

- Regional/local

The solution of the MS S Key Change by chain component is associated with action most appropriately taken at the level of local/regional governmental institutions within the MS rather than at a national level. This might include local permissions or obligations.

Associated Broad Actor Groups

- *Energy-upstream/downstream*
  Describes all stationary or commercial activities in an electricity supply industry, both upstream (fuel supply, energy or energy carrier generation) and downstream (energy trading, supply, commercial services and sales). This excludes the development and production of power generation technologies, referring instead to their actual use or deployment in providing energy services.

- *Energy engineering*
  Describes the techno-economic development and commercialization of energy production and transportation technologies, but not their practical use. Technologies include energy conversion devices such as stationary and mobile fuel cells, electrolysis equipment, SMR equipment, cryogenic truck development, hydrogen pipelines, hydrogen fuelling stations etc.

- *Infrastructure*
  Describes the deployment (and all processes thereof – investment through to physical emplacement) of stationary energy or energy carrier transportation. The technological research and development phases of such infrastructure are not included in this description.

- *Automobile*
  Describes the sum total efforts and activities of the commercial automotive industry sector.

- *Supranational government*
  Describes the involvement of EU-level governmental organizations in influencing a Key Change through direct policy measures such as targeted taxes, subsidies, exemptions, investment, loans, obligations and licenses.

- *Central government*
  Describes the role of MS central government in influencing a Key Change through direct policy measures such as targeted taxes, subsidies, exemptions, investment, loans, obligations and licenses which effect the development or deployment of technologies and activities related to the hydrogen economy.

- *Regional/local government*
  Describes the involvement of regional or local government in an MS in influencing a Key Change through direct policy measures such as targeted taxes, subsidies, exemptions, investment, loans, obligations and licenses.

- *Research, academic and consulting*
  Describes the role of both public and private organizations involved in basic or applied research of any kind, whose end product is informational rather than physical commercial products, in influencing a Key Change. Such activities may or may not be commercially motivated. These organizations need not be solely concerned with hydrogen or related topics.

- *Civil society and NGOs*
  Describes the role of concerned but not overtly commercial or public organizations in influencing a Key Change. Activities might include research, organization, lobbying, publicity, or representation. Such organizations need not be solely dedicated to the development of a hydrogen economy but might have broader related interests such as (for example) RES, CHP or CO_2 reduction.

- *Transport and logistics sector*
  Describes the role of fleet vehicle operators (conventional and specialist) on both land and sea, as well as associated ancillary activities (e.g. port handling, storage services etc.). Such operators may be independent or integrated concerns.

- *Agriculture / forestry*
  Describes the role of industries involved in the production, harvesting and supply of biomass products.

- *Waste industry*
  Describes the role played by the collection, storage, processing and supply of domestic and industrial wastes for energy production purposes.

- *Real estate construction and management*
  Describes the role played by companies involved in the design, construction, fitting, sales and management of residential, commercial, industrial or public sector real estate.

- *H_2 associations*
  Describes the role of public or private organizations or institutions dedicated to the development of a hydrogen economy in influencing a Key Change. The activities these dedicated organizations provide to this specific goal are not prescribed and might be related to research, organization, lobbying, publicity or representation.

- *Specialist hydrogen equipment manufacturing*
  Describes the role played by (usually SME scale) companies dedicated to hydrogen technology component or system manufacturing. These companies play a role in bringing innovative products to the market for niche applications. They often focus on a limited number of highly specialist products, either bringing them directly to the market, or producing them for integrated hydrogen equipment producers.

- *Financial services*

Describes the role of private institutions which provide capital or other financial services to hydrogen or related industries or activities (but not the public at large) in influencing a Key Change.

- *Media*
  Describes the informational and cultural role played by all forms of public and commercial media in influencing public opinion and values.

REFERENCES

[i] NREL (2001) Lifecycle Assessment of Hydrogen Production via Natural Gas Steam Reforming, available online at http//nrel.gov/docs/fy01osti/27637.pdf

[ii] Hemmes, K., de Groot, A., den Uil, H. (2003) *Bio-H2 – Application potential of biomass related hydrogen production technologies to the Dutch energy infrastructure of 2020-2050*, ECN, Petten, Netherlands.

[3] International Energy Agency (2004) *Hydrogen and Fuel Cells – Review of National R&D Programs*, OECD.

[4] Duic, N., Lerer, M., Carvalho, M. (2003) *Increasing the supply of renewable energy sources in island energy systems*, International Journal of Sustainable Energy, Vol. 23, No. 4, December 2003 pp. 177-186.

[v] DTI (2003) Review of the feasibility of carbon capture and storage in the UK, Cleaner Fossil Fuels Programme, London, UK. Available online at: http://www.dti.gov.uk/energy/coal/cfft/co2capture/review.pdf

[vi] European Commission (2004) *European CO_2 Capture and Storage Projects.* Project Synopses under the 6th Framework Programme.

[vii] Hyweb, available online at:http://www.hyweb.de/Knowledge/w-i-energiew-eng4.html

[viii] US DOE, available on line at: http://www.science.doe.gov/sbir/solicitations/fy%202005/18_BES9.htm

[ix] US DOE, available online at: http://www.eere.energy.gov/hydrogenandfuelcells/mypp/

[x] Tzimas, E., Filiou, C, Peteves, S.D. and Veyret, J.-B (2003) *Hydrogen Storage: State-of-the-Art and Future Perspective,* European Commission Institute for Energy, available online at: http://www.jrc.nl/publ/P2003-181=EUR20995EN.pdf

[xi] Ogden, J.M. (2004) *HyDROGEN DELIVERY MODEL FOR H2A ANALYSIS*, Institute of Transportation Studies, University of California. Available online at: http://www.its.ucdavis.edu/publications/2004/UCD-ITS-RR-04-33.pdf.

[xii] Linde (2005) Hydrogen Filling Stations. Available online at: http://www.linde-gas.com/International/Web/LG/COM/likelgcomn.nsf/DocByAlias/hydrogen_filling_station

[xiii] Pehnt, M. & Ramesohl, R. (2003) *Fuel cells for distributed power: benefits, barriers and perspectives*, World Wildlife Fund / Fuel Cell Europe.