

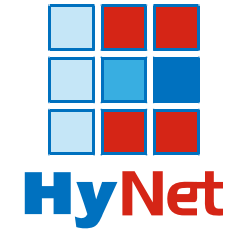
## HyNet

# Considering a Basic Area-Wide Hydrogen Fuelling Station Network in Europe

## Long Version

Prepared for HyNet  
by  
Ulrich Bünger (LBST)  
Hubert Landinger (LBST)

13<sup>th</sup> August 2004



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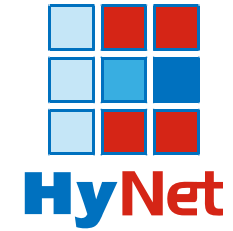
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## Motivation and Background

## HyNet - European Basic Hydrogen Fuelling Station Network

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### Motivation

The purpose of this presentation is to **prove and visualise the plausibility of the** quantities resulting from the **HyNet Roadmap**, i.e. about 5.000 to 10.000 hydrogen fuelling stations for about 2 to 9 million cars to reach a large part of Europe's population.

This snapshot **does not anticipate more detailed studies** to be carried out by the HyWays Roadmap project to validate the European hydrogen infrastructure build-up member state by member state.

## HyNet - European Basic Hydrogen Fuelling Station Network

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### Background

Many efforts have been undertaken to provide hydrogen powered vehicles in the near future. Their commercialisation is now expected for the period between 2010 and 2015.

In parallel to the development of hydrogen vehicles the timely establishment of a Europe wide hydrogen fuelling station network has to be discussed.

HyNet should encourage further and more detailed discussions with the endeavour to harmonise the approach of the stakeholders involved.



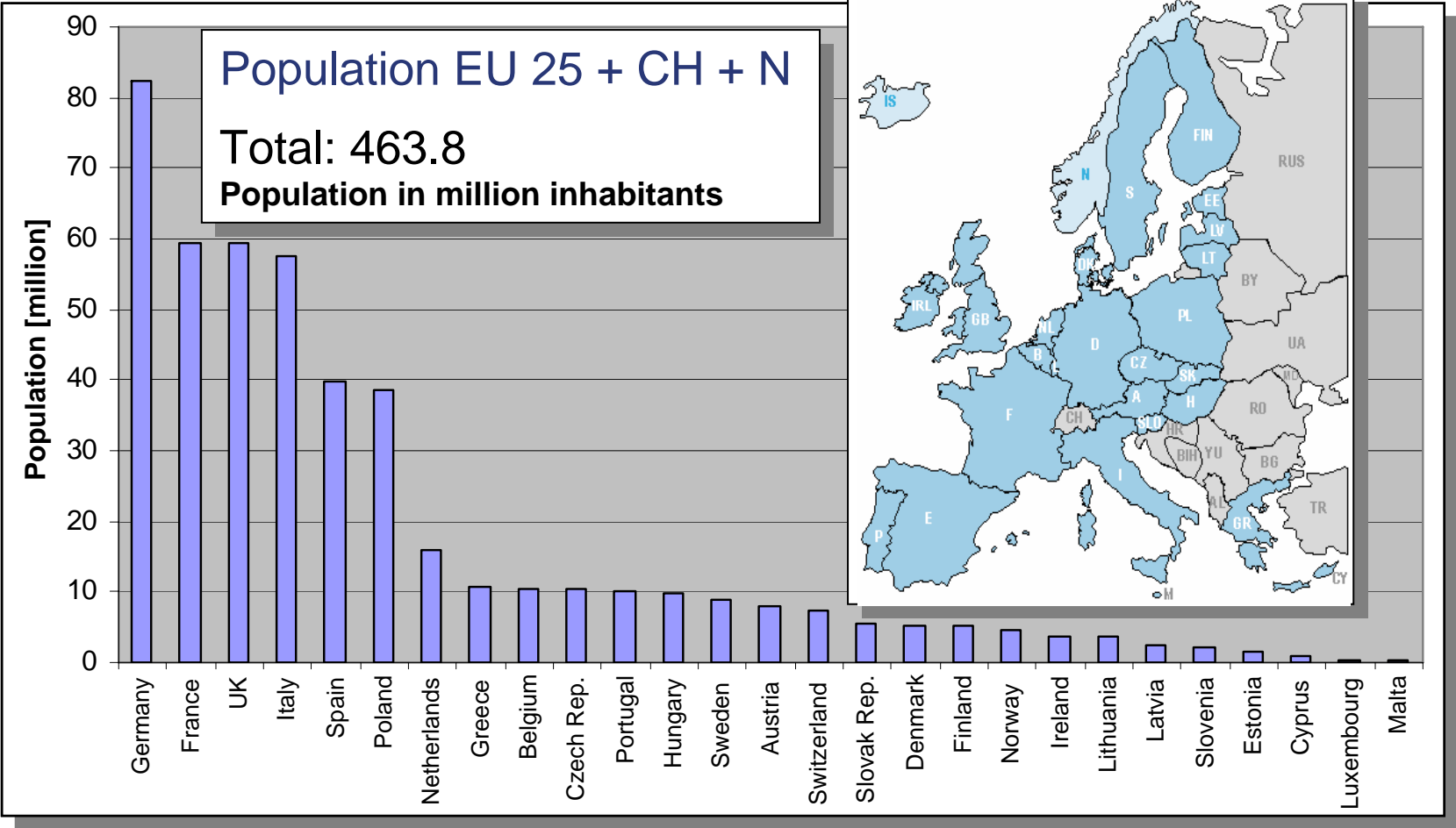
## Methodology

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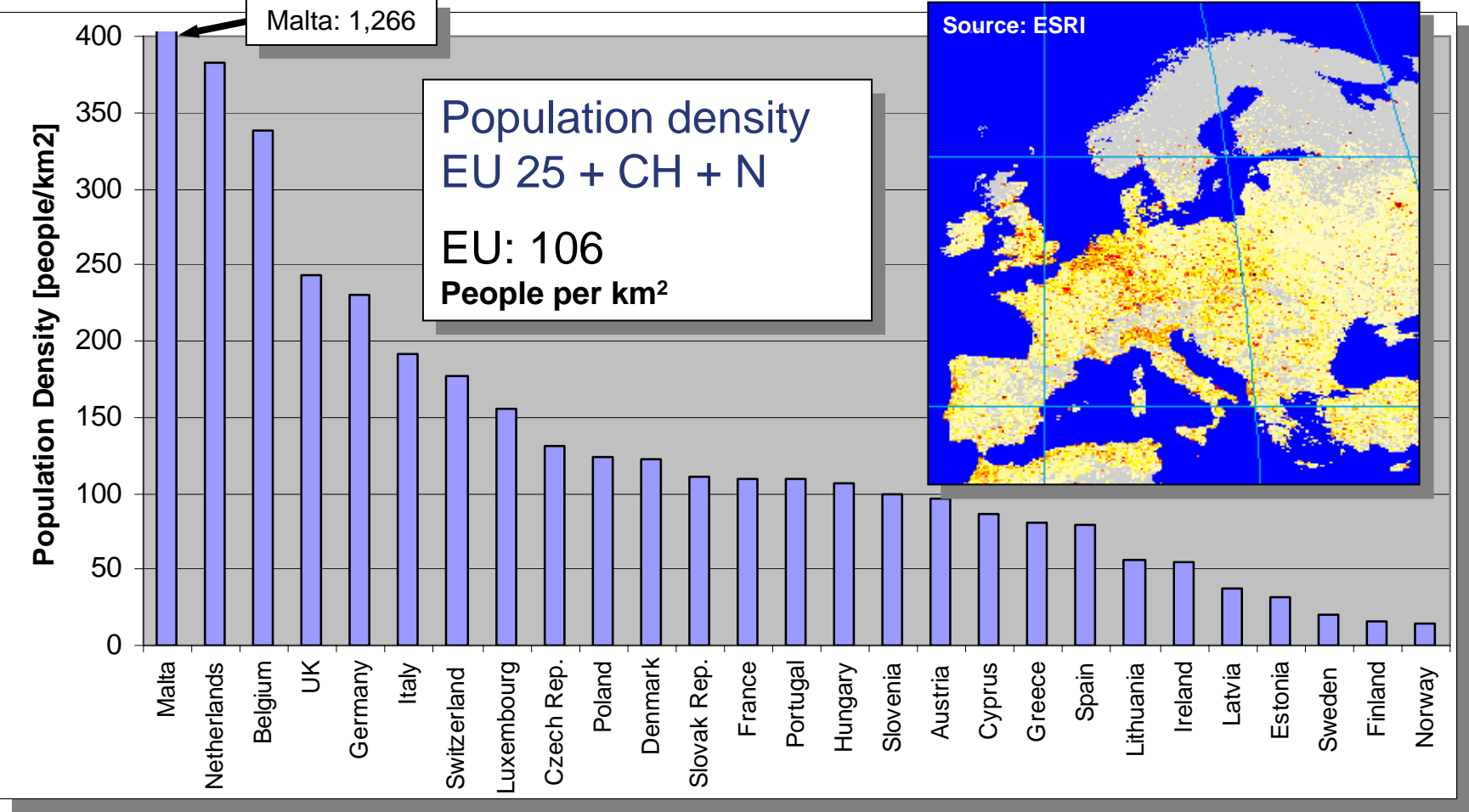
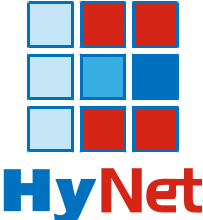
The following analysis is a potential snapshot of the hydrogen fuelling station network build-up providing clues for the following issues:

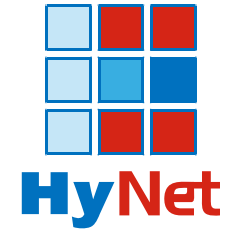
- How many fuelling stations are required in order to supply a definite percentage of the European population?
- Where should the fuelling stations be located?
- What are the investment costs for the establishment of the hydrogen infrastructure in order to reach an area-wide coverage?

# HyNet - European Basic Hydrogen Fuelling Station Network



# HyNet - European Basic Hydrogen Fuelling Station Network





## Where to locate hydrogen fuelling stations?

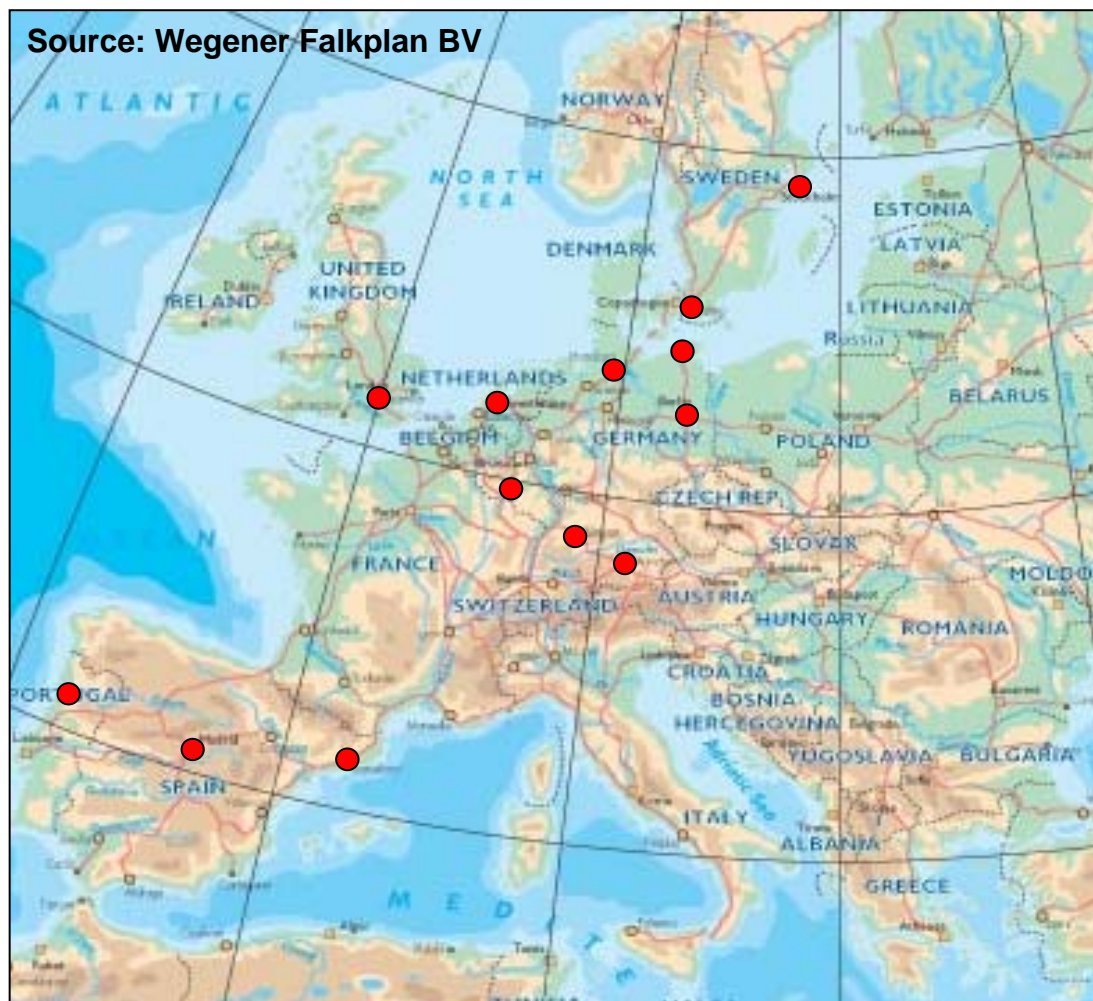
- First hydrogen fuelling stations should be available in population centres. The analysis has considered the following city population numbers:  
20,000, 50,000, 100,000 and 500,000 inhabitants
- These cities may later be interlinked by hydrogen fuelling stations installed along motorways and primary four-lane roads.

### Exemplary hydrogen fuelling station build-up in phases

A 0<sup>th</sup> order approach for the establishment of a Europe-wide hydrogen fuelling station network could incorporate 4 preparatory phases:

- I Introduction of hydrogen vehicles in **demonstration sites** (e.g. CUTE).
- II Additional use of hydrogen in **transportation fleets** (postal service, municipality vehicles, etc.) in **population and political centres** (e.g. European capitals).
- III First application of hydrogen in **privately used cars**. Growth of fuelling station network in population centres and **geographical expansion**.
- IV Further growth to comply with a **wide availability of hydrogen throughout Europe** by extension of the existing hydrogen fuelling station network in population centres and **along motorways and primary four-lane roads**.

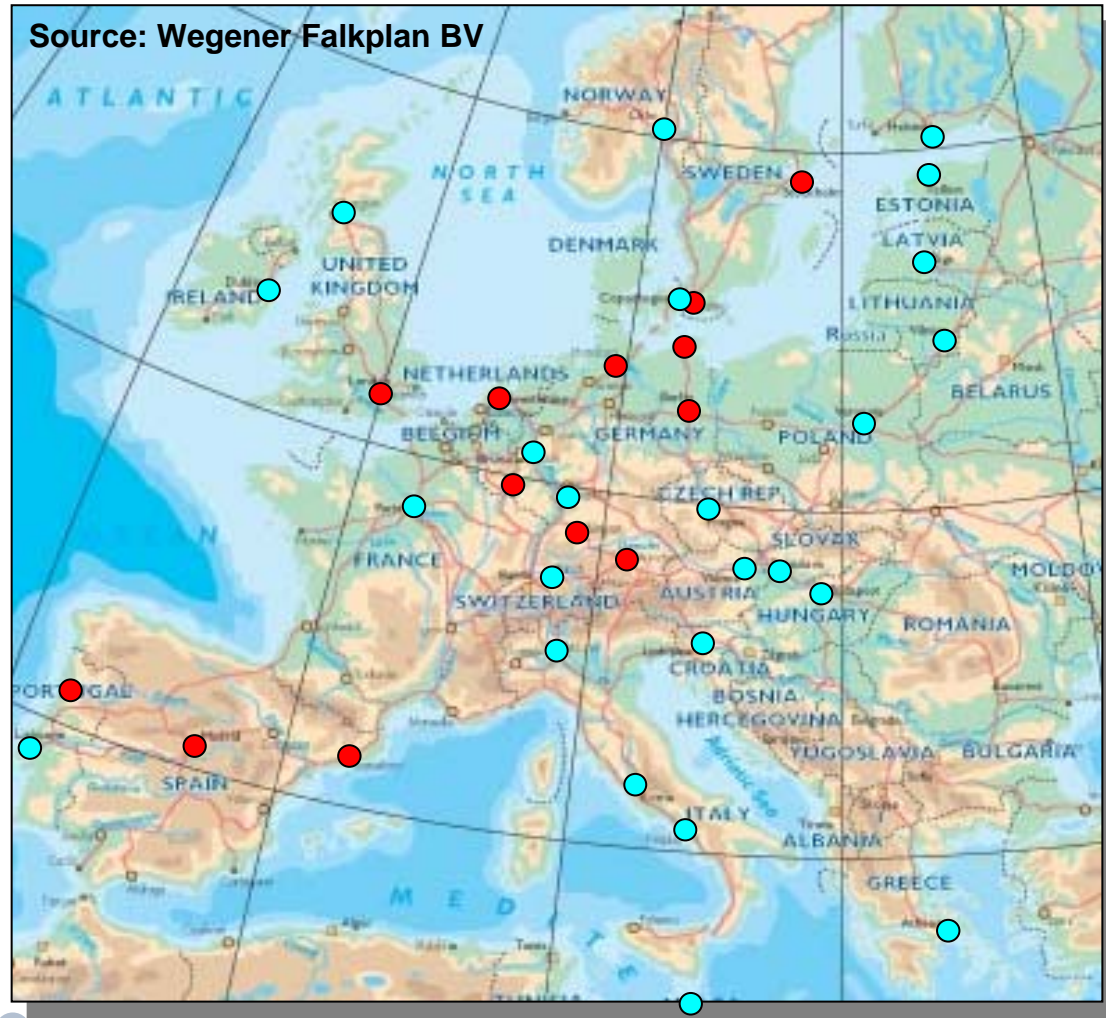
# HyNet - European Basic Hydrogen Fuelling Station Network



[www.HyNet.info](http://www.HyNet.info)

- Phase I:**
  - existing demonstration sites
  
- Phase II:**
  - extension to population centres (> 1 million) and EU capitals
  
- Phase III:**
  - growth in population centres
  - extension to further population centres
  
- Phase IV:**  
**HyNet roadmap analysis (not graphical)**

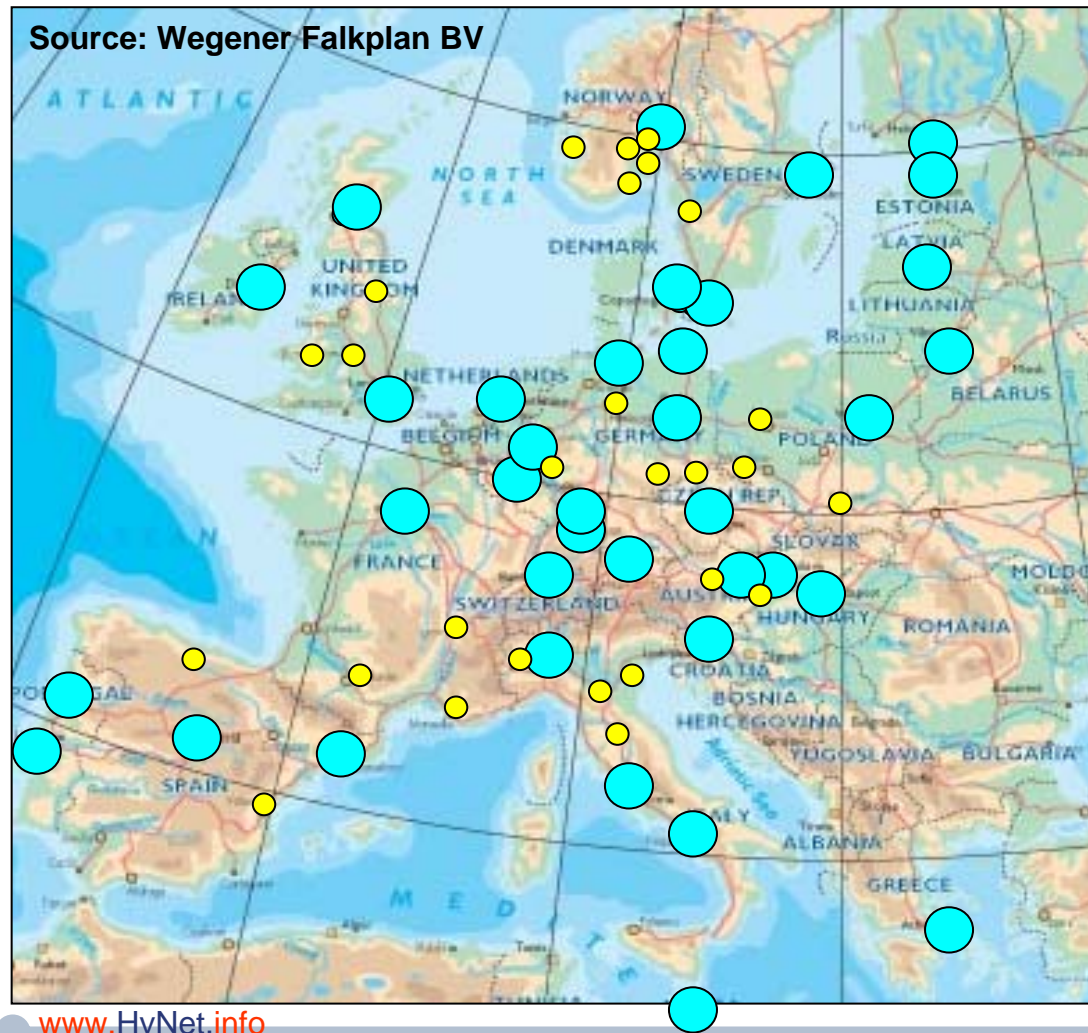
# HyNet - European Basic Hydrogen Fuelling Station Network



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- Phase I:
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# HyNet - European Basic Hydrogen Fuelling Station Network



- Phase I:**
  - existing demonstration sites
  
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- Phase III:**
  - growth in population centres
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- Phase IV:**  
**HyNet roadmap analysis (not graphical)**

### Limitations

#### Depth

The perspective considered in the analysis is limited by the parameters chosen (“population in cities” and “density of motorway grid”). Other relevant parameters are not considered here such as “driving distance to fuelling station” and “population density”.

#### Accuracy

The results only provide the order of magnitude of the required fuelling station numbers across Europe to validate the HyNet Roadmap results.

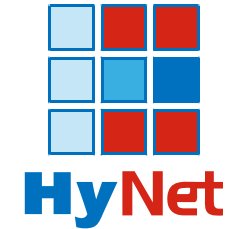
#### Relevance

Especially, it is not meant to exclude relevant member states for which the parameters chosen do not suggest an early infrastructure build-up, e.g. missing motorways will not be a killer-criterion.



## Fuelling Station Build-up in Cities

# HyNet - European Basic Hydrogen Fuelling Station Network



Country	No. of cities >20,000	People in these cities	% of population
Austria	24	2.879.000	36
Belgium	91	4.980.000	48
Cyprus	6	302.000	38
Czech Republic	63	4.541.000	44
Denmark	63	3.393.000	64
Estonia	6	684.000	49
Finland	52	3.141.000	60
France	402	22.387.000	38
Germany	683	47.395.000	58
Greece	70	5.102.000	48
Hungary	63	4.943.000	50
Ireland	16	1.155.000	30
Italy	474	29.716.000	52
Latvia	10	1.254.000	52
Lithuania	19	1.837.000	50
Luxembourg	4	180.000	45
Malta	1	22.000	6
Netherlands	236	13.026.000	82
Norway	43	2.467.000	55
Poland	222	18.705.000	48
Portugal	78	3.675.000	37
Slovak Republic	40	2.161.000	40
Slovenia	7	499.000	25
Spain	246	24.976.000	63
Sweden	119	7.090.000	81
Switzerland	30	1.800.000	25
UK	480	37.354.000	63

Population reached  
(example)

**EU:**

Nr. of Cities >20,000:

**3,548**

People in these cities:

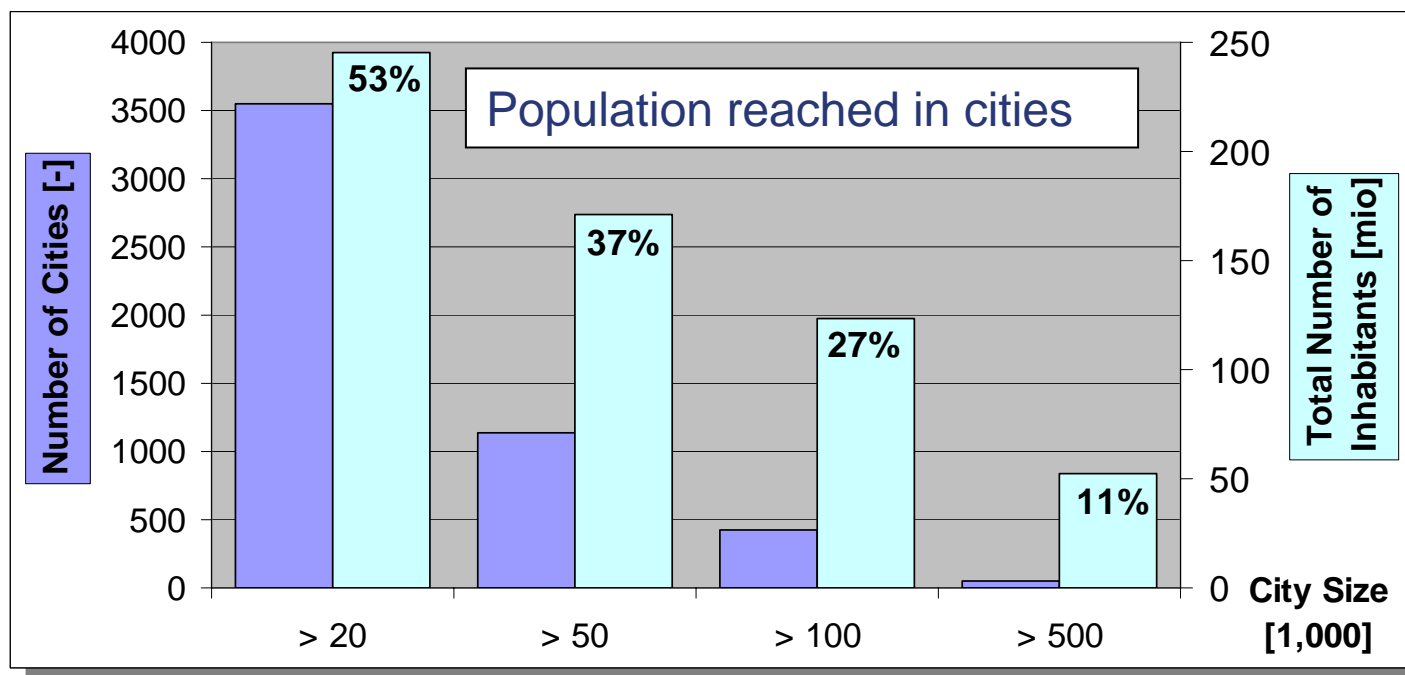
**245,664,000**

% of total population

**53**

# HyNet - European Basic Hydrogen Fuelling Station Network

City Population [Inhabitants]	Number of Cities [-]	Total Number of Inhabitants [mio]	Population Reached [% of EU + CH + N]
> 20,000	3,548	246	53
> 50,000	1,133	171	37
> 100,000	429	124	27
> 500,000	47	52	11



## HyNet - European Basic Hydrogen Fuelling Station Network

How many fuelling stations are required to supply these cities (realistic approach)?

A first linear approach for the fuelling station distribution by city size resulted in an unreasonable large number of fuelling stations in large cities.

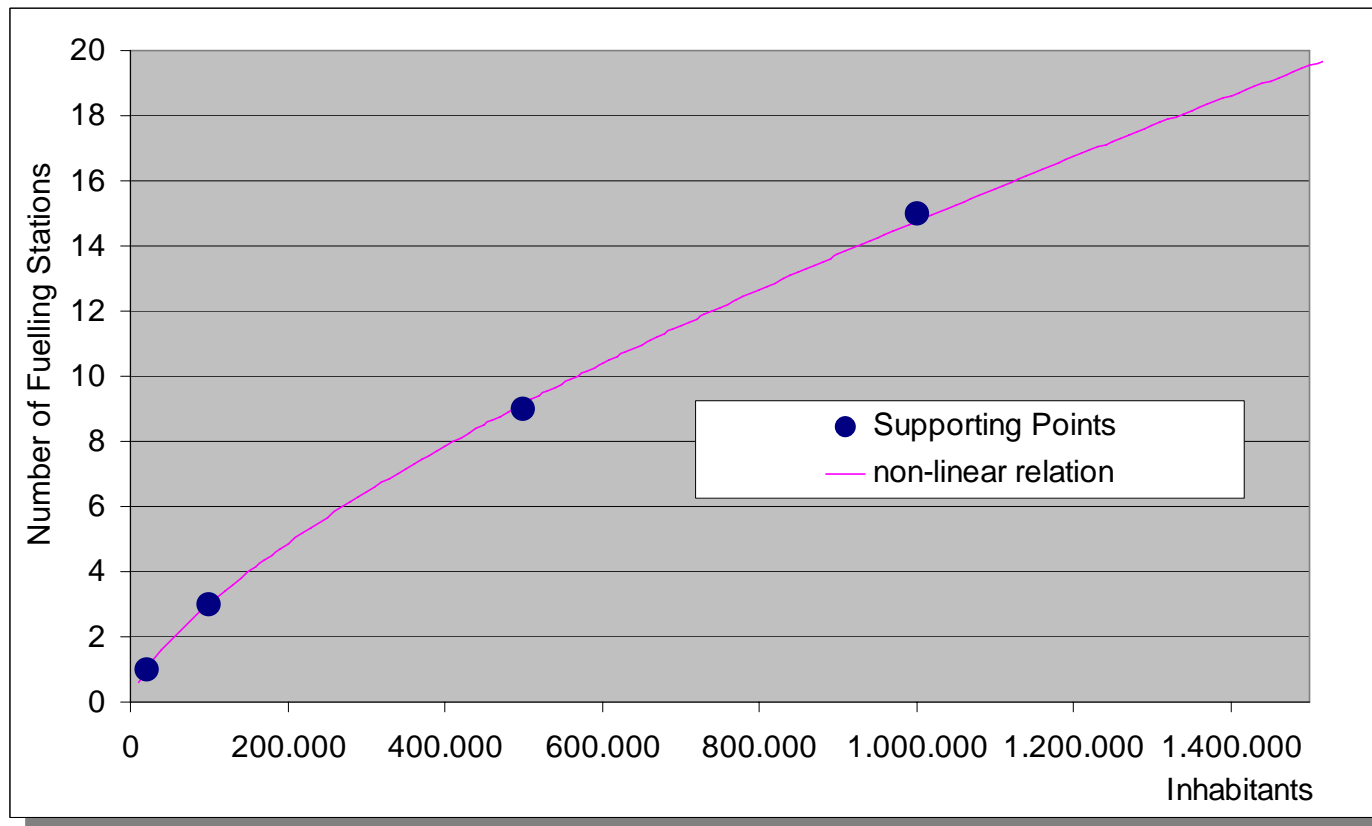
Based on **four supporting points** a non-linear relation is proposed as a first iteration (to be validated by HyWays):

x [inhabitants]	y [fuelling stations]
20,000	1
100,000	3
500,000	9
1,000,000	15

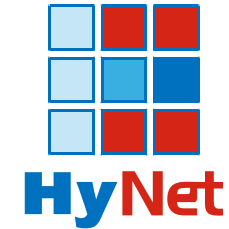
==>  $y = a \cdot x^b$  with  $a \sim 0.001$ ,  $b \sim 0.7$

## HyNet - European Basic Hydrogen Fuelling Station Network

How many fuelling stations are required to supply these cities (realistic approach)?



# HyNet - European Basic Hydrogen Fuelling Station Network



## Country No. of hydrogen fuelling stations in cities >20,000

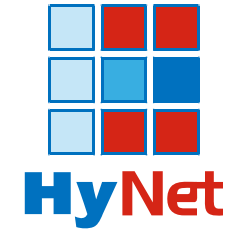
Austria	64
Belgium	159
Cyprus	11
Czech Rep.	127
Denmark	113
Estonia	18
Finland	96
France	713
Germany	1344
Greece	154
Hungary	126
Ireland	32
Italy	874
Latvia	29
Lithuania	47
Luxembourg	8
Malta	1
Netherlands	417
Norway	77
Poland	512
Portugal	121
Slovak Rep.	71
Slovenia	15
Spain	636
Sweden	226
Switzerland	55
UK	1010

Fuelling stations required to supply these cities

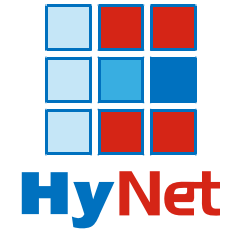
If hydrogen fuelling stations are erected in cities > 20,000 inhabitants in EU 25 + CH + N (table on the left) **7,056** hydrogen fuelling stations were required in total.

Other specific population numbers result in the following total numbers of hydrogen fuelling stations:

Population in Cities ...	FS in these Cities
> 20,000	<b>7056</b>
> 50,000	4029
> 100,000	2431
> 500,000	703



## Fuelling Station Build-up along Trunk Roads (Phase IV and after)

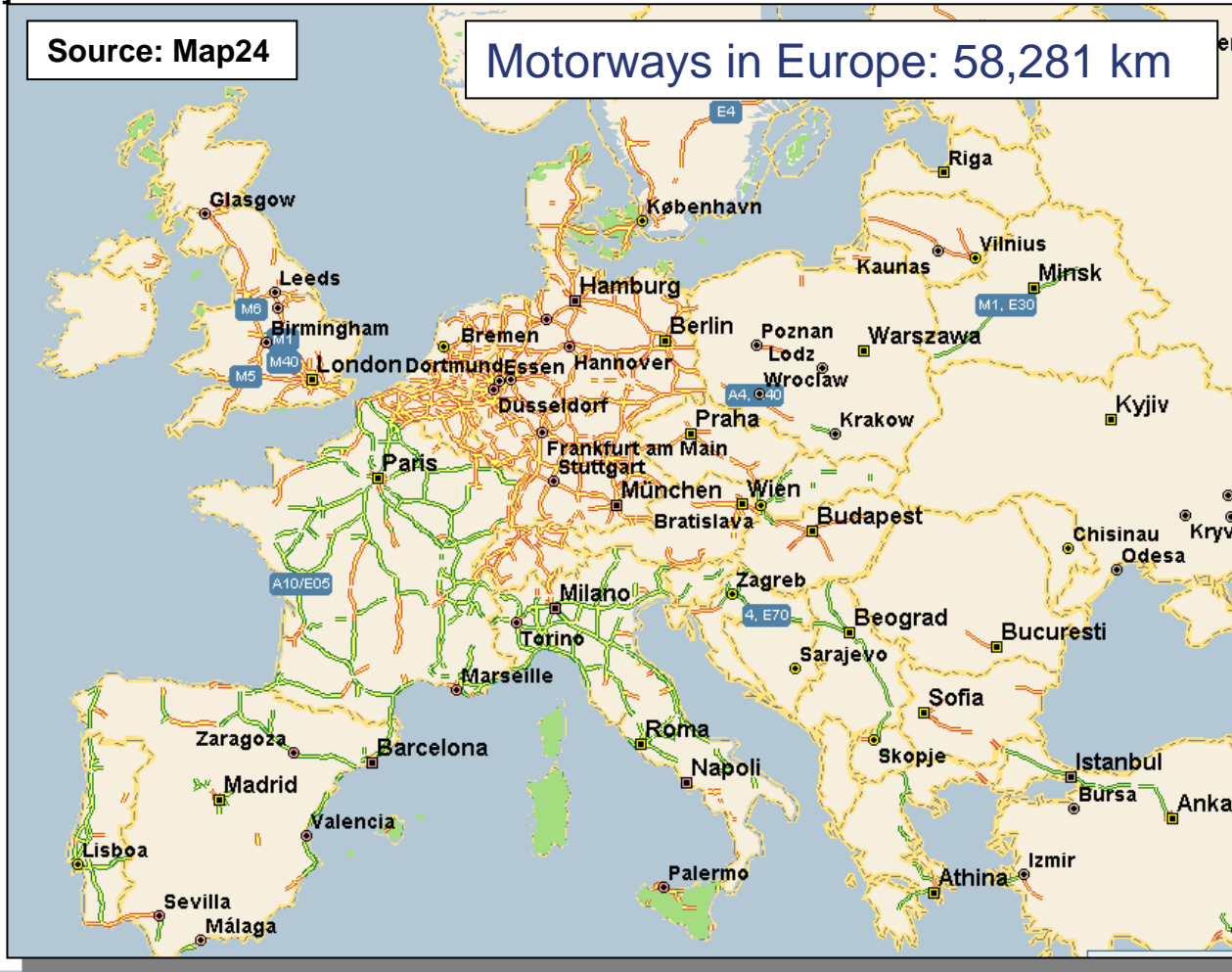


### Expansion from urban areas

- The expansion from the demonstration sites (Phase I) or from larger cities (Phase II and Phase III) will cause a build-up of fuelling stations along trunk roads\* in Phase IV.
- A simple 0<sup>th</sup> order assumption is to erect these fuelling stations along trunk roads\*.

# HyNet - European Basic Hydrogen Fuelling Station Network

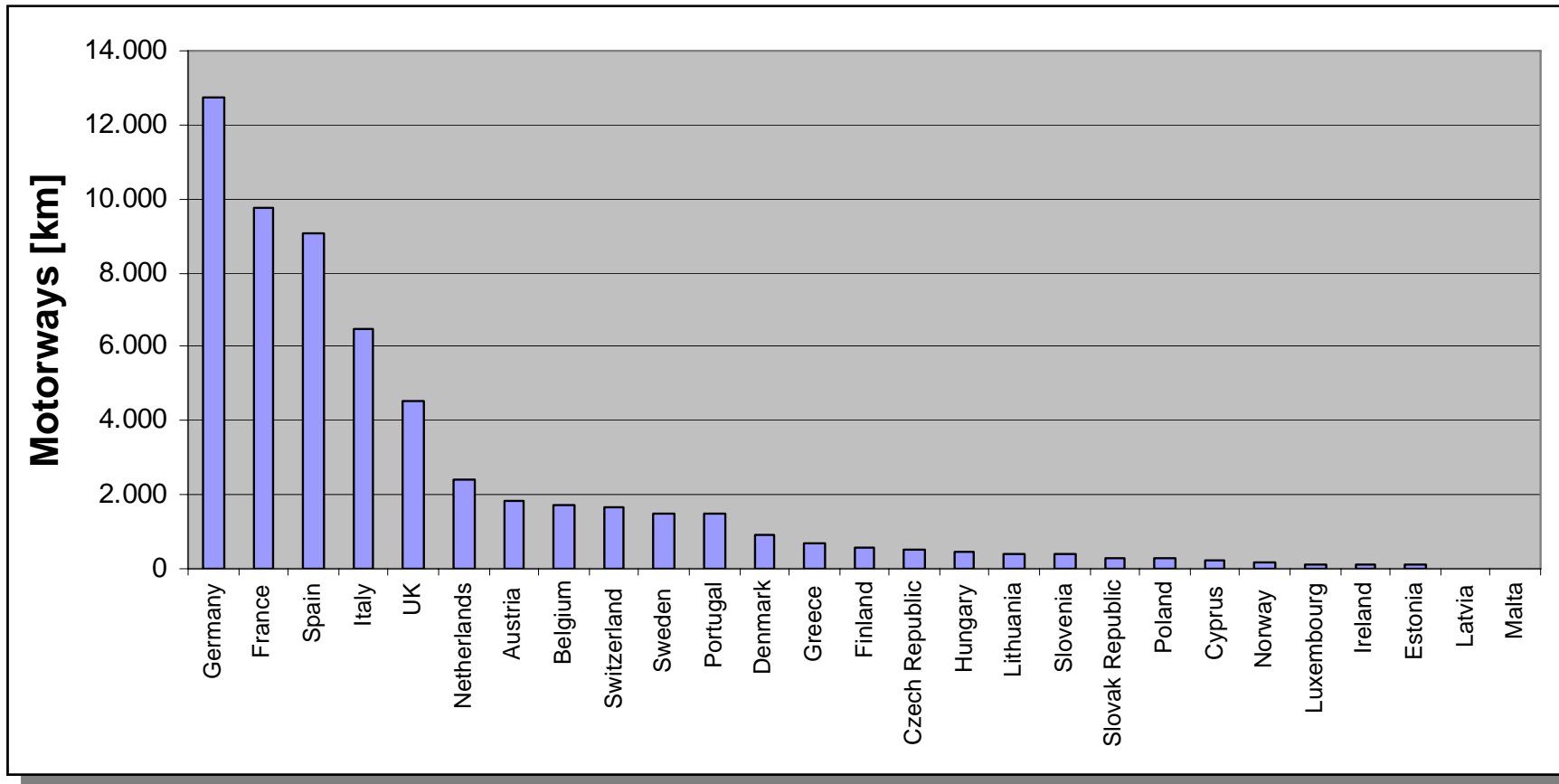
Country	Motorways [km]
Austria	1,840
Belgium	1,700
Cyprus	220
Czech Rep.	500
Denmark	920
Estonia	87
Finland	550
France	9,770
Germany	12,710
Greece	707
Hungary	440
Ireland	103
Italy	6,480
Latvia	0
Lithuania	420
Luxembourg	120
Malta	0
Netherlands	2,390
Norway	144
Poland	268
Portugal	1,480
Slovak Rep.	290
Slovenia	400
Spain	9,050
Sweden	1,500
Switzerland	1,642
UK	4,550



# HyNet - European Basic Hydrogen Fuelling Station Network



## Motorways in Europe: 58,281 km



## HyNet - European Basic Hydrogen Fuelling Station Network

### Country                      Nr. of hydrogen fuelling stations at motorways

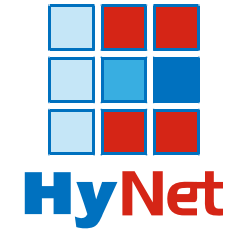
Austria	74
Belgium	68
Cyprus	9
Czech Rep.	20
Denmark	37
Estonia	3
Finland	22
France	391
Germany	508
Greece	28
Hungary	18
Ireland	4
Italy	259
Latvia	0
Lithuania	17
Luxembourg	5
Malta	0
Netherlands	96
Norway	6
Poland	11
Portugal	59
Slovak Rep.	12
Slovenia	16
Spain	362
Sweden	60
Switzerland	66
UK	182

Fuelling stations required to supply these trunk roads

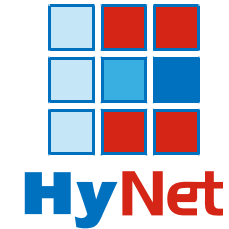
If hydrogen fuelling station pairs are erected along all trunk roads in EU 25 + CH + N each 50 km (table on the left) **2,331** hydrogen fuelling stations were required in total.

Other distances between fuelling station sites result in the following total numbers of hydrogen fuelling stations:

Hydrogen Fuelling Stations Every ... km	Nr. of Fuelling Stations
20	5828
50	<b>2331</b>
100	1166



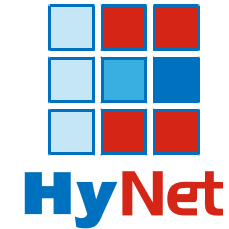
## Fuelling Station Build-up Total (Phase IV and after)



## Relevant parameter combinations

For the four hydrogen fuelling station build-up phases the following combinations have been chosen (due to the high uncertainty a bandwidth has been used for Phase IV):

	Population in Cities...	Trunk Road FS every ... km
Phase I	-	0
Phase II	> 500,000	0
Phase III	> 100,000	<i>only insular FS</i>
Phase IV - low	> 50,000	100
Phase IV - high	> 20,000	50



How many fuelling stations are required for these infrastructure build-up phases?

The following fuelling station numbers result from the previous parameter combinations:

	FS in Cities	FS at motorways	Total
Phase I	dozens	0	dozens
Phase II	703	0	703
Phase III	2431	dozens	2431
Phase IV - low	4029	1166	5195
Phase IV - high	7056	2331	9387

## HyNet - European Basic Hydrogen Fuelling Station Network

How many fuelling stations are required in order to supply a definite percentage of the population?

~ 7,000 hydrogen fuelling stations in cities

~ 2,332 hydrogen fuelling stations at motorways

==> ~ **9,400** hydrogen fuelling stations will provide access

for ~ 250 million people or ~ **55%** of the European

population in ~ 3,500 cities to **hydrogen** as a vehicle fuel!!

HyNet Roadmap validation:

How many fuelling stations are required in Phase IV to supply a definite percentage of the population?

Phase IV - low

Up to **40%** of the population (or ~170 million) in ~1,100 cities > 50,000 inhabitants could have access to hydrogen as a fuel by building **~5,000** hydrogen fuelling stations (~4,000 in cities and ~1,000 along motorways)

Phase IV - high

Up to **55%** of the population (or ~250 million) in ~3,500 cities > 20,000 inhabitants could have access to hydrogen as a fuel by building **~10,000** hydrogen fuelling stations (~7,500 in cities and ~2,500 along motorways)

### How many vehicles can be served in Phase IV?

Based on the assumed fuelling station size the following conclusions can be drawn for “Phase IV - low” / “Phase IV - high”:

- The **~1,000 / 2,500** fuelling stations at motorways do **not** contribute to increase the population coverage with hydrogen vehicles!
- **~4,000 / 7,000** hydrogen fuelling stations will be installed in cities
- In total they can serve **~3.5 / 6** million or **~1.8 / 3%** of all passenger cars



## Fuelling Station Investments

### What are the investment costs to reach an area-wide coverage in Phase IV?

The influence of economic learning curves on hydrogen fuelling station investments is shown for the example of on-site hydrogen refuelling:

	low*	high**
1 <sup>st</sup> unit:	EUR 1,040,000 - 1,880,000	
5,000 <sup>th</sup> unit:	EUR 444,000 - 802,000	
10,000 <sup>th</sup> unit:	EUR 414,000 - 748,000	
==> average (@5,000 units):	EUR 731,000 - 891,000	
==> average (@10,000 units):	EUR 712,000 - 831,000	

These cost figures represent long-term aspirational goals.

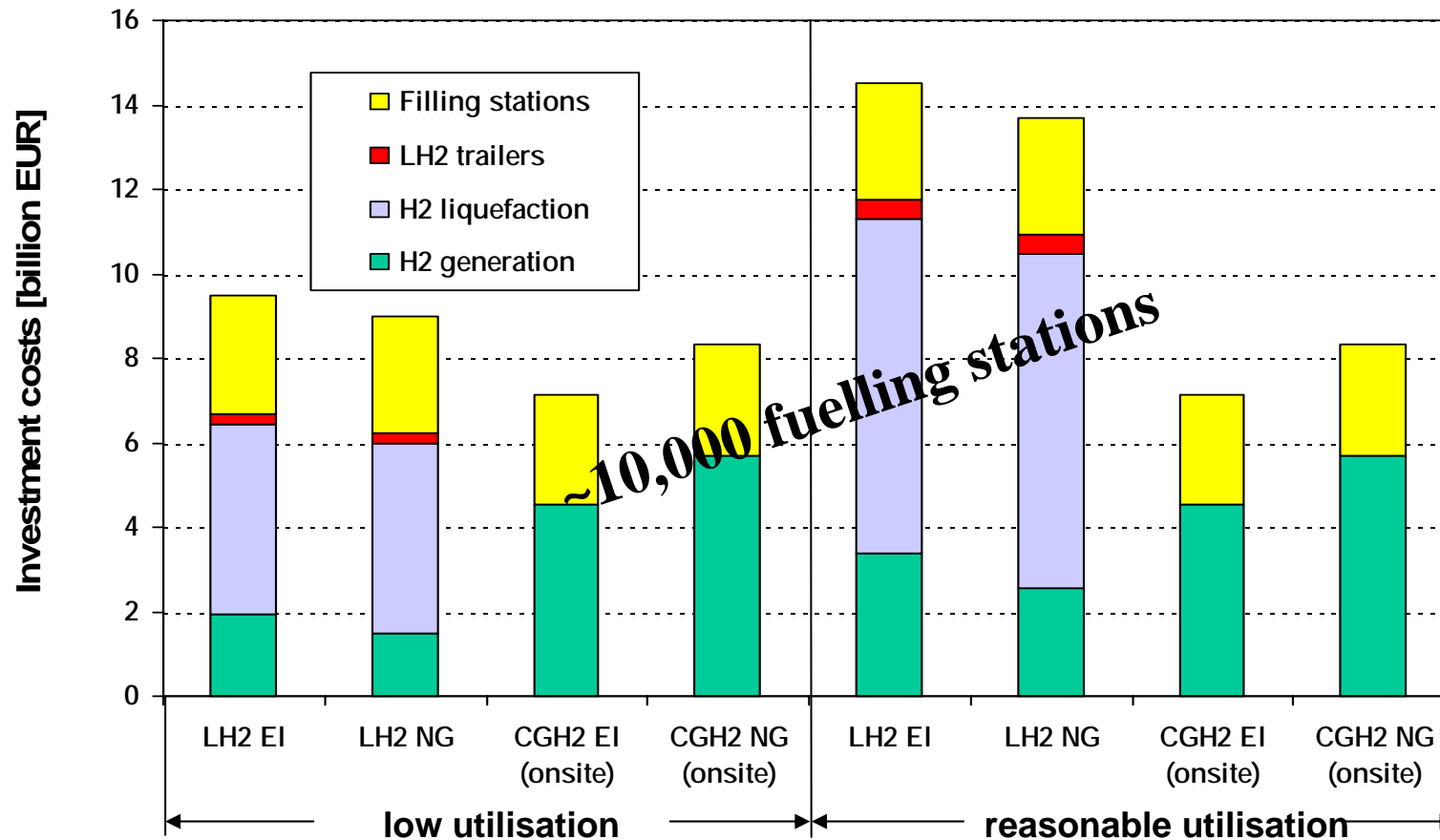
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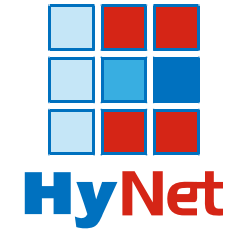
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What are the characteristics of one of these fuelling stations\* (reasonable utilisation)?

- 1 dispenser with 2 fuelling hoses
- 12 opening hours / day
- 6 fuelling procedures / hour
  - ==> 72 fuelling procedures / day
  - ==> “reasonable utilisation”!!
- 395 kg hydrogen sold per day
- ~ EUR 750,000 investments  
(onsite hydrogen production included)
- 880 hydrogen vehicles served

## What are the investments for an area-wide coverage?





### What are the investments for an area-wide coverage?

The total investments for a basic pan-European area-wide hydrogen fuelling station network based on  $\text{CGH}_2$  (onsite) and  $\text{LH}_2$  (central) will amount to about

**EUR 3.5 - 7.5 billion\*** for 5,000 fuelling stations and

**EUR 7 - 14 billion\*** for 10,000 fuelling stations

These cost figures are dependant on achieving significant technological and economic breakthroughs.



## Scoping of Results

### Economic magnitude of the fuelling infrastructure build-up

On-site natural gas reforming and electrolysis from mainly fossil electricity are proven technologies to be replaced by renewable energy options in the medium- to long-term. In the transition phase (example “Phase IV - high”) however they offer an economically efficient hydrogen provision:

Erecting **~10.000 hydrogen fuelling stations** in EU 25 + CH + N costs ~10 billion EUR. An annual investment of ~1 billion EUR for 10 years corresponds to

~0.01% of the GDP\*

or just ~2 EUR per person

**6 million hydrogen cars** sold over 10 years cost 120 - 300 billion EUR. An annual sales volume of 600,000 cars or 12 - 30 billion EUR corresponds to

~0.1 - 0.3% of the GDP\*

or ~3% of total annual cars sold (@ 10% annual fleet turnover)



## HyNet - European Basic Hydrogen Fuelling Station Network

### Scoping the HyNet infrastructure build-up analysis

Respecting the geographic and demographic differences ~5,000 - 10,000 hydrogen fuelling stations for a potential of ~3.5 – 6\* million cars and for ~40 - 55% of all ~450 million inhabitants cost ~7 - 15 billion EUR.

They correspond roughly with

Transport Energy Strategy Germany (TES)

1,500 - 2,000 fuelling stations for an area-wide coverage (80 million inhabitants).

“Hydrogen - The First Step” - GM study for the U.S.

6,500 fuelling stations in 100 metropolitan areas and 5,200 fuelling stations at national highways (or 11,700 in total) for 1 million cars and 70% of the total population of 280 million cost 10 - 15 billion U.S.\$.

[www.HyNet.info](http://www.HyNet.info)

\* The HyNet Roadmap claimed 2 - 9 million cars. The difference results from the additional assumption that 2,500 out of 10,000 fuelling stations do not contribute to the area-wide coverage.



## Conclusions

### Conclusions

- A four phase infrastructure build-up is assumed. Its last phase corresponds with the HyNet Roadmap analysis.
- The fuelling station number of 5,000 - 10,000 for EU 25 + CH + N, resulting from the HyNet Roadmap, are validated. The total investments amount to 7 - 15 billion EUR.
- Thereby, up to 40 - 55% of the population could gain access to hydrogen as a vehicle fuel. The fuelling capacity is adequate to supply up to 3.5 - 6 million vehicles or 1.8 - 3% of all passenger cars.
- The results stand for a 0<sup>th</sup> order approach, to be validated by the HyWays Roadmap Project.