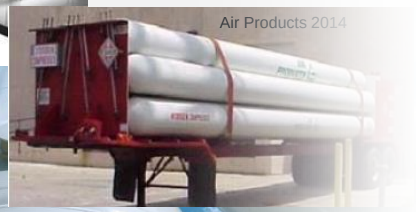


NewBusFuel

thinkstep

The 30th International Electric Vehicle Symposium & Exhibition, 2017

NewBusFuel – Large scale hydrogen refuelling infrastructure for fuel cell bus fleets

Dr. Benjamin Reuter

Stuttgart - October 9, 2017

FCH | FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

Agenda

1. What does thinkstep do?

2. Introduction into the NewBusFuel project
   - Case studies produced within the project

3. Project Output #1:
   Guidance document for planning of hydrogen refuelling stations (HRS)
   - Technical aspects
   - Economic aspects
   - Environmental aspects

4. Project Output #2:
   Recommendations for improving the cost-efficiency of hydrogen refuelling for bus fleets

What does thinkstep do?

NewBusFuel thinkstep

thinkstep GaBi

- Life Cycle Assessment and E… n. Footprinting
- Design for Com… ment
- Colla… mmunication
- Integra… d Calculation Engines
- Compliance Process Management

Product Sustainability

thinkstep SoFi

- Carbon & Energy Optimizati…
- Environmental M…
- Susta… nability
- Supply … inability
- Portfolio Sustainability Management

Corporate Sustainability

Proprietary & Industry-specific Content

- LCA Databases and Sustainabil… Content
- Regulatory Conte… mpliance
- Best P… y
- Benchmarking Libraries

Data Provision

thinkstep Consulting

- Technical, Economic… Analysis
- Sustain…
- Sustaina… d Management
- Sustainab… y Performance and Improvement

Consulting & R+D Services

Introduction

- New Bus Refuelling for European Hydrogen Bus Depots: (short: NewBusFuel)
  - Pan-European research project
  - Funded by the Fuel Cell and Hydrogen Joint Undertaking (FCH JU)

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

- Aim: **Resolving the knowledge gap** on large scale hydrogen refuelling infrastructure for fuel cell bus fleets

Introduction

- Key **challenges** of large scale hydrogen refuelling (to bus fleets):
  - Scale: throughputs in excess of 2,000 kg H_2/day
  - Reliability: close to 100% reliability to refuel
  - Refuelling time: time window for refuelling usually only 4 – 6 hours/day
  - Footprint: limited space availability in urban bus depots
  - Storage demand: desire for considerable storage capacity (usually >2 t H_2)
  - Business models: novel partnerships between suppliers and bus operators necessary

- General approach of NewBusFuel:
  - Bringing together experts from technology providers and bus operators

Locations and partners

1 Aberdeen
- Linde
- Aberdeen City Council

9 Oslo/Akershus
- HYOP
- Akershus County Council

2 Birmingham
- ITM Power
- Birmingham City Council

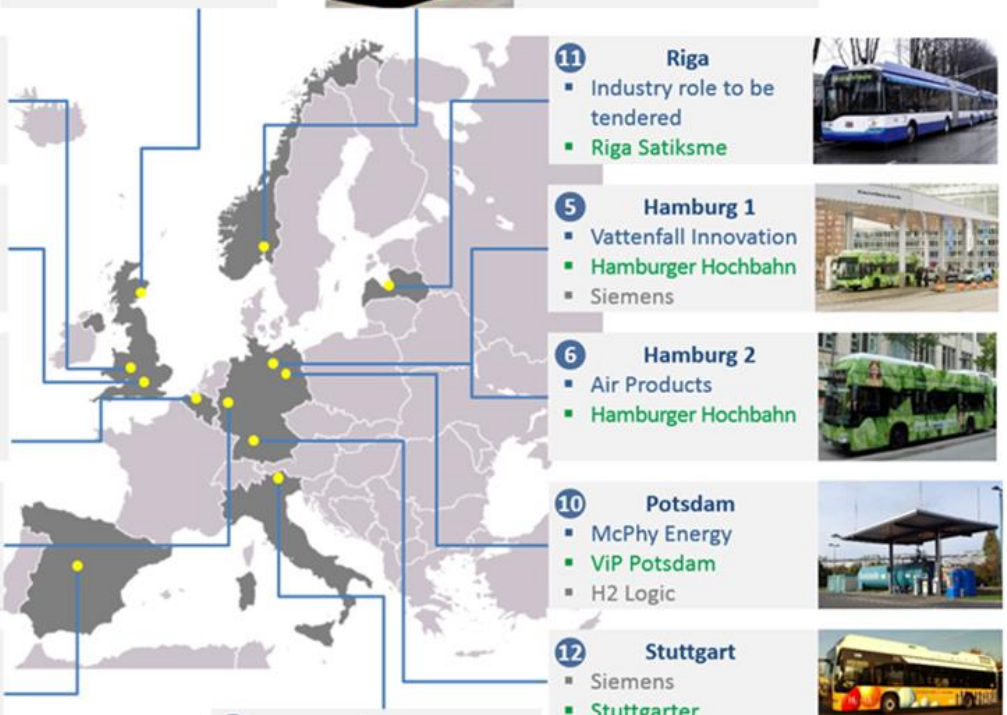
7 London
- Air Products
- London Bus Services Limited

4 De Lijn
- Linde
- De Lijn

13 Wuppertal
- Hydrogenics
- Wuppertaler Stadtwerke

8 Madrid
- Abengoa Hidrógeno
- Empresa Municipal de Transportes de Madrid

3 Bolzano
- Ingenieurbüro Bergmeister
- Inst. für Innovative Technologien Bozen Konsortial
- Siemens, Linde



11 Riga
- Industry role to be tendered
- Riga Satiksme

5 Hamburg 1
- Vattenfall Innovation
- Hamburger Hochbahn
- Siemens

6 Hamburg 2
- Air Products
- Hamburger Hochbahn

10 Potsdam
- McPhy Energy
- ViP Potsdam
- H2 Logic

12 Stuttgart
- Siemens
- Stuttgarter Strassenbahnen

Local partnerships: Industrial lead
Operator lead
Other industrial

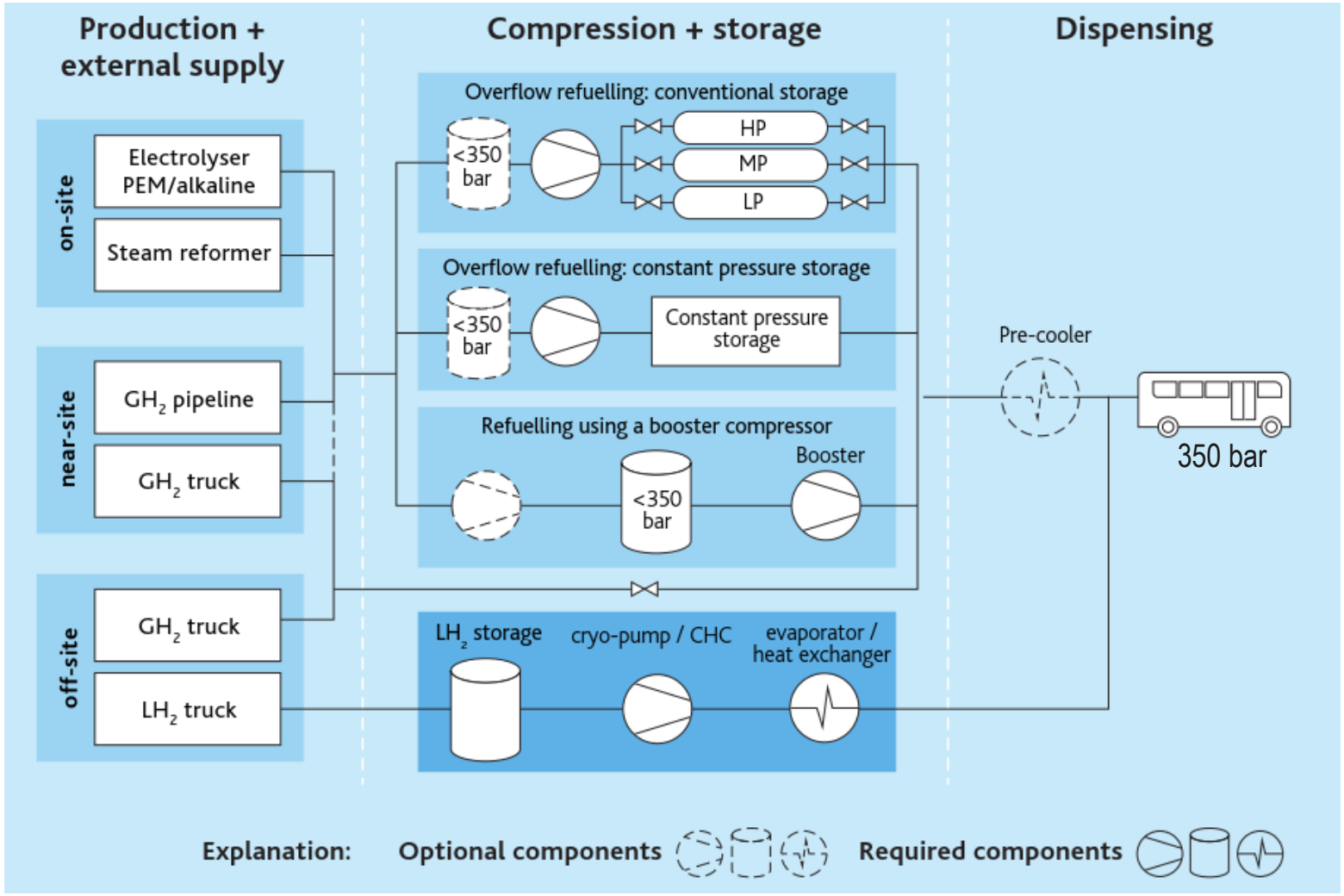
Inter-study partners: Element Energy, thinkstep, OREEC

13 case studies for 12 cities

- Results of the case studies:
  - In-depth **technical concepts**
  - Detailed **construction plans** with required safety zones
  - Comprehensive **cost assessments**

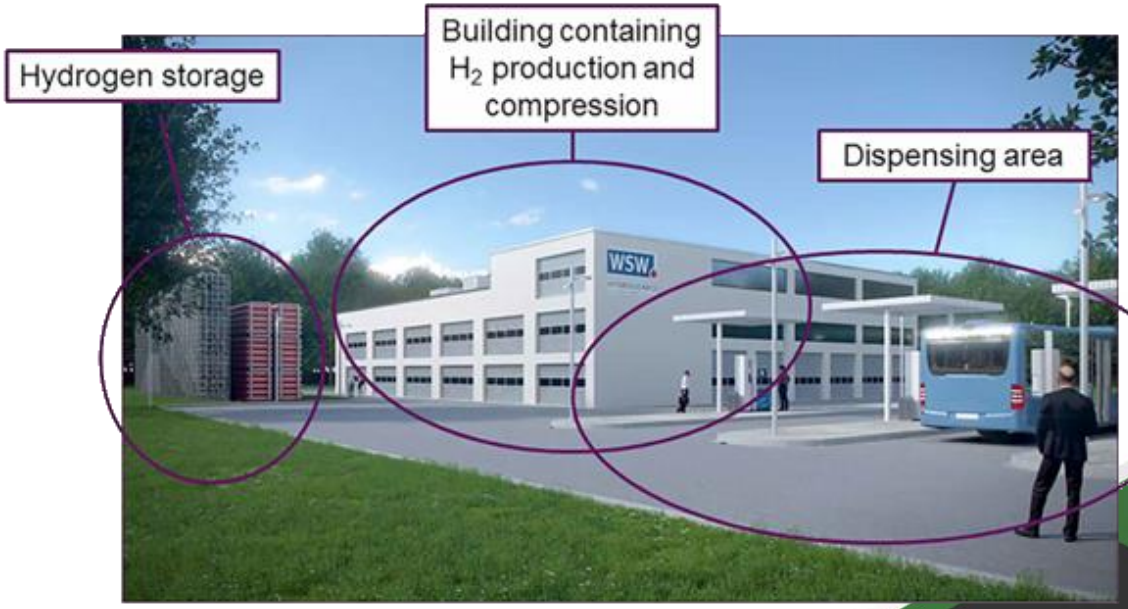
- **Optimisation** of the developed solutions, especially with respect to:
  - Cost
  - Refuelling reliability
  - Site-specific space restrictions
  - Authorities
  - Compliance with regulations, codes and standards (RCS)
  - …

Technical variety among the case studies



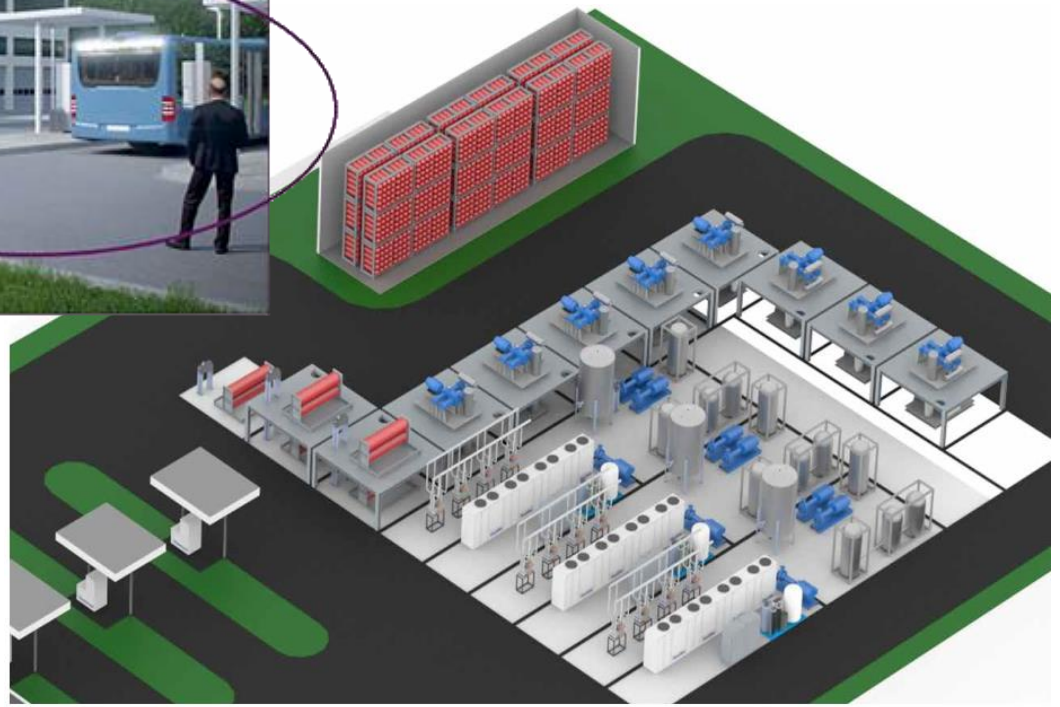
HRS examples from NBF

On-site H_2 generation I



Hydrogen Refuelling Station (HRS) with **on-site electrolysis** and a maximum daily capacity of 6 t H_2/d

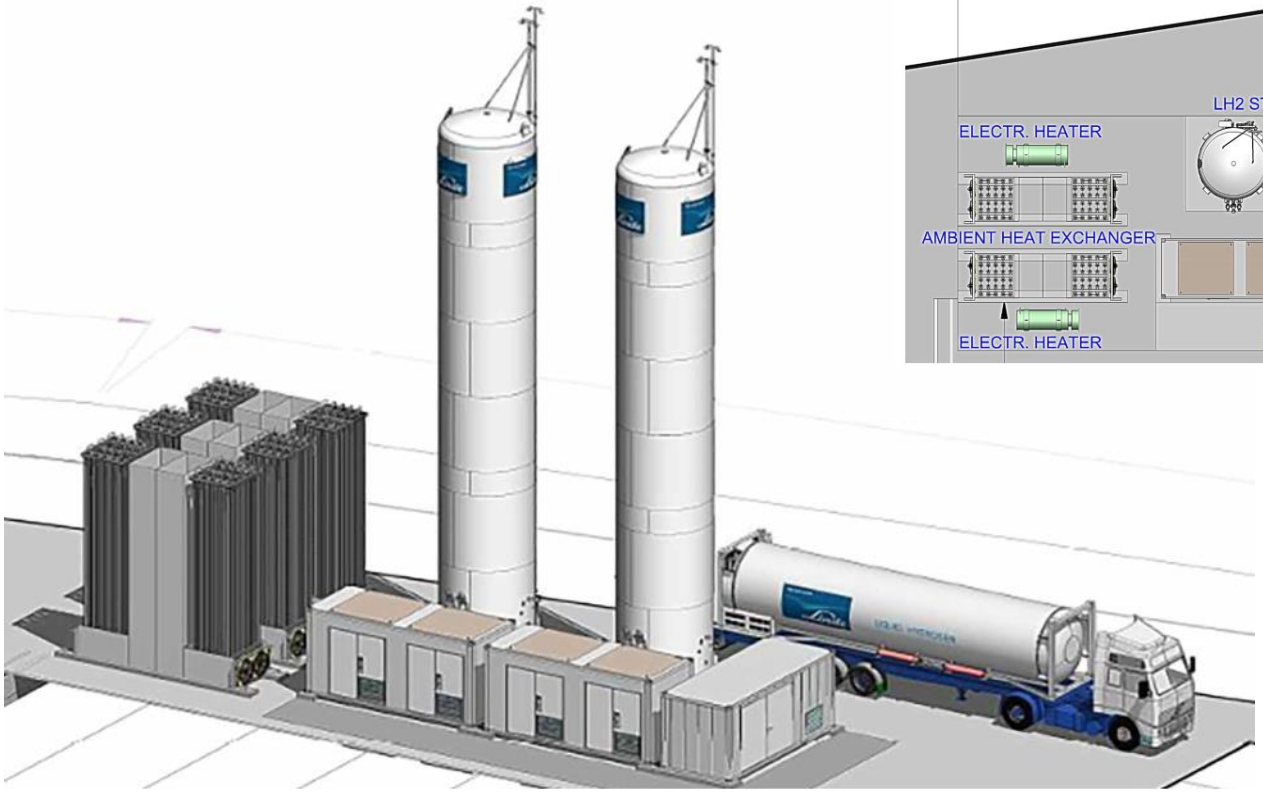
1 t H_2/d supplies 40 FC buses @ 25 kg H_2/d

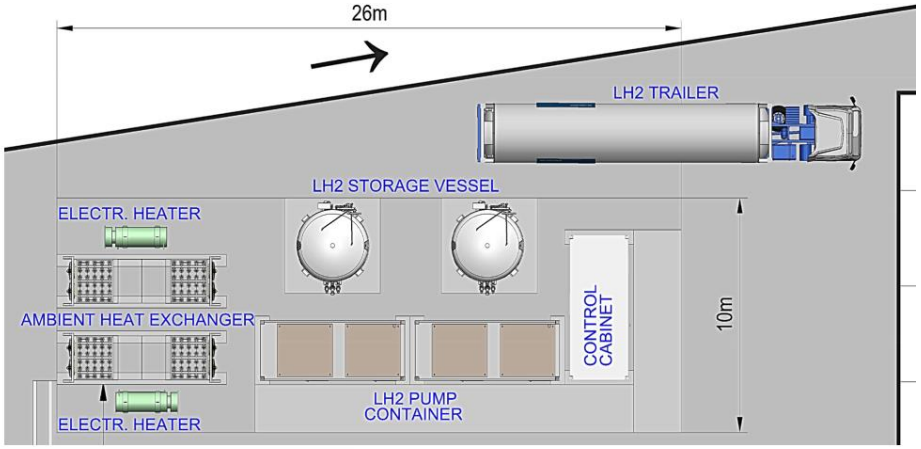


Source: WSW/Hydrogenics

HRS examples from NBF

H_2 delivery





HRS using LH_2 delivery with a daily capacity of 2.25 t H_2/d

1 t H_2/d supplies 40 FC buses @ 25 kg H_2/d

Source: Linde

Aim of our work

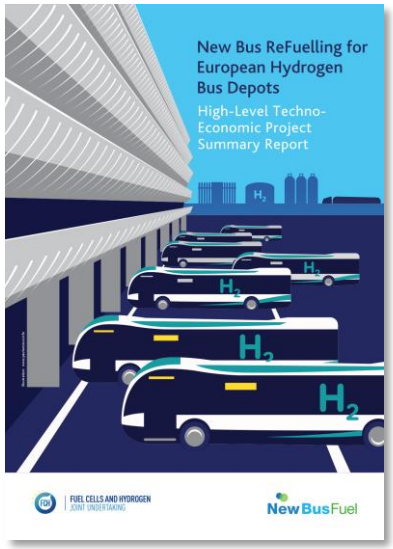
- Gather data and information from all case studies and **capture key lessons learned**

- **Provide insights** to relevant stakeholders (in aggregated and anonymised form)

Two public documents:

1. Guidance Document on Large Scale Bus Refuelling
   → Assistance for development of HRS

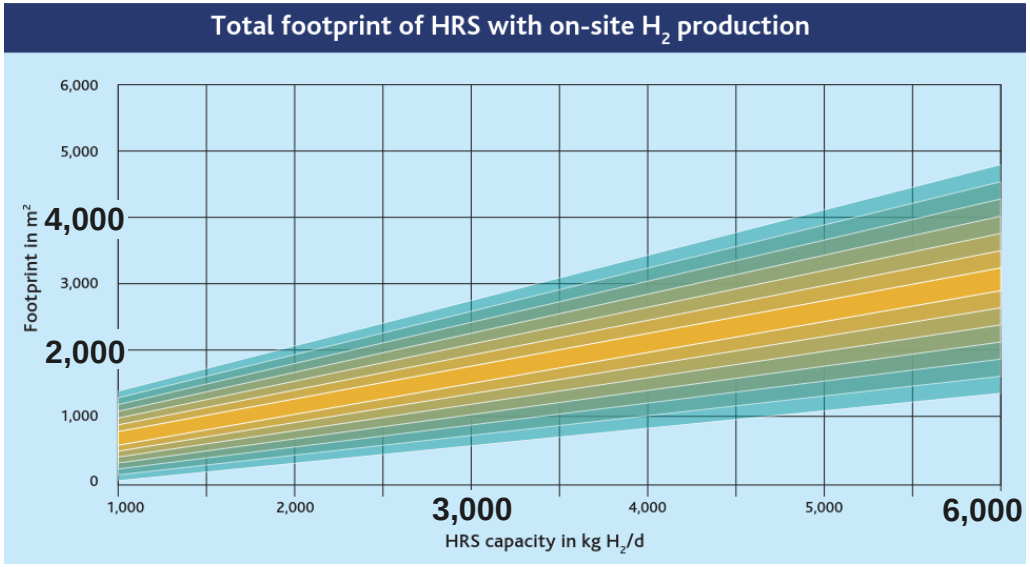
2. High-Level Techno-Economic Summary Report
   → Recommendations for improving cost efficiency (addressing bus operators, technology suppliers, policy makers)

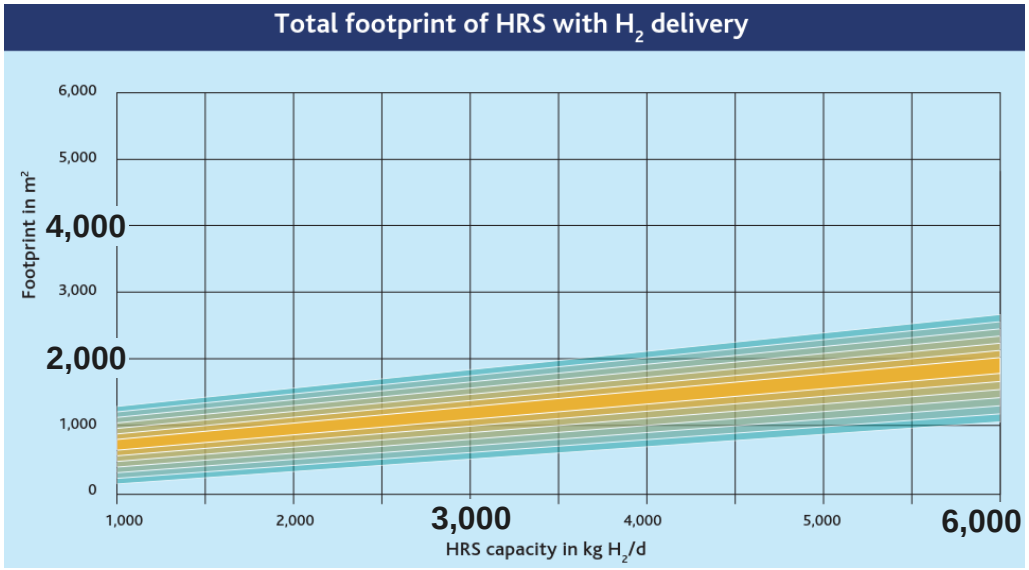


Guidance: Technical characteristics

HRS footprint

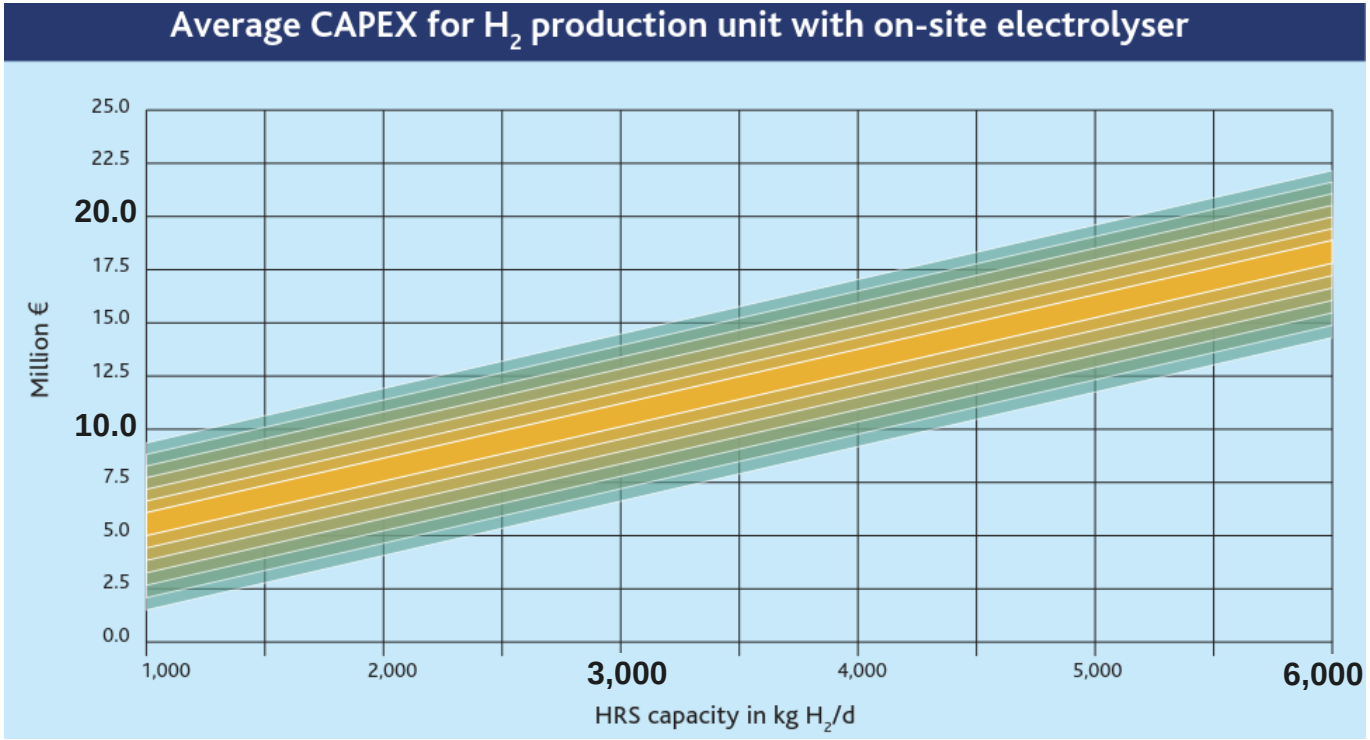
- Space constraints for the HRS at the bus depot can be crucial
- Range of results from all HRS case studies used → capacity dependent indication
- Indications on many other technical characteristics are provided in the guidance document





Guidance: Economic characteristics

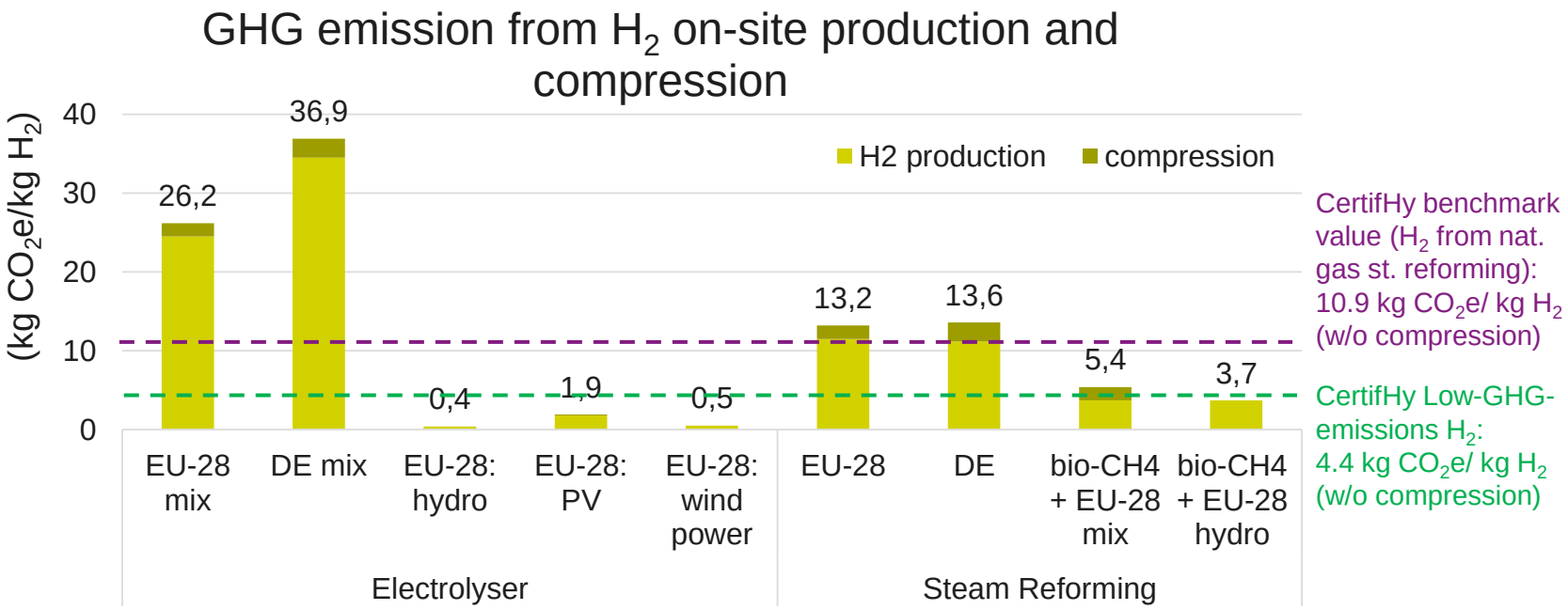
Cost of HRS modules and overall HRS costs



- Indicative approximations also derived for economic characteristics, e.g. investment of HRS modules, overall HRS cost, OPEX and CAPEX contributions, etc.

Guidance: Environ. characteristics

HRS with on-site H_2 production

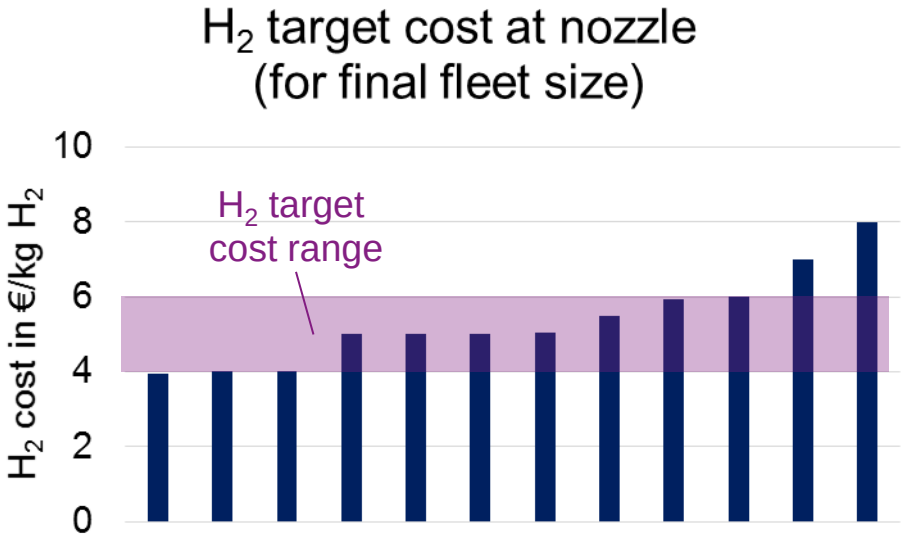


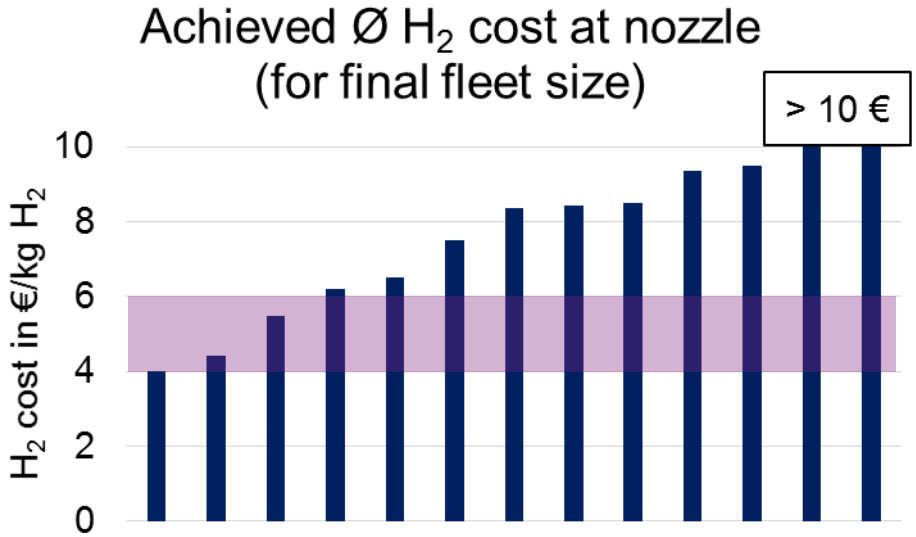
- Addressing the greenhouse gas (GHG) emissions for different HRS concepts and in various countries
- Comparison of GHG emissions of H_2 from electrolysis and steam reforming and analysis of effect of using renewable energies (green electricity and biomethane)

Final H_2 cost analysis

Target cost and achieved cost

- H_2 target cost range
  - 4 – 6 €/kg H_2 for most studies (fuel cost parity with diesel)
  - was achieved by three studies with different HRS concepts
  - case studies exceeding target cost → identification of levers for improving the cost efficiency





Recommendations

Bus operators: Balance between reliability and cost

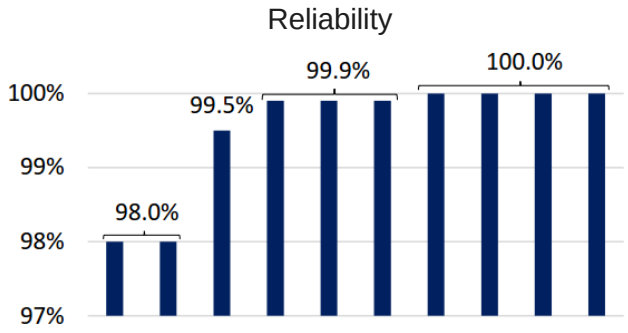
- High refuelling reliability is required by all bus operators

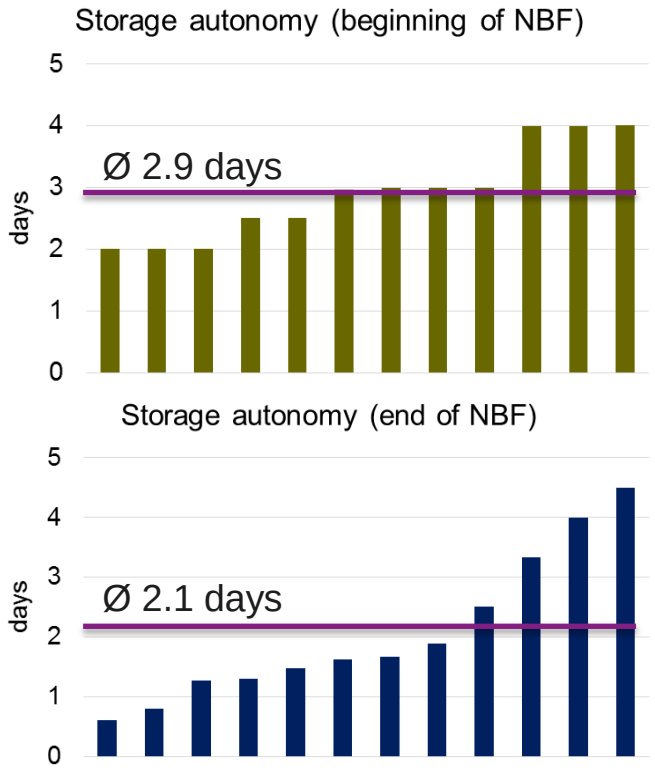
Common but cost intensive approaches for refuelling reliability:

- ‘n+1’ redundancy
- Large H_2 storage capacity

More cost-efficient measures:

- Stocking critical spare parts
- Quick response of trained staff
- Enforcement via contractual framework
- Modularity creates redundancy for larger HRS





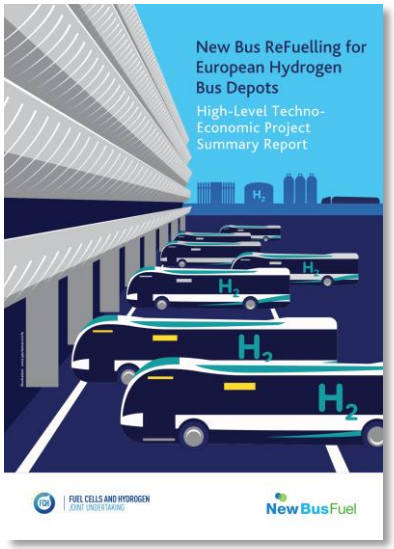
Results

These and many other recommendations are explained comprehensively in the two public documents:

- **Guidance Document** on Large Scale Hydrogen Bus Refuelling
- High-Level Techno-Economic Project **Summary Report**

→ Both documents downloadable at: http://newbusfuel.eu/

→ Or contact us in case you have further questions



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Thank you for your attention!

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