

**HyWays**  
**Handbook**  
**Member State Energy Pathway Analysis**  
**WP1, WP2 and WP3**

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Background

Methodology

Choice of Potential Hydrogen Energy Chains

E3 Database

Provision of Data

Energy Chain Screening

# Background

### Introduction

A major task in identifying the roadmap towards hydrogen energy in Europe member state by member state is to choose relevant energy pathways along which hydrogen will be provided, distributed/transported and supplied to the end-user.

This task has been split in two work packages: WP1 - Data Provision and WP2 - Energy Pathway Analysis.

This handbook provides an introduction into the methodology and tools used for this process. It is meant as user guide for those member states which are observers in Phase I and will become full partners in Phase II.

### Issues to be Addressed

Which are the most relevant 5 - 6 member state specific hydrogen energy chains (WtW/StU or combined) and processes (**Phase I:** 6 member states, **Phase II:** further 6 member states) concerning

- individual geographical and climatic conditions,
- primary energy resource situation and
- policy orientation?

Which are the relevant regionalised processes and the specific techno-economic input data or regional limitations?

Which are the global energy chain and individual process efficiencies, GHG emissions and (micro-economic) hydrogen supply costs for the chains identified?

Which are common and different energy chains between member states?

# Methodology

The member states experts and stakeholders are „coached“ by the WP1/WP2 modelling partners CEA, ECN and LBST, iteratively comprising the following steps:

	<u>Participants</u>
1. Identification of relevant hydrogen energy pathways Well-to-Wheel (WtW) for road transport and Source-to-User (StU) for all other applications	MS experts, industry
2. Structuring of the hydrogen energy pathways	WP1 / WP2 partners
3. Identification of data gaps	WP1 partners
4. Data provision	WP1 partners, external*
5. Incorporation of data in relational database	WP1 partners
6. Calculation of CO <sub>2</sub> equivalent emissions and costs	CEA, ECN, <u>LBST</u>
7. Interpretation of results and screening of pathways	WP2 partners

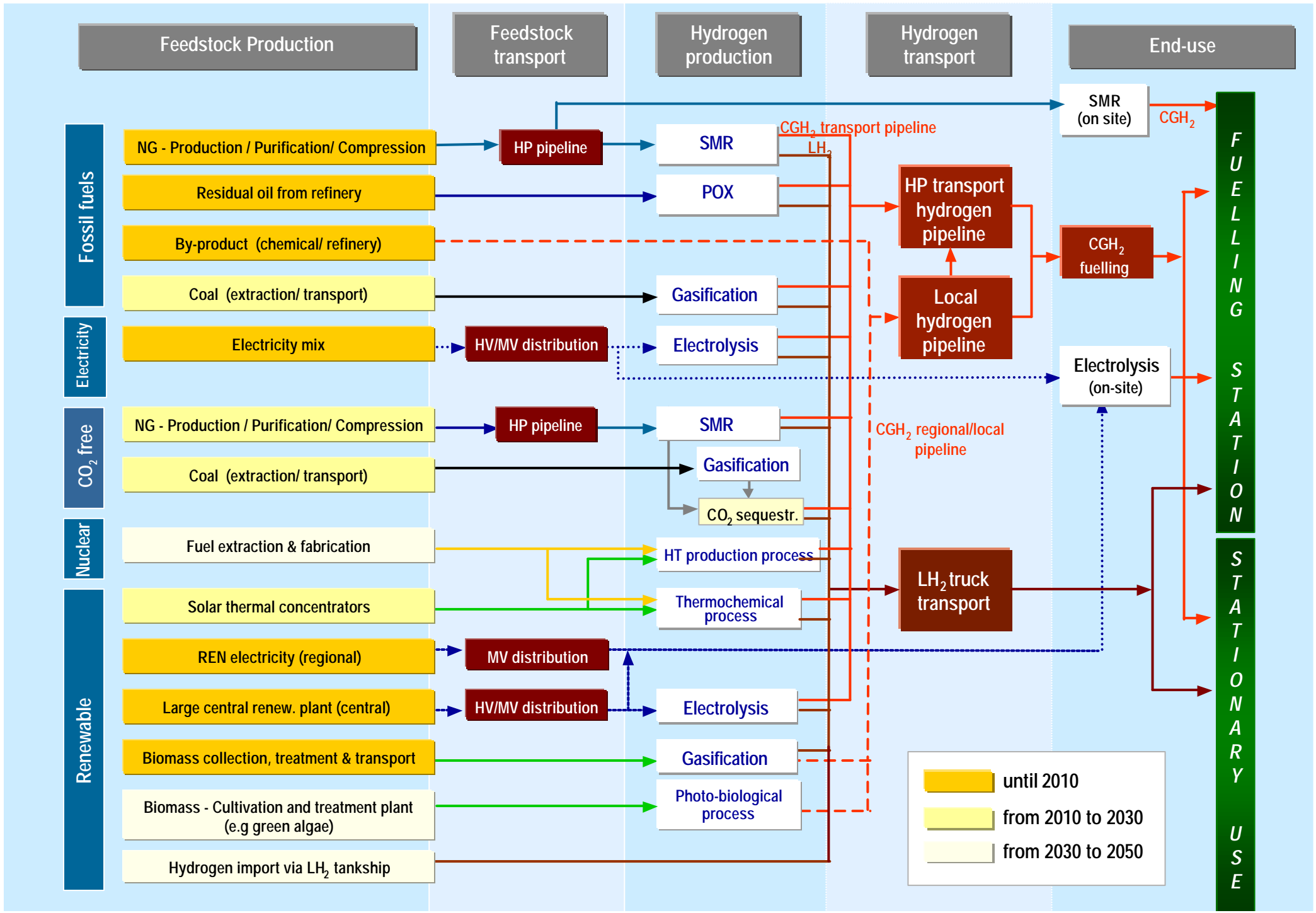
# Choice of Potential Hydrogen Energy Chains

About 5 - 7 individual major hydrogen energy chains, characterised by their hydrogen provision, should be proposed by each member state.

To choose possible hydrogen energy chains new HyWays member state partners are advised to study the following pages:

- Overview graph of potential chains from fossil, electricity mix, CO<sub>2</sub>-free or -reduced and renewable energy (slide 10)
- Overview graph of potential hydrogen end-use applications (slide 11)
- Tables on potential pathways for the periods < 2010 (slide 13 - 14), 2010 - 2030 (slide 15 - 17) and 2030 - 2050 (slide 18 - 20) for the different energy sources

The energy chains under consideration in each member state should be grouped accordingly.

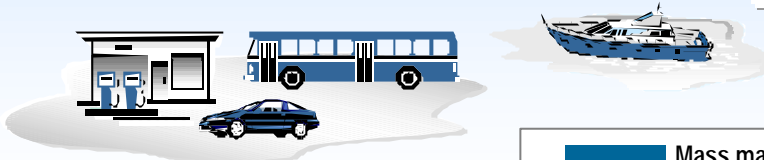


# TRANSPORT

Fuelling station  
CGH<sub>2</sub>

Fuelling station  
LH<sub>2</sub>

ROAD	RAIL	RIVERS / LAKES	COASTAL WATERS
Private car – FC and ICE	Traction commuter train	Propulsion amusement ships	Propulsion ferry
Citybuses – FC and ICE	Traction tourist train	Propulsion leisure boats	Propulsion fishing boats
Delivery vans	Traction shunting locomotive	Propulsion sporting boats	Propulsion tourist boats
Tracks			Propulsion submarines
Coaches			
FC bikes			
FC scooters			
FC customised (e.g. handicap)			

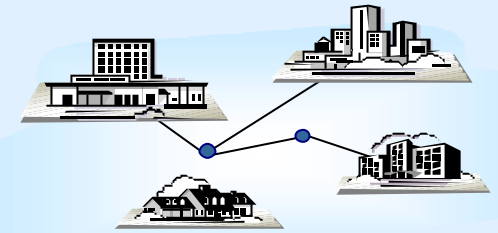


■ Mass markets  
■ Short-term niches  
■ Pressure bottles (cartridges)

# STATIONARY

Hydrogen pipeline  
(microgrid)

Residential /Commercial – FC (CHP - <200 kW)	Emergency power
Distributed power – FC plants (> 200 kW)	Grid quality control
Remote – FC systems	Tele-communications



# PORTABLE

Pressure bottles  
(cartridges)

APU	
Aircraft	Recreational vehicles (camper, yacht)
Heavy duty vehicles, taxis	Craftsmen applications

BATTERY REPLACEMENT
Portable units (mobile phone, etc.)
Defence applications
Rail (e.g. identification)

### Definitions

For the location of the plants 3 cases are distinguished at this stage:

- **Remote plants**, involving HVDC electricity transport or LH<sub>2</sub> ship transport
- **Large plants**, including
  - central (500 km average truck transport distance)\*
  - regional (150 km average truck transport or 50 km pipeline distribution distance)\*
- **On-site plants**, including small hydrogen microgrids (max. 5 km)\* from hydrogen production (e.g. biomass gasifier at city border) to end-use location

# Choice of Potential Hydrogen Energy Chains (5)

## Hydrogen Energy Chains < 2010: Fossil

No <sup>1</sup>	Energy in <sup>2</sup>	Fuel	Primary processes <sup>3</sup>	Intermediate fuel	Secondary H <sub>2</sub> processes <sup>3</sup>	Remarks <sup>4</sup>	Reference
<b>1. Fossil</b>							
1.1.1	NG	CGH <sub>2</sub>	NG production, purification, compression, HP pipeline transport	NG	steam reforming (large), H <sub>2</sub> compression, MP pipeline, CGH <sub>2</sub> fuelling station		
1.1.2		LH <sub>2</sub>			steam reforming (large), H <sub>2</sub> liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
1.1.3		CGH <sub>2</sub>			steam reforming (on-site), CGH <sub>2</sub> fuelling station		
1.1.4			NG production, purification, liquefaction (LNG), ship transport, HP pipeline transport		steam reforming (large), H <sub>2</sub> compression, MP pipeline, CGH <sub>2</sub> fuelling station		
1.1.5		LH <sub>2</sub>			steam reforming (large), H <sub>2</sub> liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
1.1.6		CGH <sub>2</sub>			steam reforming (on-site), CGH <sub>2</sub> fuelling station		
1.2.1	Mineral oil	CGH <sub>2</sub>	(Oil production, transport by ship,) residual oil from refinery	Residual oil	Partial oxidation (large), H <sub>2</sub> compression, MP pipeline, CGH <sub>2</sub> fuelling station	Realistically, only residual oil will be converted to hydrogen	
1.2.2		LH <sub>2</sub>			Partial oxidation (large), H <sub>2</sub> liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
1.4.1	By-product	CGH <sub>2</sub>	GHG-emissions equivalent with e.g. NG, possibly purification and compression	GH <sub>2</sub>	MP distribution pipeline, CGH <sub>2</sub> fuelling station	By-product supply is depending inherently on the underlying process	

<sup>1</sup> 1 – fossil; 2 – CO<sub>2</sub>-reduced or -free; 3 – renewable

<sup>2</sup> E.g. mineral oil, MS specific natural gas mix or NG from well, nuclear electricity, MS specific electricity mix, residual wood

<sup>3</sup> Major processes (if relevant with intermediate flows)

<sup>4</sup> CONCAWE/EUCAR/JRC well to wheel study by LBST

# Choice of Potential Hydrogen Energy Chains (6)

## Hydrogen Energy Chains < 2010: Electricity Mix, Reduced CO<sub>2</sub>, Renewable

2. Electricity Mix							
2.1.1	Electricity mix (depending on spec. MS situation)	CGH <sub>2</sub>	Electricity production mix, HV/MV transport and distribution	Electricity	H <sub>2</sub> O electrolysis, CGH <sub>2</sub> fuelling station	Electricity from a mix of fossil, nuclear and renewable sources	
2.1.2		LH <sub>2</sub>			H <sub>2</sub> O electrolysis, H <sub>2</sub> liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
2.1.3		CGH <sub>2</sub>			H <sub>2</sub> O electrolysis, H <sub>2</sub> liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
3. Reduced CO <sub>2</sub>							
4. Renewable							
4.1.1	Renewable electricity	CGH <sub>2</sub>	Electricity production (e.g. hydropower), MV transport and distribution	Electricity	H <sub>2</sub> O electrolysis, H <sub>2</sub> microgrid, CGH <sub>2</sub> fuelling station	Dedicated electricity	
4.1.2	Large central renewable electricity		Electricity production (e.g. wind-offshore), HV/MV transport and distribution		H <sub>2</sub> O electrolysis, H <sub>2</sub> microgrid, CGH <sub>2</sub> fuelling station	Dedicated electricity	
4.1.3		LCGH <sub>2</sub>			H <sub>2</sub> O electrolysis, H <sub>2</sub> liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	Dedicated electricity	
4.2.4	Biomass gasification	CGH <sub>2</sub>	Biomass collection, treatment (e.g. drying) and transport (e.g. 50 km radius)	Pre-treated biomass	Gasification, hydrogen microgrid (e.g. 5 km), CGH <sub>2</sub> fuelling station		

<sup>1</sup> 1 – fossil; 2 – CO<sub>2</sub>-reduced or -free; 3 – renewable

<sup>2</sup> E.g. mineral oil, MS specific natural gas mix or NG from well, nuclear electricity, MS specific electricity mix, residual wood

<sup>3</sup> Major processes (if relevant with intermediate flows)

<sup>4</sup> CONCAWE/EUCAR/JRC well to wheel study by LBST

# Choice of Potential Hydrogen Energy Chains (7)

## Hydrogen Energy Chains 2010 - 2020: Fossil

No <sup>1</sup>	Energy in <sup>2</sup>	Fuel	Primary processes <sup>3</sup>	Intermediate fuel	Secondary H <sub>2</sub> processes <sup>3</sup>	Remarks <sup>4</sup>	Reference
<b>1. Fossil</b>							
1.1.1	NG	CGH <sub>2</sub>	NG production, purification, compression, HP pipeline transport	NG	steam reforming (large), H <sub>2</sub> purification & compression, MP pipeline, CGH <sub>2</sub> fuelling station		
1.1.2		LH <sub>2</sub>			steam reforming (large), H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
1.1.3		CGH <sub>2</sub>			steam reforming (on-site), CGH <sub>2</sub> fuelling station		
1.1.4		CGH <sub>2</sub>	NG production, purification, liquefaction (LNG), ship transport, HP pipeline transport		steam reforming (large), H <sub>2</sub> purification & compression, MP pipeline, CGH <sub>2</sub> fuelling station		
1.1.5		LH <sub>2</sub>			steam reforming (large), H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
1.1.6		CGH <sub>2</sub>			steam reforming (on-site), CGH <sub>2</sub> fuelling station		
1.2.1	Mineral oil	CGH <sub>2</sub>	(Oil production, transport by ship,) residual oil from refinery	Residual oil	Partial oxidation (large), H <sub>2</sub> purification & compression, MP pipeline, CGH <sub>2</sub> fuelling station	Only residual oil will be converted to hydrogen (possible decrease of available H <sub>2</sub> due to higher use of H <sub>2</sub> for refinery purposes)	
1.2.2		LH <sub>2</sub>			Partial oxidation (large), H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
1.3.1	Coal	CGH <sub>2</sub>	Coal extraction, transport (ship or rail)	Coal	Partial oxidation (large), H <sub>2</sub> purification & compression, MP pipeline, CGH <sub>2</sub> fuelling station		
1.3.2		LH <sub>2</sub>			Partial oxidation (large), H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
1.4.1	By-product	CGH <sub>2</sub>	GHG-emissions equivalent with e.g. NG, possibly purification and compression	GH <sub>2</sub>	MP distribution pipeline, CGH <sub>2</sub> fuelling station	By-product supply is depending inherently on the underlying process	

<sup>1</sup> 1 – fossil; 2 – CO<sub>2</sub>-reduced or -free; 3 – renewable

<sup>2</sup> E.g. mineral oil, MS specific natural gas mix or NG from well, nuclear electricity, MS specific electricity mix, residual wood

<sup>3</sup> Major processes (if relevant with intermediate flows)

<sup>4</sup> CONCAWE/EUCAR/JRC well to wheel study by LBST

# Choice of Potential Hydrogen Energy Chains (8)

## Hydrogen Energy Chains 2010 - 2020: Electricity Mix, Reduced CO<sub>2</sub>

2. Electricity Mix							
2.1.1	Electricity mix (depending on spec. MS situation)	CGH <sub>2</sub>	Electricity production mix, HV/MV transport and distribution	Electricity	H <sub>2</sub> O electrolysis, CGH <sub>2</sub> fuelling station	Electricity from a mix of fossil, nuclear and renewable sources H <sub>2</sub> can be used in order to equalise the energy demand along the day	
2.1.2		LH <sub>2</sub>			H <sub>2</sub> O electrolysis, H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
3. Reduced or CO <sub>2</sub> free							
3.1.1	NG	CGH <sub>2</sub>	NG production, purification, compression, HP pipeline transport	NG	steam reforming (large), CO <sub>2</sub> capture and sequestration (total or partial), H <sub>2</sub> purification & compression, MP pipeline, CGH <sub>2</sub> fuelling station	Plant can be built near sequestration sites, due to wide NG network	
3.1.2		LH <sub>2</sub>			steam reforming (large), CO <sub>2</sub> capture and sequestration (total or partial), H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
3.2.1	Coal	CGH <sub>2</sub>	Coal extraction, transport (ship or rail)	Coal	Partial oxidation (large), CO <sub>2</sub> capture and sequestration (total or partial), H <sub>2</sub> purification & compression, MP pipeline, CGH <sub>2</sub> fuelling station	Different ways to transport CO <sub>2</sub> to sequestration sites, depending on the distance from plant	
3.2.2		LH <sub>2</sub>			Partial oxidation (large), CO <sub>2</sub> capture and sequestration (total or partial), H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
3.3.1	Nuclear	CGH <sub>2</sub>	Nuclear fuel extraction and fabrication	Nuclear	Direct high temperature conversion, H <sub>2</sub> purification & compression, MP pipeline, CGH <sub>2</sub> fuelling station		
3.3.2		LH <sub>2</sub>			Direct high temperature conversion, H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	

<sup>1</sup> 1 – fossil; 2 – CO<sub>2</sub>-reduced or -free; 3 – renewable

<sup>2</sup> E.g. mineral oil, MS specific natural gas mix or NG from well, nuclear electricity, MS specific electricity mix, residual wood

<sup>3</sup> Major processes (if relevant with intermediate flows)

<sup>4</sup> CONCAWE/EUCAR/JRC well to wheel study by LBST

## Choice of Potential Hydrogen Energy Chains (9)

### Hydrogen Energy Chains 2010 - 2020: Renewable

4. Renewable							
4.1.1	Renewable electricity	CGH <sub>2</sub>	Electricity production (e.g. hydropower), MV transport to H <sub>2</sub> conversion plant	Electricity	H <sub>2</sub> O electrolysis, H <sub>2</sub> micro grid, CGH <sub>2</sub> fuelling station		
4.1.2	Large central renewable electricity	CGH <sub>2</sub>	Electricity production (e.g. wind-offshore), direct HV/MV transport to H <sub>2</sub> conversion plant		H <sub>2</sub> O electrolysis, MP pipeline and/or H <sub>2</sub> micro grid, CGH <sub>2</sub> fuelling station	H <sub>2</sub> can be used in order to equalise the energy demand along the day, whenever renewable electricity production exceeds 15-20%	
4.1.3		LCGH <sub>2</sub>			H <sub>2</sub> O electrolysis, H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station		
4.2.1	Biomass	CGH <sub>2</sub>	Biomass collection, treatment (e.g. drying) and transport to process plant	Biomass (wood residues, straw, cultivated plants, wastes)	H <sub>2</sub> production and purification, CGH <sub>2</sub> fuelling station		
4.2.2		LH <sub>2</sub>			H <sub>2</sub> production and purification, H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station		
4.3.1	Solar	CGH <sub>2</sub>	Solar collectors and thermal conversion	Solar energy	H <sub>2</sub> production, H <sub>2</sub> micro grid, CGH <sub>2</sub> fuelling station		

# Choice of Potential Hydrogen Energy Chains (10)

## Hydrogen Energy Chains 2030 - 2050: Fossil

No <sup>1</sup>	Energy in <sup>2</sup>	Fuel	Primary processes <sup>3</sup>	Intermediate fuel	Secondary H <sub>2</sub> processes <sup>3</sup>	Remarks <sup>4</sup>	Reference
<b>L Fossil</b>							
1.1.1	NG	CGH <sub>2</sub>	NG production, purification, compression, HP pipeline transport	NG	steam reforming (large), H <sub>2</sub> purification & compression, MP pipeline, CGH <sub>2</sub> fuelling station		
1.1.2		LH <sub>2</sub>			steam reforming (large), H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
1.1.3		CGH <sub>2</sub>			steam reforming (on-site), CGH <sub>2</sub> fuelling station		
1.1.4		CGH <sub>2</sub>	NG production, purification, liquefaction (LNG), ship transport, HP pipeline transport		steam reforming (large), H <sub>2</sub> purification & compression, MP pipeline, CGH <sub>2</sub> fuelling station		
1.1.5		LH <sub>2</sub>			steam reforming (large), H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
1.1.6		CGH <sub>2</sub>			steam reforming (on-site), CGH <sub>2</sub> fuelling station		
1.2.1	Mineral oil	CGH <sub>2</sub>	(Oil production, transport by ship,) residual oil from refinery	Residual oil	Partial oxidation (large), H <sub>2</sub> purification & compression, MP pipeline, CGH <sub>2</sub> fuelling station	Only residual oil will be converted to hydrogen (possible decrease of available H <sub>2</sub> due to higher use of H <sub>2</sub> for refinery purposes)	
1.2.2		LH <sub>2</sub>			Partial oxidation (large), H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
1.3.1	By-product	CGH <sub>2</sub>	GHG-emissions equivalent with e.g. NG, possibly purification and compression	GH <sub>2</sub>	MP distribution pipeline, CGH <sub>2</sub> fuelling station	By-product supply is depending inherently on the underlying process	
1.4.1	Coal	CGH <sub>2</sub>	Coal extraction, transport (ship or rail)	Coal	Gasification (large), H <sub>2</sub> purification & compression, MP pipeline, CGH <sub>2</sub> fuelling station		
1.4.2		LH <sub>2</sub>			Gasification (large), H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	

<sup>1</sup> 1 – fossil; 2 – CO<sub>2</sub>-reduced or -free; 3 – renewable

<sup>2</sup> E.g. mineral oil, MS specific natural gas mix or NG from well, nuclear electricity, MS specific electricity mix, residual wood

<sup>3</sup> Major processes (if relevant with intermediate flows)

<sup>4</sup> CONCAWE/EUCAR/JRC well to wheel study by LBST

# Choice of Potential Hydrogen Energy Chains (11)

## Hydrogen Energy Chains 2030 - 2050: Electricity Mix, Reduced CO<sub>2</sub>

2. Electricity Mix							
2.1.1	Electricity mix (depending on spec. MS situation)	CGH <sub>2</sub>	Electricity production mix, HV/MV transport and distribution	Electricity	H <sub>2</sub> O electrolysis, H <sub>2</sub> compression, MP pipeline, CGH <sub>2</sub> fuelling station	Electricity from a mix of fossil, nuclear and renewable sources H <sub>2</sub> can be used in order to equalise the energy demand along the day	
2.1.2		LH <sub>2</sub>			H <sub>2</sub> O electrolysis, H <sub>2</sub> liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
3. Reduced or CO <sub>2</sub> free							
3.1.1	NG	CGH <sub>2</sub>	NG production, purification, compression, HP pipeline transport	NG	steam reforming (large), CO <sub>2</sub> capture and sequestration (total or partial), H <sub>2</sub> purification & compression, MP pipeline, CGH <sub>2</sub> fuelling station	Plant can be built near sequestration sites, due to wide NG network	
3.1.2		LH <sub>2</sub>			steam reforming (large), CO <sub>2</sub> capture and sequestration (total or partial), H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
3.2.1	Coal	CGH <sub>2</sub>	Coal extraction, transport (ship or rail)	Coal	Gasification (large), CO <sub>2</sub> capture and sequestration (total or partial), H <sub>2</sub> purification & compression, MP pipeline, CGH <sub>2</sub> fuelling station	Different ways to transport CO <sub>2</sub> to sequestration sites, depending on the distance from plant	
3.2.2		LH <sub>2</sub>			Gasification (large), CO <sub>2</sub> capture and sequestration (total or partial), H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	
3.3.1	Nuclear	CGH <sub>2</sub>	Nuclear fuel extraction and fabrication	Nuclear	High temperature production process (large), H <sub>2</sub> compression, MP pipeline, CGH <sub>2</sub> fuelling station		
3.3.2		LH <sub>2</sub>			High temperature production process (large), H <sub>2</sub> liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station	All LH <sub>2</sub> stations also supply CGH <sub>2</sub>	

<sup>1</sup> 1 – fossil; 2 – CO<sub>2</sub>-reduced or -free; 3 – renewable

<sup>2</sup> E.g. mineral oil, MS specific natural gas mix or NG from well, nuclear electricity, MS specific electricity mix, residual wood

<sup>3</sup> Major processes (if relevant with intermediate flows)

<sup>4</sup> CONCAWE/EUCAR/JRC well to wheel study by LBST

# Choice of Potential Hydrogen Energy Chains (12)

## Hydrogen Energy Chains 2030 - 2050: Renewable

4. Renewable							
4.1.1	Renewable electricity	CGH <sub>2</sub>	Electricity production (e.g. hydropower, minihydro), MV transport to H <sub>2</sub> conversion plant	Electricity	H <sub>2</sub> O electrolysis, H <sub>2</sub> micro grid, CGH <sub>2</sub> fuelling station		
4.1.2	Large central renewable electricity	CGH <sub>2</sub>	Electricity production (e.g. wind-offshore), direct HV/MV transport to H <sub>2</sub> conversion plant		H <sub>2</sub> O electrolysis, MP pipeline and/or H <sub>2</sub> micro grid, CGH <sub>2</sub> fuelling station	H <sub>2</sub> can be used in order to equalise the energy demand along the day, whenever renewable electricity production exceeds 15-20%	
4.1.3		LCGH <sub>2</sub>			H <sub>2</sub> O electrolysis, H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station		
4.2.1	Biomass	CGH <sub>2</sub>	Biomass collection, treatment (e.g. drying) and transport to process plant	Biomass (wood residues, straw, cultivated plants, wastes)	Gasification, H <sub>2</sub> purification & compression, MP pipeline, CGH <sub>2</sub> fuelling station		
4.2.2		LH <sub>2</sub>			Gasification, H <sub>2</sub> purification & liquefaction, truck distribution, LCGH <sub>2</sub> fuelling station		
4.2.3	Biomass	CGH <sub>2</sub>	Specific plant (e.g. green algae) cultivation and treatment (tbd)	Cultivated plants	Photo-biological production process, H <sub>2</sub> micro grid, CGH <sub>2</sub> fuelling station		
4.3.1	Solar	CGH <sub>2</sub>	Solar collectors and thermal conversion	Solar energy	H <sub>2</sub> production, H <sub>2</sub> micro grid, CGH <sub>2</sub> fuelling station		

<sup>1</sup> 1 – fossil; 2 – CO<sub>2</sub>-reduced or -free; 3 – renewable

<sup>2</sup> E.g. mineral oil, MS specific natural gas mix or NG from well, nuclear electricity, MS specific electricity mix, residual wood

<sup>3</sup> Major processes (if relevant with intermediate flows)

<sup>4</sup> CONCAWE/EUCAR/JRC well to wheel study by LBST

## E3 Database

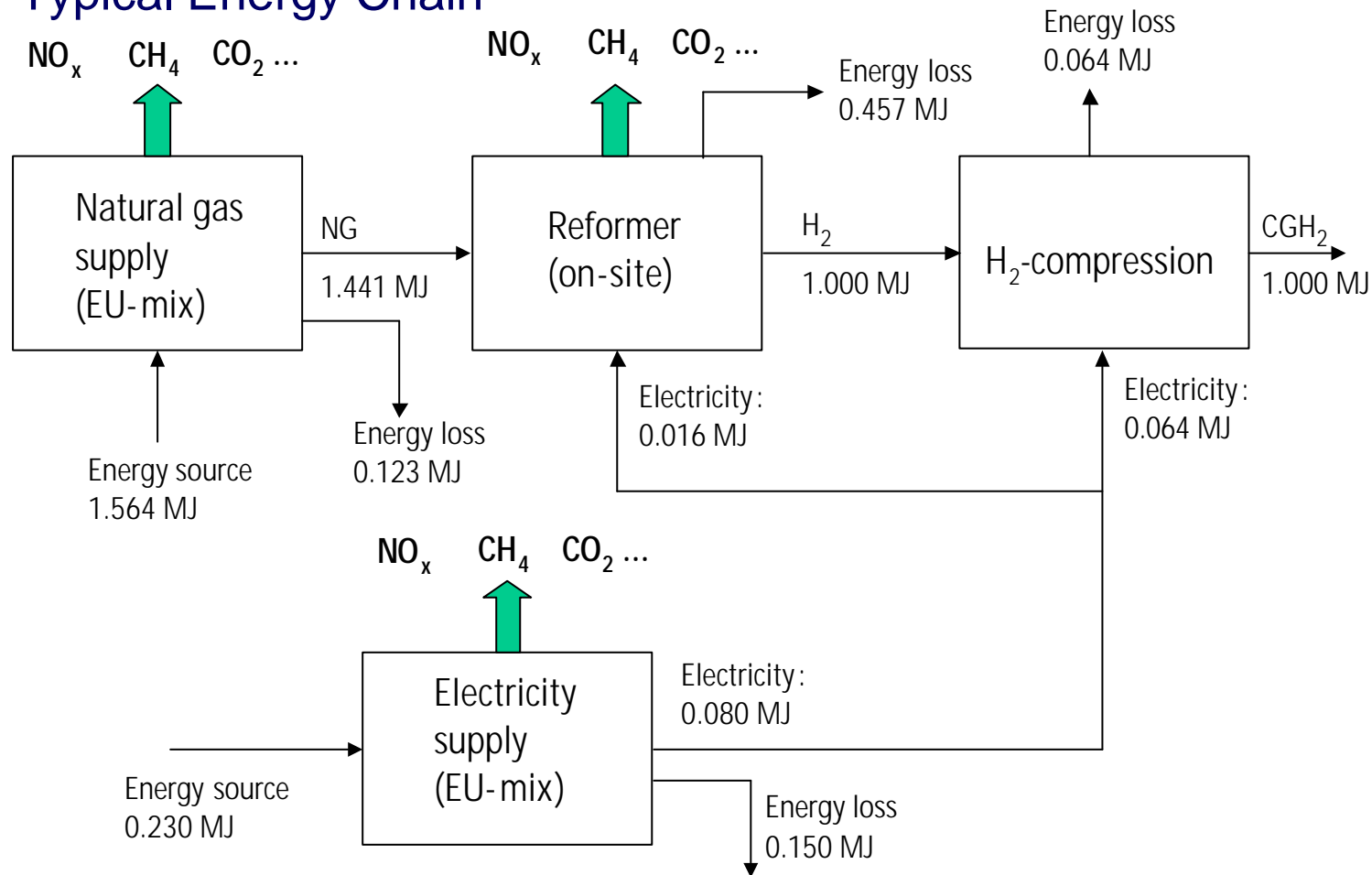
### Glossary (1)

<i>CO<sub>2</sub>-Factors</i>	<i>CO<sub>2</sub>-Factors</i> are factors, how many times more effective a specified gaseous emission is with regard to global warming than carbon dioxide (CO <sub>2</sub> ) (IPCC 2001: CO <sub>2</sub> = 1; CH <sub>4</sub> = 23, N <sub>2</sub> O = 296, etc.)
<i>Energy chain</i>	(also „fuel pathway“) well-to-wheel WtW (transport), source-to-use StU (stationary) or combined <i>energy chains</i> from energy source to final energy end-use, consisting of several <i>Processes</i> linked by <i>Material</i> flows, called <i>Chain</i> in E3database.
<i>GHG emissions</i>	equivalent to <i>CO<sub>2</sub>-equivalent</i> emissions (See <i>CO<sub>2</sub>-Factors</i> )
„Grey“ <i>energies</i>	Energy for construction, maintenance and scrapping of plants/components
<i>Handbook</i>	A briefing in „presentation format“ about the methodology of WP1 and WP2

### Glossary (2)

<i>Material</i>	<i>Materials</i> are inputs and/or outputs of <i>Processes</i> , to build links between processes as either input or output of a process. A <i>Material</i> can be a material literally (e.g. steel, concrete, etc.) or an energy carrier (e.g. natural gas, crude oil, electricity, etc.) or also a non material entity like a service (e.g. vehicle-km, t-km, etc.).
<i>Process</i>	One element of an <i>energy chain</i>
<i>Reference</i>	<i>Reference</i> is used for documentation purposes. <i>Reference</i> was introduced to store further information about <i>Material</i> and <i>Process</i> sources. <i>Material</i> and <i>Process</i> can refer to the same <i>Reference</i> .
<i>Regionalisation</i>	Process to adapt <i>energy chains</i> to a member state/„political“ region
<i>Scenario*</i>	List of relevant <i>energy chains</i> to be combined for one member state
<i>Toolbox</i>	Collection of guidelines, data and issues for the member state partners to carry out the work in WP1 and WP2

Typical Energy Chain



### Scope

Calculate total efficiency, local/global emissions and (complex) energy chains in iterative runs to accompany the regionalisation process

- use validated input data (harmonised datasets, e.g. CONCAWE/EUCAR/JRC)
- identify data gaps and distribute work load among WP1 / WP2 participants (mainly industry) to acquire data (partially MS specific)
- graphically present energy chains (WtW, StU)
- deliver output data in EXCEL format as interface to economic models (i.e. MARKAL)

### Type of Input Data

#### Technology data

- *Material* name, unit (*material* type), *reference*, lower/higher heating value, density, time horizon, process scale, data range (bandwidth), major/secondary *Process* input(s) and output(s)

#### Emission-specific data

- CO<sub>2</sub>-content (derived from carbon content), CO<sub>2</sub>-Factors, specific SO<sub>2</sub>, NO<sub>x</sub>,... emissions

#### Economic data

- construction time, useful lifetime, dismantling time
- further data on separate page

## User Interface for Data Input

**Process Description**

Process Name: GH2 / NG / Steam Reforming / Haldor Topsoe  
 Project Name: Stapler  
 Process Type: Energy Conversion

Main Output: GH2  
 Main Input: NG

id\_group: <unknown group>  
 id\_timestamp: 12/11/2003 5:08:29 PM

**HEAD (1)**

**IN / OUT (3)**

Material: NG  
 IO\_Type: Input  
 Amount: 1.4406 kWh/kWh

Distribution: Normal  
 Param1: 1.4118  
 Param2: 1.4406  
 Param3: 1.4694

Notes:  
 Natural gas input: 1,6 MPa required  
 Assumption for distribution:  
 NG-consumption 1,4406 kWh/kWh +/- 2%

**BASICS (2)**

Time Horizon	Process Scale kWh/h	Data Range
2000	960	Average
2000	1380	Average
2000	1680	Average
2000	1680	Average
2000	3859	Average

General Data | Economic Data | Emissions | N2O, CH4 | Reference

Input Date: 12/5/2003  
 Data Precision: good (w/w)

Construction time: 0 yr  
 Useful Lifetime: 15 yr  
 Dismantling time: 0 yr

Country:

Notes:  
 - The useful lifetime is estimated  
 - Maintenance costs: spare parts = 2 % of investment over 2 years  
 - CO2 = 203 g/kWh of NG from EU NG mix

**Chosen I/Os:**

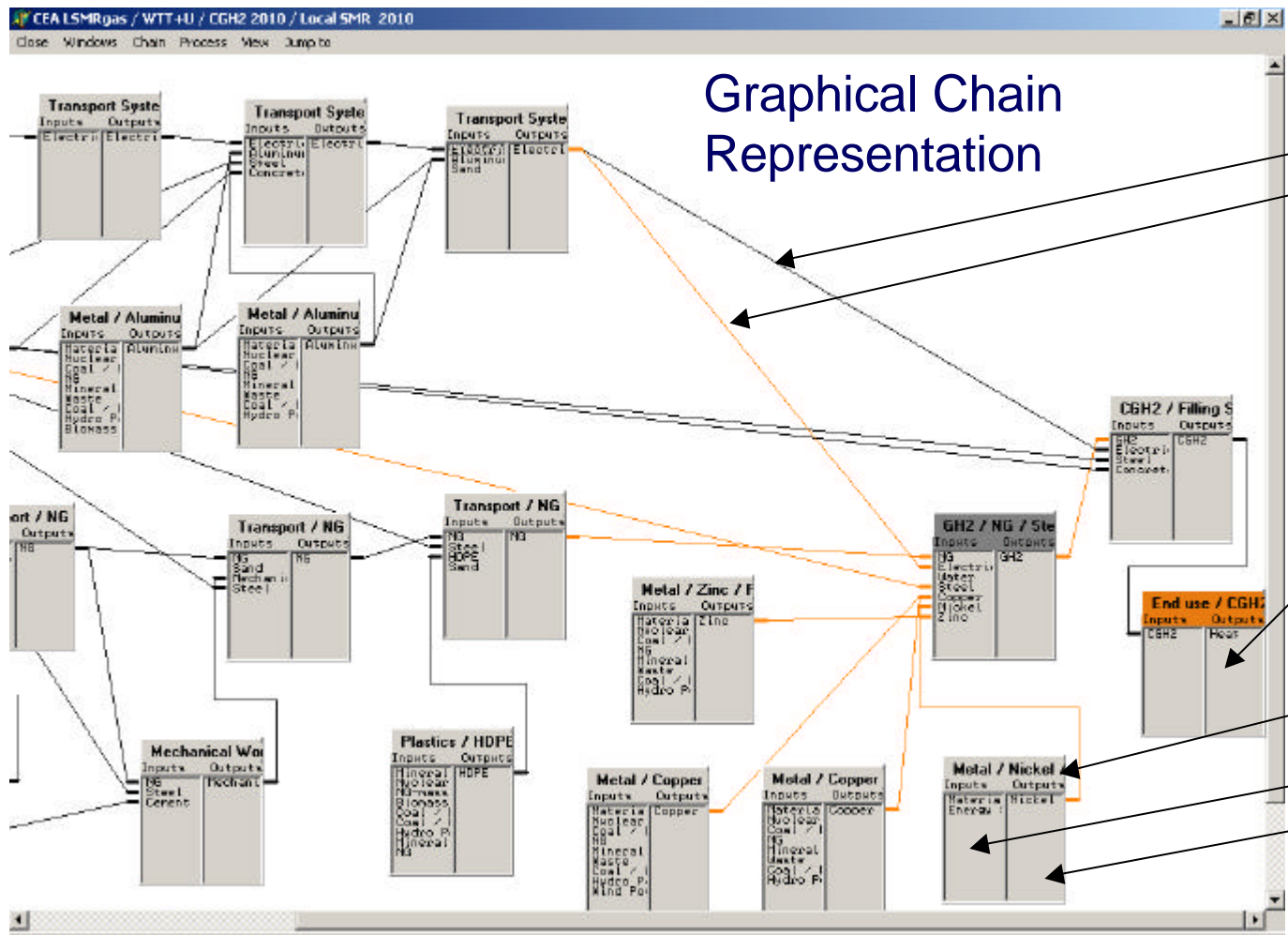
MATERIAL_NAME	IO_TYPE	AMOUNT
Copper	Input	4
Electricity	Input	0.0161
NG	Input	1.4406
Nickel	Input	12
Steel	Input	52000
Water	Input	0.2363
Zinc	Input	12
GH2	Output	1

### Internal Data Organisation

- relational SQL-database
- high flexibility in creating *energy chains* from individual *processes*
- efficient data organisation by storing process variants with individual data modifications
- transparent and repeatable data and information storage

# E3 Database (8)

# HyWays



Graphical Chain Representation

Process link  
 (Black: normal link  
 yellow: „detective“  
 blue: „credit“ link)

Tail process  
 (End of chain)

Process head

Process box  
 (left: *Material* input,  
 right: *Material* output)

### Data Output (Extract)

#### Technological data

- Energy demand or efficiencies of individual processes and chains

#### Emission-specific data

- CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, SF<sub>6</sub>, CF<sub>4</sub> .... emissions
- CO<sub>2</sub>-equivalent emissions of energy chains (with or without “grey” energies): net + credit = gross CO<sub>2</sub>-emissions
- SO<sub>2</sub>, NO<sub>x</sub>, .... emissions

#### Economic data

- specific „levelized“ hydrogen production costs from:
- total costs (construction, operation, dismantling) including:
  - investment costs, capital expenditure and overhead charges
  - operation and maintenance expenditures
  - energy and material supply expenditures

### Special Features

#### Statistical analysis

- Monte-Carlo analysis can be applied to quantify uncertainties by providing confidence bounds around best estimates
- parametric probability values are determined and then used to stochastically simulate the range of uncertainty for the overall pathway in question
- Every time an energy path is newly calculated certain parameters of some or all processes (i.e. for those processes where distributions are applied) shall assume random values according to predefined probability distributions (energy inputs, material inputs, CH<sub>4</sub>-emissions, N<sub>2</sub>O-emissions)

#### Scenario modelling

- mixed supply chains can be analysed to build regional hydrogen supply and demand scenarios

**Both features are not applied for HyWays!**

### Validity of Data

- E<sup>2</sup>/E<sup>3</sup>-Database development dates back to projects in '95
- algorithm validation “by hand” in 1<sup>st</sup> version
- numerous cross-checks with other worldwide WtW projects
- quality of data output depends on quality of input data
- “industrially validated” database (transport/stationary fuel pathways)\*
  - Low emission drive systems for urban vehicles (I, P; Germany) 1995
  - Transport Energy Strategy (TES) (I, P; Germany) 1998 - 2001
  - TAB Fuel Cell Project (P, R; Germany) 1999
  - Volkswagen SYNFUEL/SUNFUEL pathways (I; Germany) 2001
  - GM WtW Study (I; Germany) 2001 - 2002
  - CONCAWE/EUCAR/JRC Ispra (I; EU) 2002 - 2003
  - FC-Ship (P, I; EU) 2003 - 2004
  - LPG pathways (I; Germany) 2003
  - Transport fuel matrix (P; Germany) 2004

## Provision of Data

### Methodology

Each member state expert is coached by one of the WP1/WP2 modellers CEA, ECN and LBST.

1. Derive information gaps from pathways suggested by MSs and document them in structured format in GAPS FILE
2. Define possible data providers in industry (responsible individuals) and responsible modellers (one for each member state) in TASK ASSIGNMENT LIST
3. Use data from CONCAWE, EUCAR, JRC\* as default
4. Collect and discuss data with providers and incorporate them in E3 Database, mirrored in TECHNOLOGY FACT SHEETS

\* to be downloaded from: <http://ies.jrc.cec.eu.int/Download/eh>

### Tools

1. **TASK ASSIGNMENT LIST:** Structured task assignment by partner/individual (included in GAPS FILE)
2. **GAPS FILE:** document data requirements in WORD (input for data providers, dynamically updated and posted on HyWays website\*)
3. **TECHNOLOGY FACT SHEETS\*:** Mirror of techno-economic data used in E3 Database calculations in EXCEL (dynamically updated and posted on HyWays website\*)

\* to be accessed via: <http://www.HyWays.de>

# Energy Chain Screening

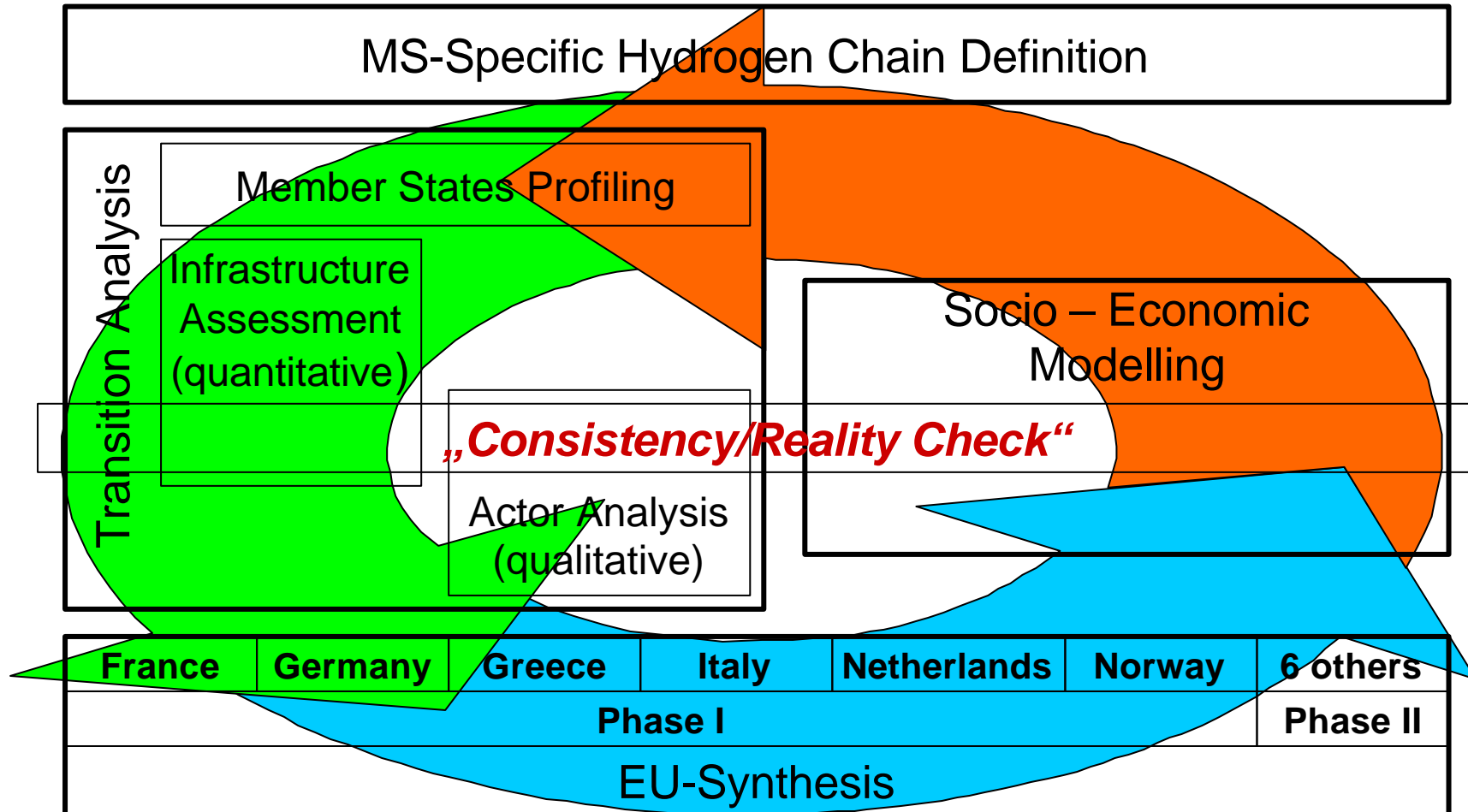
### Introduction

The screening of energy chains is an **iterative process** moderated by the WP1/WP2 modellers aiming at a reduction of a larger number of alternative energy chains for one member state to a smaller number to be finalised for input to the economic models in WP3.

It will involve HyWays partners from WP1, WP2, WP3 and the member state experts. The member state experts should engage in involving other member state stakeholders in the discussion.

To invoke the process with member state stakeholders and as assistance to the member state experts **central issues** have been raised here.

To alert the E3 Database modellers the **analysis tasks** and possible **consequences for the Hydrogen Energy Pathways Analysis** have been documented here.



**Issue A: Hydrogen transport infrastructure (Imperial College)**

*„What determines how hydrogen will be distributed/transported within a specific member state or region?“*

or

*„Under what condition will a specific infrastructure for distribution/transport of hydrogen be able to develop and what consequences does it have for the hydrogen energy system?“*

**Issue B: Hydrogen production (IST)**

*„How will the transition from fossil based hydrogen to renewable hydrogen take place? What are the drivers? What are the barriers?“*

or

*„If hydrogen technology and infrastructure is introduced mainly based on fossil fuels, how will the transition to renewable based hydrogen take place?“*

**Issue C: Actor analysis (IST)**

*„Which actors are involved in building the infrastructure and hydrogen end-use market?“*

or

*„What is their role, responsibility and commitment?“*

### Considerations to identify differences between member states:

- **supply chain** (availability of resources, cost of primary energies and energy transport...)
- **hydrogen transport** (geographical barriers, can existing infrastructure be used, presence of regions with a concentration of potential hydrogen end-users)
- **matching supply and demand** (what is necessary\* to make hydrogen follow demand, how flexible is the existing energy infrastructure, **infrastructure build-up**: how is the hydrogen system integrated into the existing energy system)
- **fleet characteristics\*\*** (what mix of vehicles is on the road and how do the specific conditions in the member state affect performance characteristics)
- **stationary system characteristics\*\*** (heat/electricity demand for CHP systems, electricity grid and mix characteristics influence the type of system to be used in each member state)

\* in terms of storage or introduction of flexible production options

\*\* To initiate the discussion the HyWays Scoping Report provides data ([www.HyWays.de](http://www.HyWays.de))

### Analysis Task: Hydrogen Transport Infrastructure

- What is the level of demand in a specific region which is necessary to sustain such a pipeline infrastructure?
- Will hydrogen transport through pipelines be used for "interregional" transport?
- In regions where such a pipeline infrastructure is not feasible, will hydrogen be transported by other methods (e.g. as trucked LH<sub>2</sub>) or will it be generated on-site?
- More general, what influence do different methods of transport have on the economic feasibility of end-use systems (in particular on stationary systems?).
- If hydrogen is to be distributed/transported by pipeline, what intermediate steps are there in building such an infrastructure?

### Energy Chain Consequences: Hydrogen Transport Infrastructure

- To be able to contribute to answering these questions, the chain analysis focuses on comparing different options for transport of hydrogen.
- The discussion of results should not only focus on the total energy chain, but also explicitly report the different steps in the chain. It is important to show explicitly how much cost, emissions and energy losses are associated with transport.
- It is necessary to perform some form of "sensitivity analysis" on the transport section of the chain. How are costs affected by (under-) utilisation of the infrastructure? How are costs influenced by synergy with other chains?

### Analysis Task: Hydrogen Production

- How does availability of resources affect the chains.
- Is the infrastructure for hydrogen transport and distribution the same for fossil based as with renewable?
- Will there be a shift in end-use if the system is based on renewable energy instead of fossil fueled? (for example: what stationary end-use makes sense if the system is based on renewable energy)

### Energy Chain Consequences: Hydrogen Production

- The energy chain analysis needs to clarify the difference between renewable and fossil based energy chains (required infrastructure, potential and possible end-use).