CUTE

FUEL CELL BUS PROJECT

Producing Hydrogen: Learnings from CUTE

Holger Grubel, Vattenfall Europe Hamburg AG

Klaus Stolzenburg, PLANET GbR

VATTENFALL

PLANET GbR

COFUNDED BY THE EUROPEAN COMMISSION DG tren

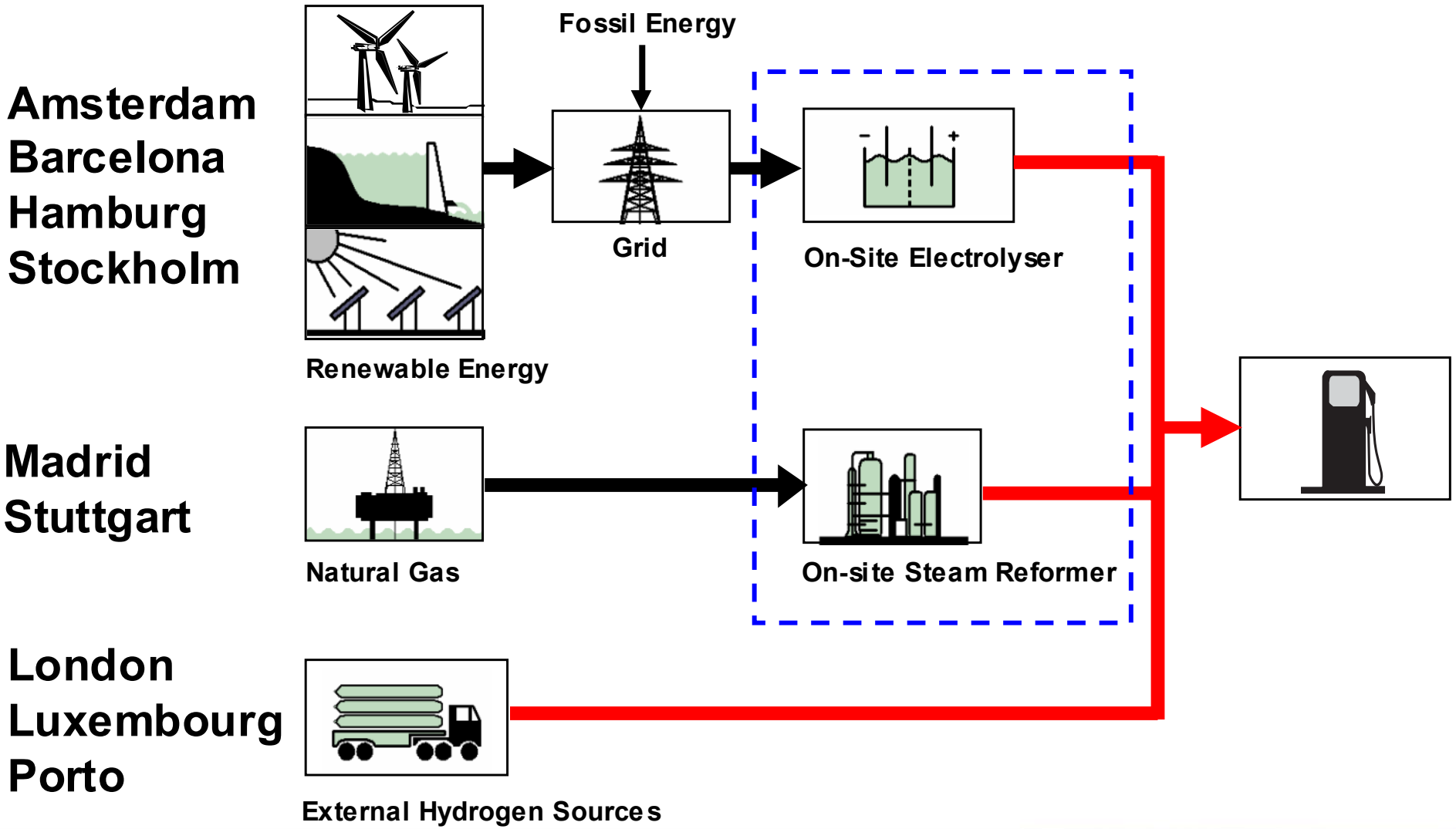
Structure

1. Introduction
2. Overview
3. Characteristics and Performance of the Electrolysis Units
4. Characteristics and Performance of the Reformer Units
5. Further Learnings from Operation
6. Conclusions and Outlook

1. Introduction

- **Build-up and operation of a hydrogen infrastructure in nine cities with nine different approaches**
- **Goal to ensure a reliable supply to the buses with identical hydrogen quality (pressure, purity, quantity)**
- **Pathways with different strengths, weaknesses, environmental impact and other framework conditions**
- **Focus of this presentation: On-site hydrogen production units (not external supply, not compressing and dispensing)**

2. Overview of Hydrogen Supply Pathways



2. Overview CUTE Assessment Framework

- **Guiding Questions, for example:**
  - **What were the main problems and learnings during planning, implementation and operation of the infrastructures?**
- **Indicators, including:**
  - **Amount of hydrogen generated on site, supplied from external sources, and dispensed**
  - **Availability of production unit and station unit**
  - **Causes for downtime**
  - **Energy demand per unit of hydrogen produced**

2. Key Operating Figures

Over two years about …

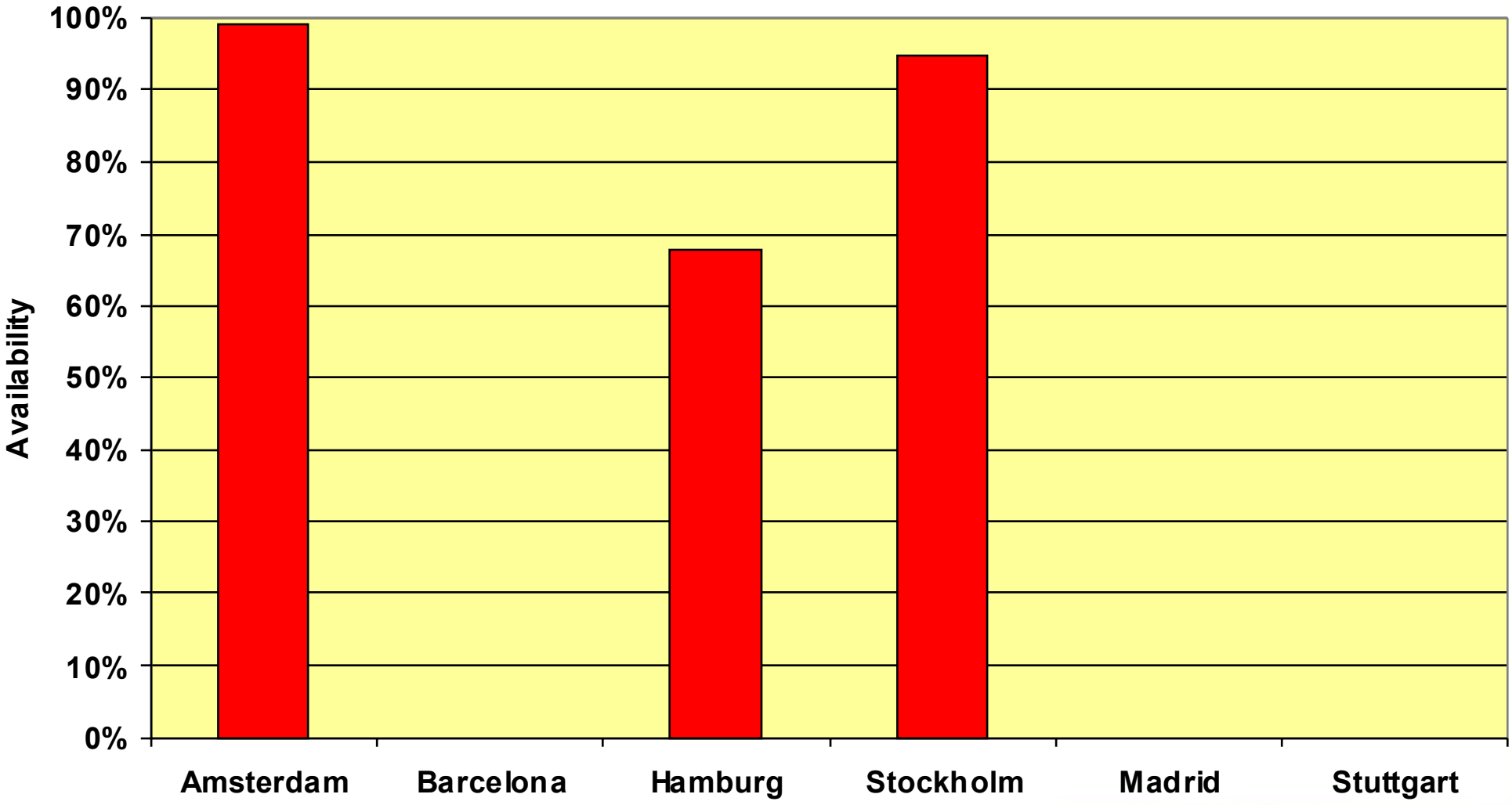
- **274.500 kg hydrogen**
  - **ca. 153.500 kg from external sources**
  - **ca. 121.000 kg from on-site generation from**
    - **electrolysis ca. 78.500 kg**
    - **steam methane reforming ca. 42.500 kg**
- **More than 56% of on-site generation from renewable energy**
- **192.000 kg hydrogen dispensed**
- **Buses more than 8.900 times refuelled**

3. Electrolysers in Amsterdam, Barcelona, Hamburg and Stockholm

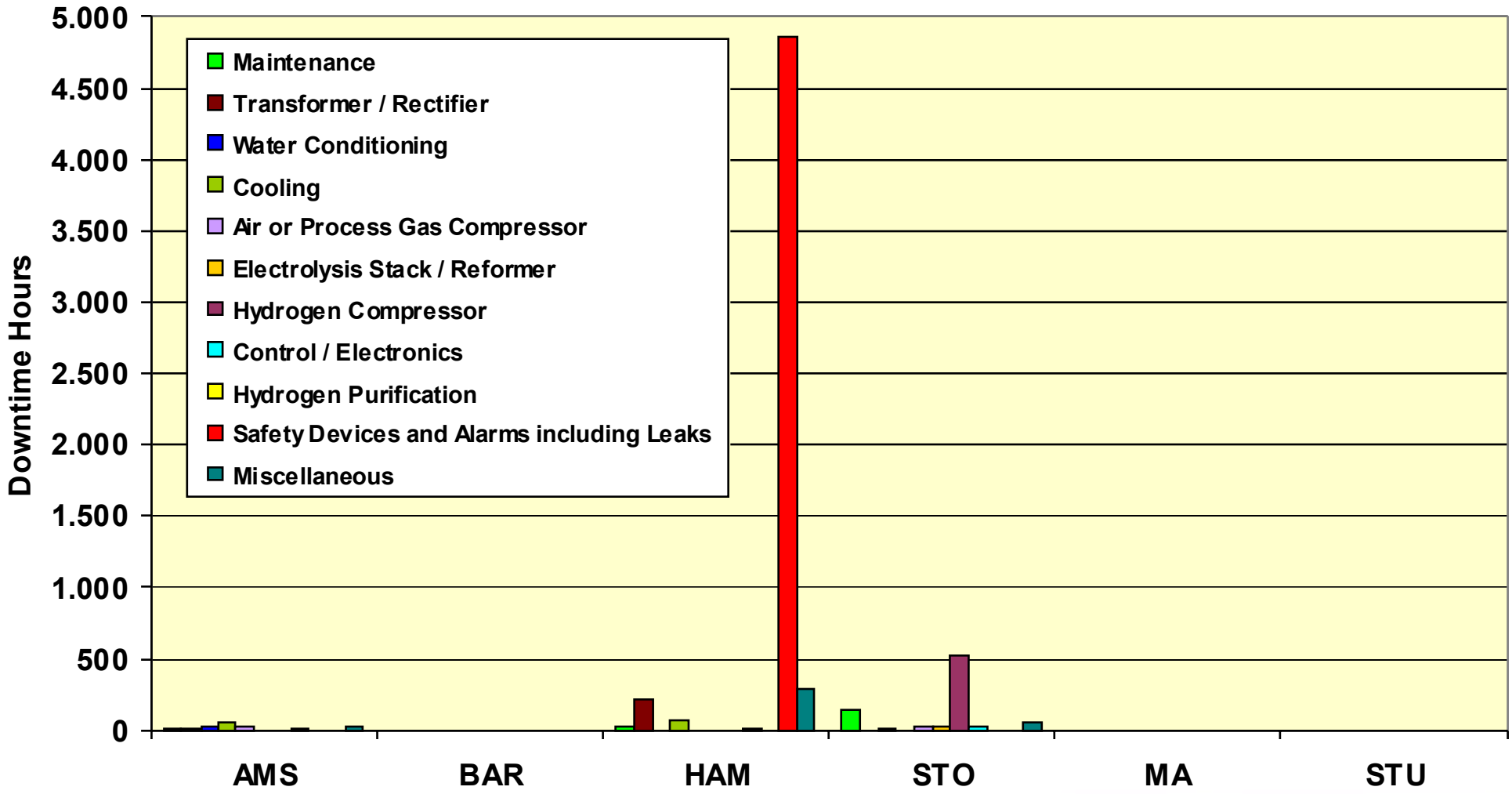
3. Electrolysis: Design Data

	Amsterdam	Barcelona	Hamburg	Stockholm
Rated production [Nm^3/h]	15 – 60	15 - 60	30 – 60	15 - 60
Installed power [kW]	400	400	390	400
Power source	green	grid mix (+ PV on site)	green	green
Rated energy demand (stack+pumps) [kWh/Nm^3]	4,8 +/- 0,1			
Resulting efficiency	63%			
External supply	no	backup	(backup)	no

3. Performance Indicators: Availability Production Units



3. Performance Indicators: Causes for Downtime

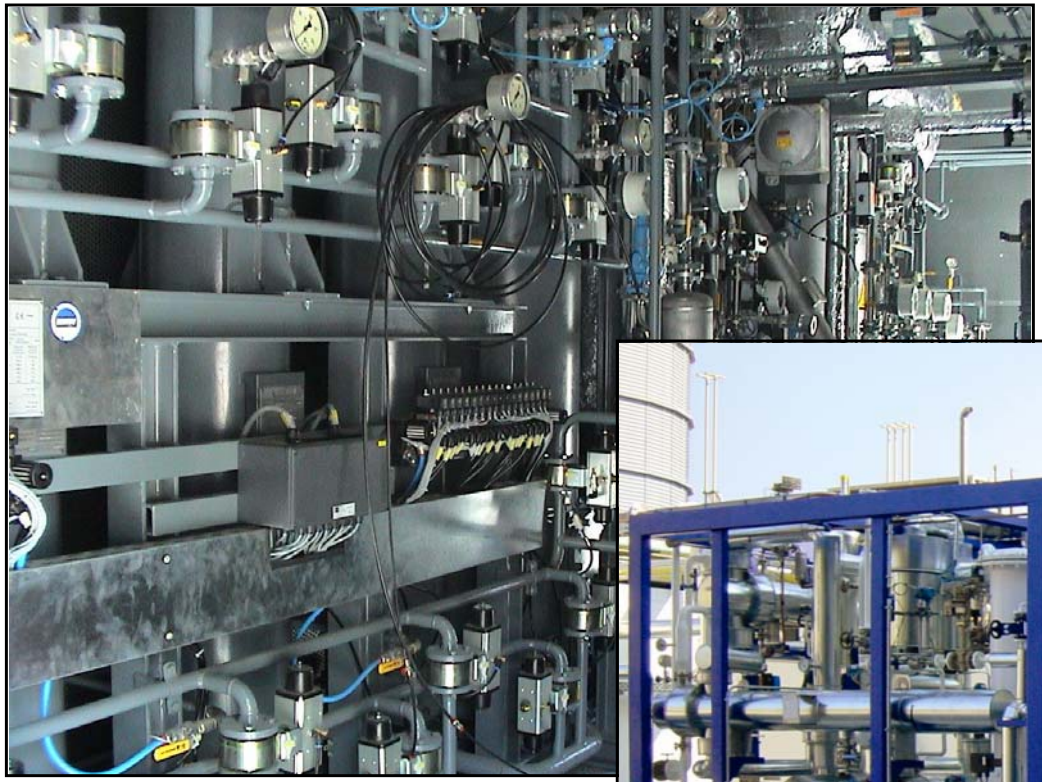


3. Electrolysis: Learnings from Operation

Explanation Hamburg / Leakage

- Crack corrosion caused leakages in lye loop
  (30 % KOH, ~80°C, 15 bar, oxygen saturated)
- Pipe material (AISI 316L) had to be exchanged
- New material (Douplex SAF 2205) may not be welded under these conditions
- Pipes < DN 20 connected through fittings type “Gyrolock”
- Larger pipes have to be nickel coated

4. Steam Reformer in Madrid and Stuttgart

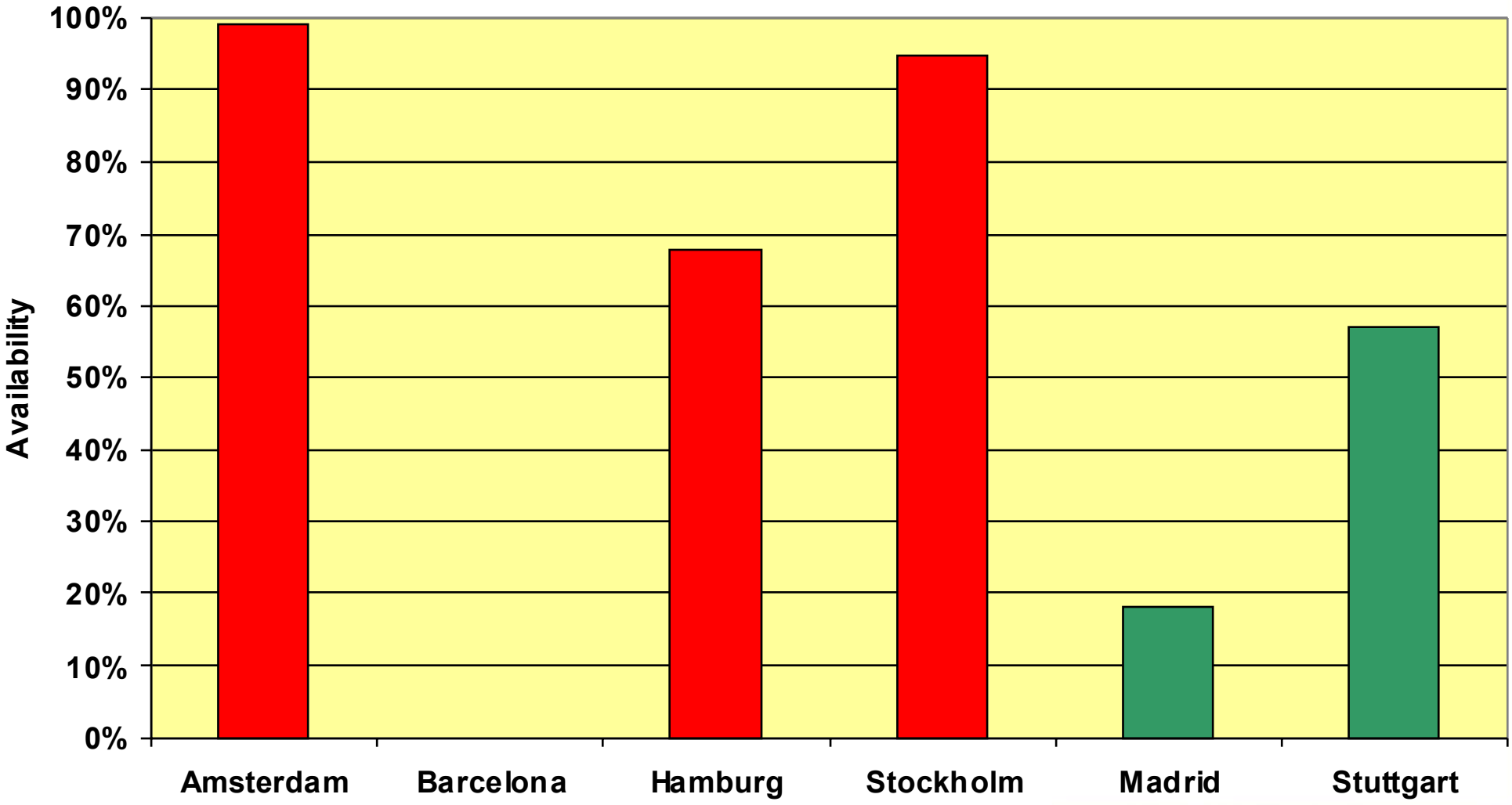


COFUNDED BY THE EUROPEAN COMMISSION DG tren

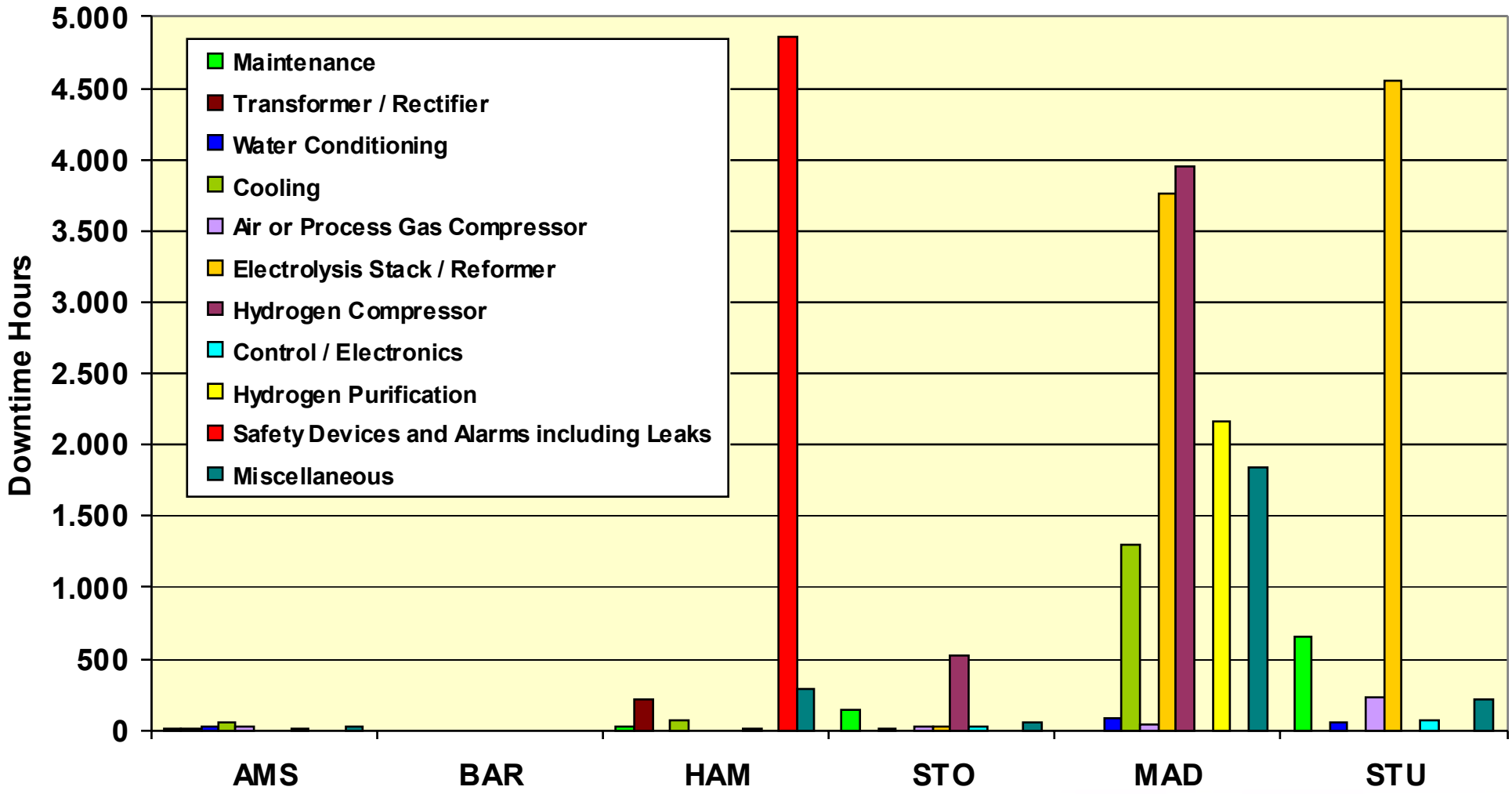
4. Steam Reformer: Design Data

	Madrid	Stuttgart
Rated production [Nm^3/h]	30 – 50	50 – 100
Installed power [kW]	45	89
Power source	grid mix	grid mix
Rated thermal energy demand [kWh/Nm^3]	4,86	4,65
Resulting thermal efficiency	62%	65%
External supply	regular	backup

4. Performance Indicators: Availability Production Units



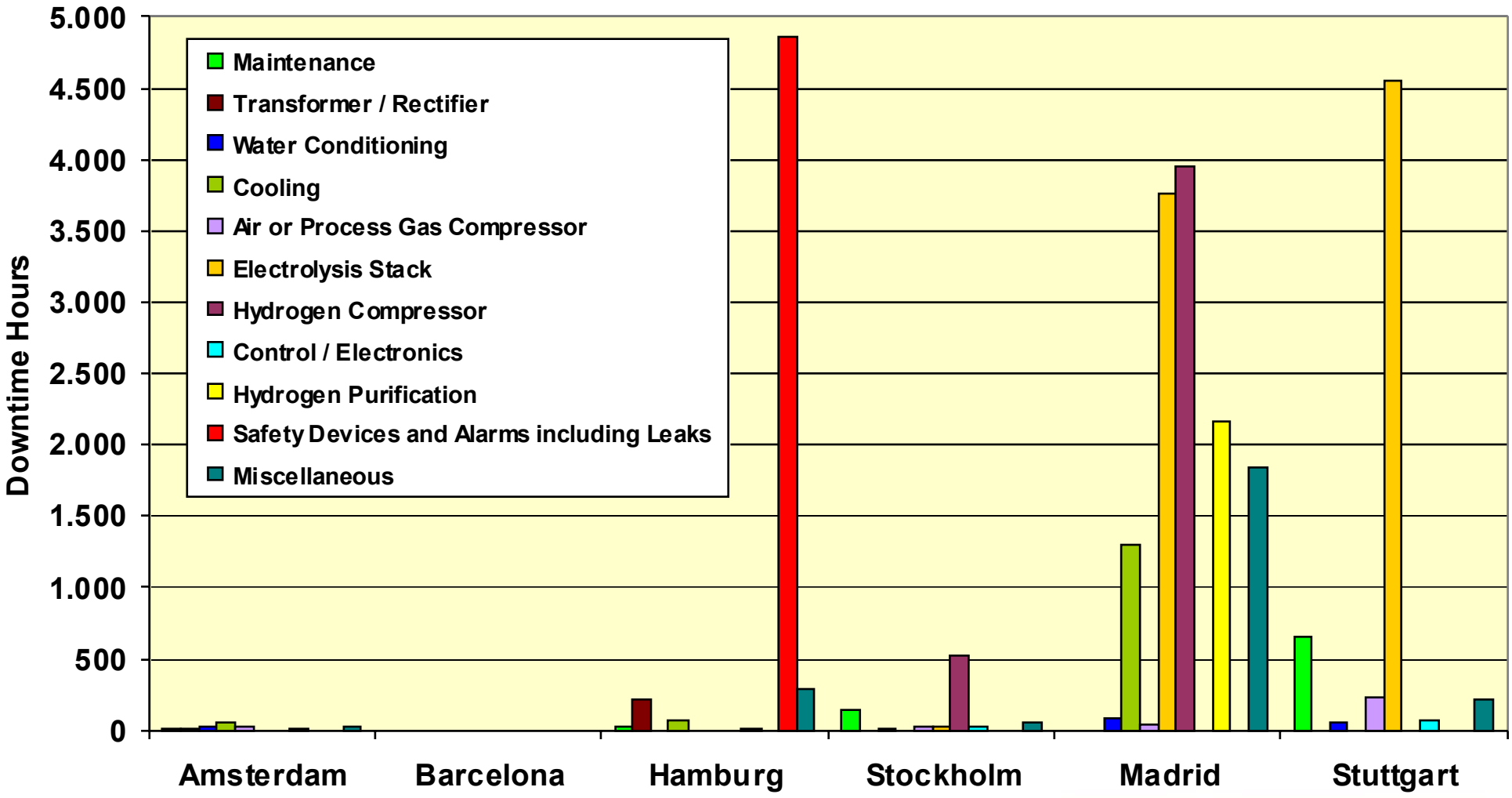
4. Learnings from Operation: Causes for Downtime



4. Steam Reforming: Learnings from Operation

- **Stuttgart: single problem**
  higher reformer temperatures than anticipated
  → material issues (cracks, construction element damaged)

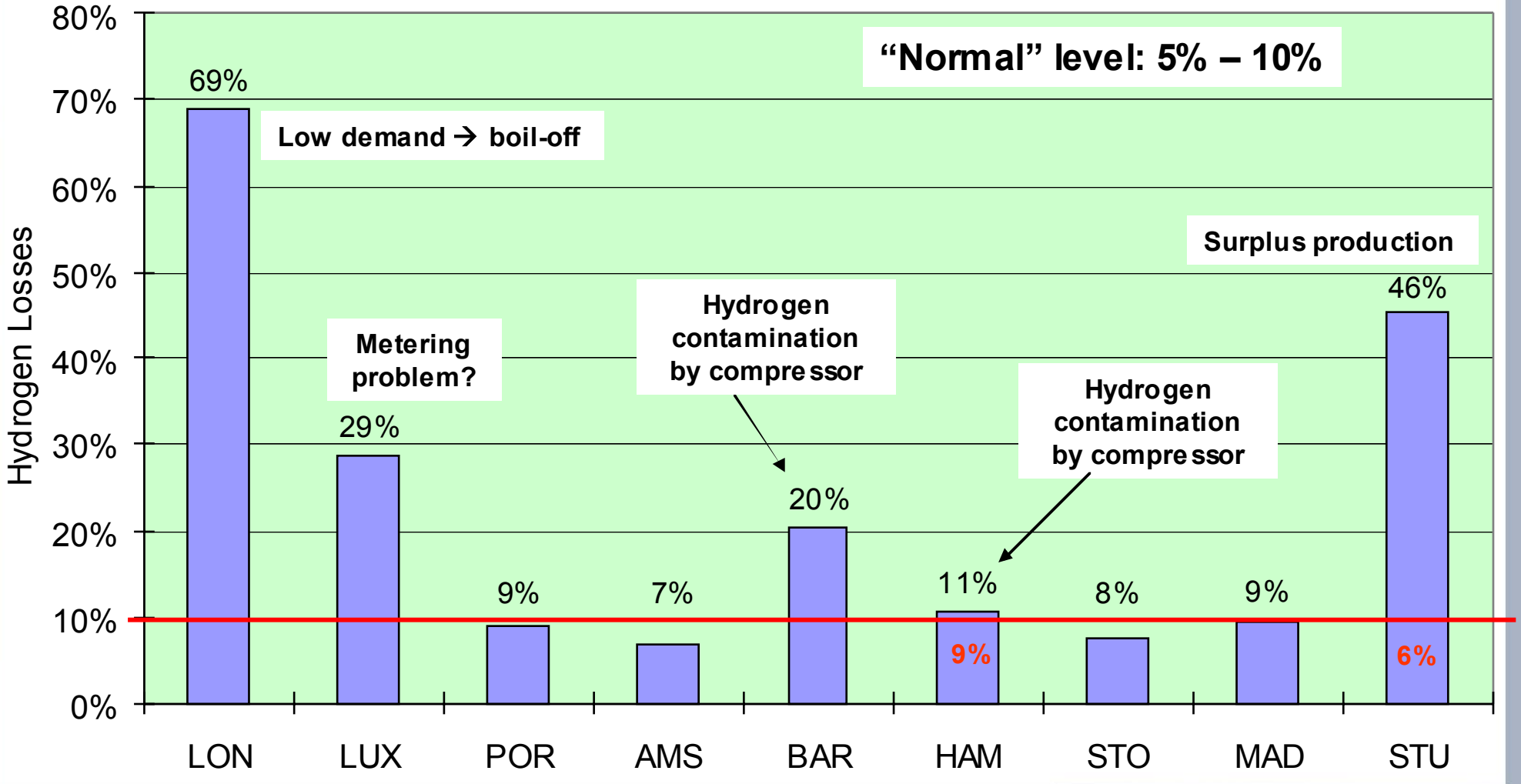
4. Learnings from Operation: Causes for Downtime



4. Steam Reforming: Learnings from Operation

- **Stuttgart: single problem**
  higher reformer temperatures than anticipated
  → material issues (cracks, construction element damaged)
- **Madrid: series of different issues**
  with reformer, compressors, cooling, purification, …
- **Start-up and shut-down cycles complex**
  → operate continuously at the cost of venting surplus hydrogen
- **Part-load operation reduces thermal efficiency**
  Madrid: 62% rated → 39%
  Stuttgart: 65% rated → 42%

5. Further Learnings from Operation: Hydrogen Losses



6. Conclusions I

- **The hydrogen supply infrastructure in general is viable, approvable and reliable.**
- **The energy demand, hydrogen losses and the consumption of inert gases must be reduced.**
- **The chosen performance indicators serve well to characterise the hydrogen infrastructure in a quantitative way.**

6. Conclusions II

- **Steam reformers performed below expectations start-stop cycles, load flexibility, catalyst durability**
- **Electrolysers performed well**
- **Compressors caused impurities and unscheduled downtime**
- **Optimised system integration, namely of production unit, compressor, storage and dispenser remains a challenge**
- **Standardisation of interfaces**
- **Best practice definition hardly possible**

6. Outlook

- **“Best practise” definition for future hydrogen infrastructure projects require very well defined data acquisition and evaluation framework – integration at an early stage**
- **Comparable operation, surveillance and maintenance over a number of sites to allow reliable information about system performance**
- **Clustered approach**
- **Large “fleet test” of a number of filling stations of similar type necessary**

Thank you very much for your attention!

Holger Grubel, Vattenfall Europe Hamburg AG

Holger.Grubel@vattenfall.de

Klaus Stolzenburg, PLANET GbR

K.Stolzenburg@planet-energie.de