International Conference on Smart Energy Systems and 4th Generation District Heating
Copenhagen, 25-26 August 2015

Hydrogen to link Heat and Electricity in transition stage towards Future Smart Energy Systems

Benedetto Nastasi

Gianluigi Lo Basso

AALBORG UNIVERSITY
DENMARK

SAPIENZA
UNIVERSITÀ DI ROMA

4DH
4th Generation District Heating
Technologies and Systems

4DH
4th Generation District Heating Technologies and Systems

Outline

- **Background**
- **Research Questions**
- **Energy System Model**
- **Centralized vs Distributed Generation**
- **Hydrogen Technologies**
- **Energy Scenario with 30% - 40% - 50% of RES**
- **Conclusions**

4DH
4th Generation District Heating Technologies and Systems

Background

- **Increasing of RES share in energy mix**
- **OECD Countries have more power than needed**
- ✓ ***Different RES priority on the market (PV, Wind, etc.)***
- **Decreasing of price in peak hours**
- **Existing fossil-fuel power plants work at partial load**
- ✓ ***Grid Efficiency changes (RES, Repowering, Old Plants)***
- **Excess is not only a safety issue but economic one**
- **Vision of Grid as a backup option of RES and DG**
- ✓ ***Power-to-Gas, H2 as a solution (H2NG, SCH4, etc.)***

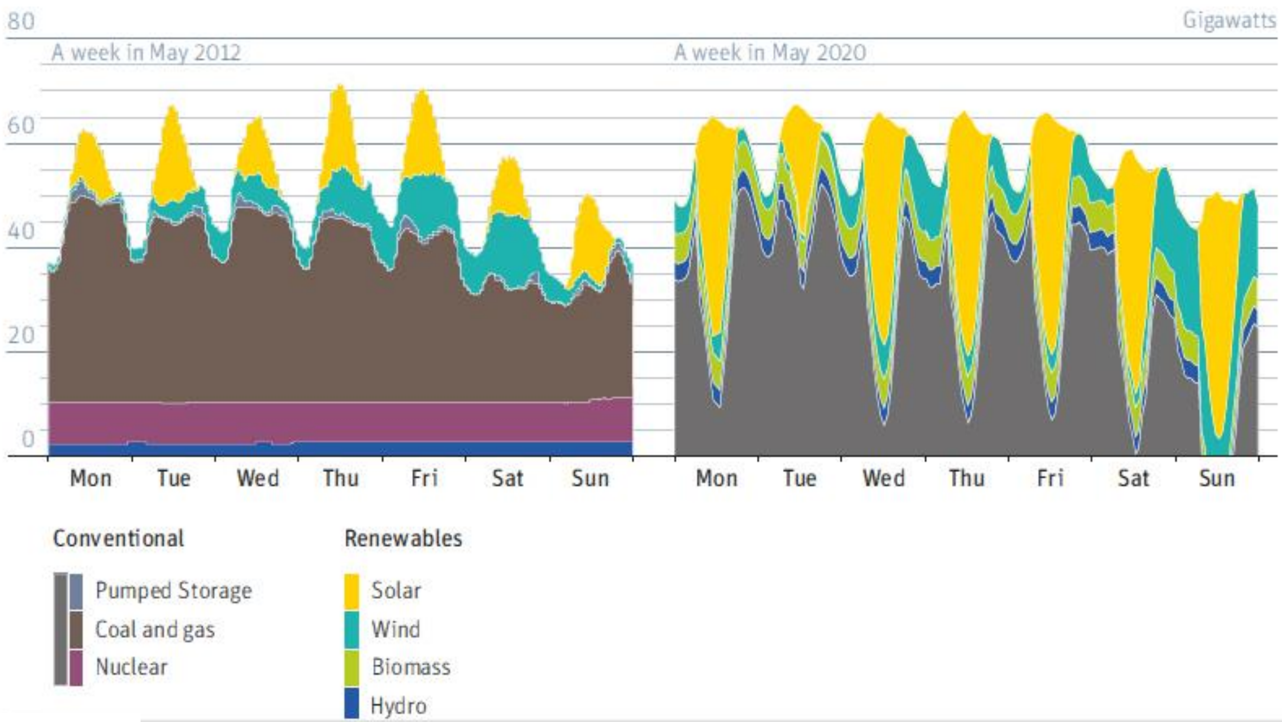
Source: IEA, 2013; OECD, 2014.

Energy Transition

Renewables need flexible backup, not baseload

Estimated power demand over a week in 2012 and 2020, Germany

Source: Volker Quaschning, HTW Berlin



Source: BMWI, 2013; Energiewende, 2015.

NG in the Energy Transition

- **Natural Gas-based Countries (Italy, Netherlands, etc.)**
- **Large extension of existing pipelines**

✓ ***Well-proven energy infrastructures***

- **Distributed Hydrogen production**
- **Direct injection of H2 in the Gas Grid**

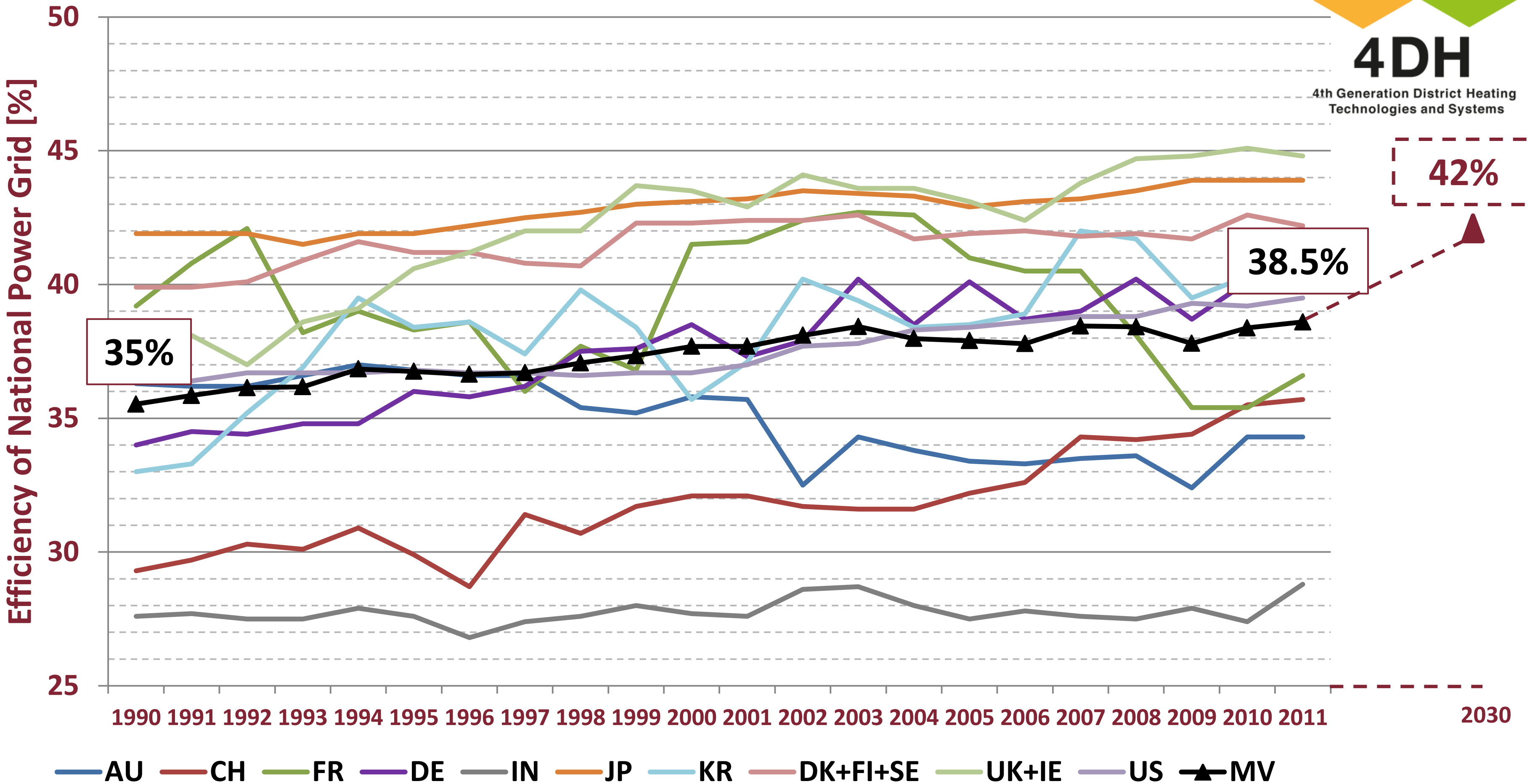
✓ ***Pipelines as storage infrastructures***

- **Fossil fuel production is shifting to Natural Gas**
- **Energy independence is still a geopolitical issue**

✓ ***Power-to-Gas, i.e. Power-to-Hydrogen***

Source: IEA, 2013; OECD, 2014.

National Grid Efficiency



Source: IEA, 2013; Ecofys, 2014.

Research Questions

4DH
4th Generation District Heating Technologies and Systems

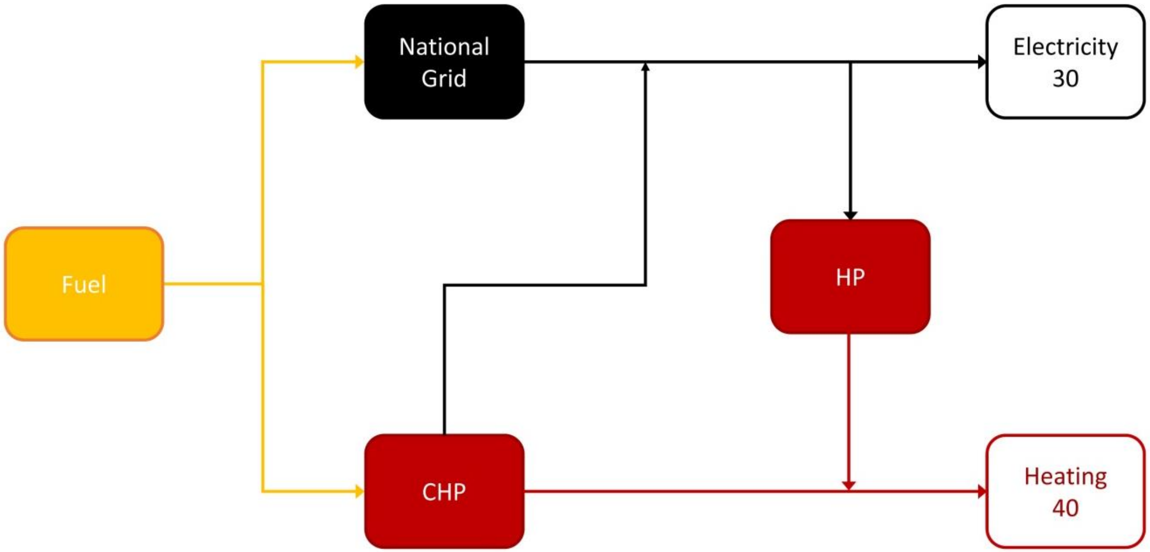
What Renewable Hydrogen Technology could be involved in linking Heat and Electricity but considering the use in well-proven technologies?

Hydrogen for Sustainable Heat Purposes

What kind of contribution, in terms of Primary Energy Saving, could be provided by Hydrogen Technologies when the share of RES increases at 30%, 40% and 50% in the energy mix?

Potential for CHP and DHC feeded by those H2T

Energy System Model



A Simplified Stationary model

4DH
4th Generation District Heating Technologies and Systems

Sensitivity Analysis

Grid Efficiency

$\eta_1 = 0.35$ $\eta_2 = 0.385$ $\eta_3 = 0.42$

Demand Power to Heat Ratio

0.75 (30 – 40) 0.4 (20 – 50) 0.16 (10 – 60)

CHP Efficiency

Electrical 0.2 to 0.42 Thermal 0.5

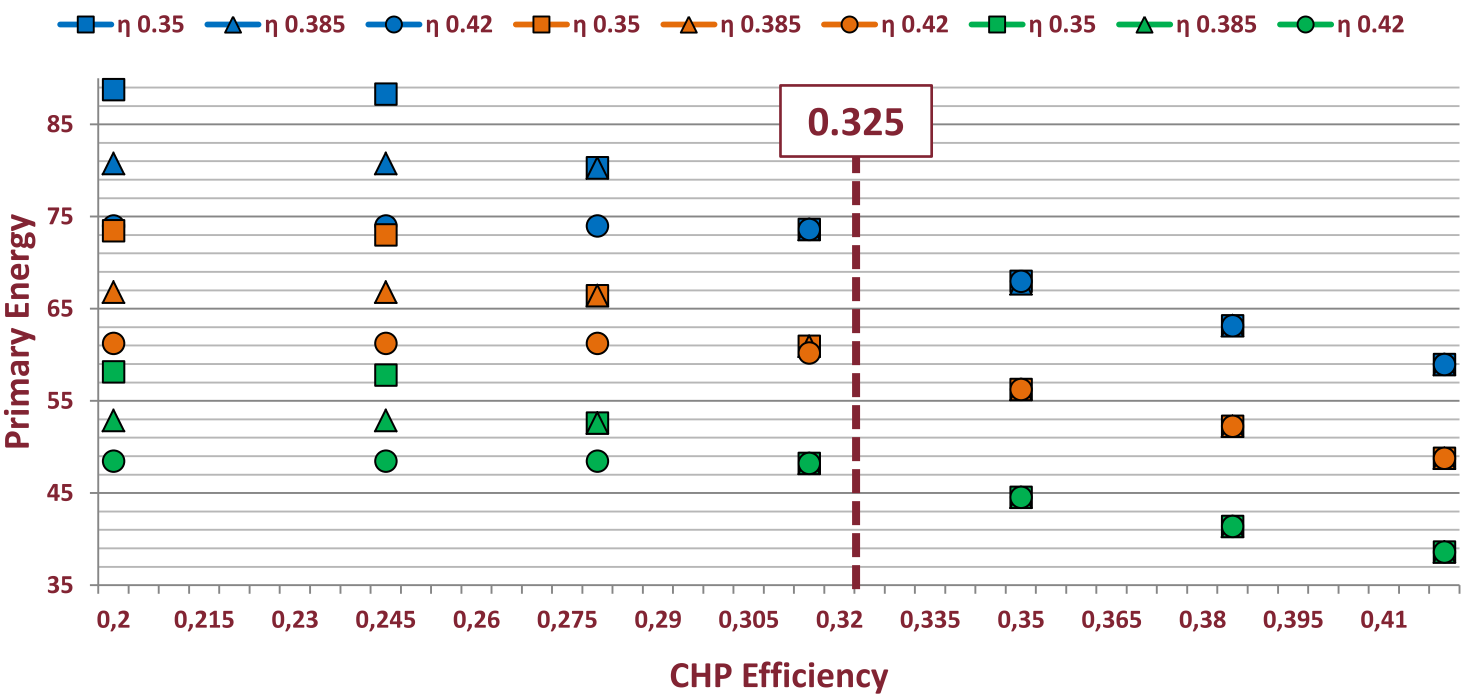
Efficiency Improvement due to H2 addition to NG

0.01 per 10% of H2 volumetric fraction

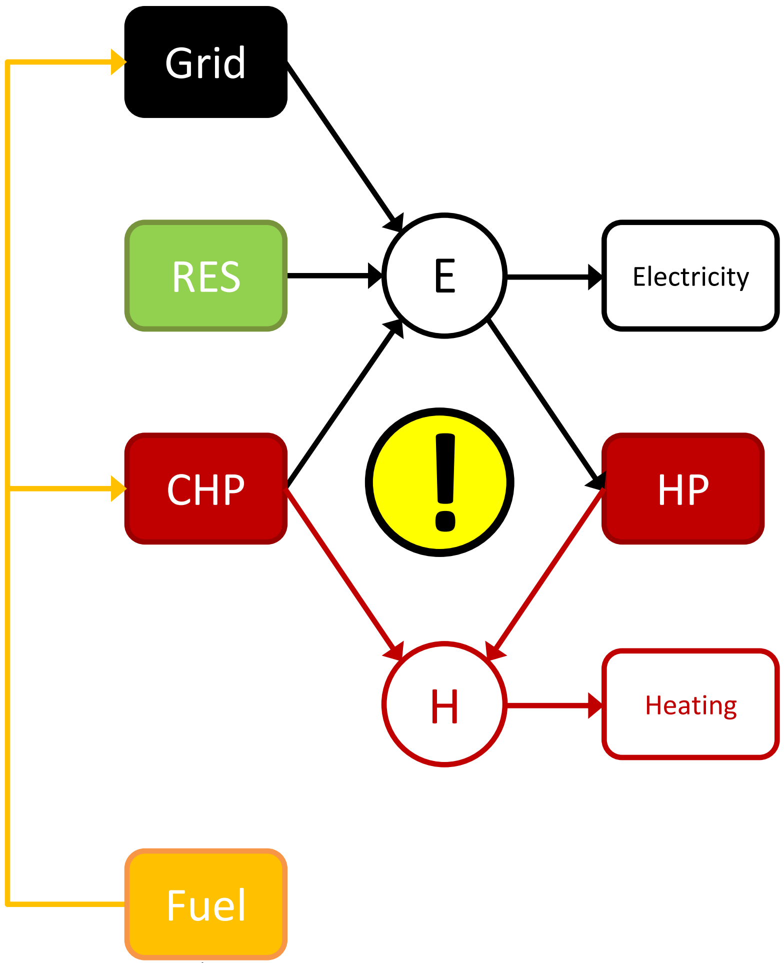
Source: Lo Basso et al., 2015; Nastasi, 2015.

Sensitivity Analysis

National (30/40) District (20/50) Building (10/60)



Energy System Balance Equations



Electricity Node

$$E_{el,GRID} + E_{el,RES} + E_{el,CHP} - E_{el,HP} = E_{el,D} \quad (1)$$

Share of RES

$$f_{RES} = \frac{E_{el,RES}}{(E_{el,D} + E_{el,HP})} \quad (2)$$

Heat Node

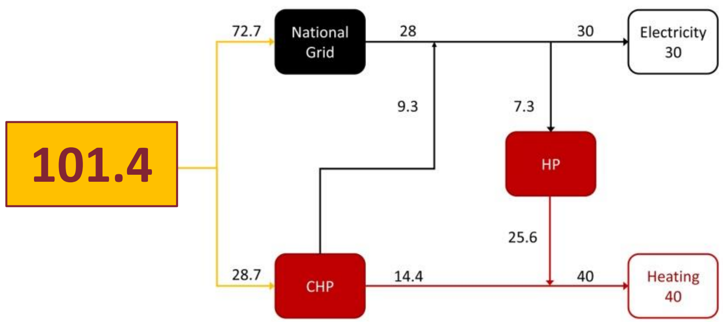
$$E_{h,HP} + E_{h,CHP} = E_{h,D} \quad (3)$$

Objective Function

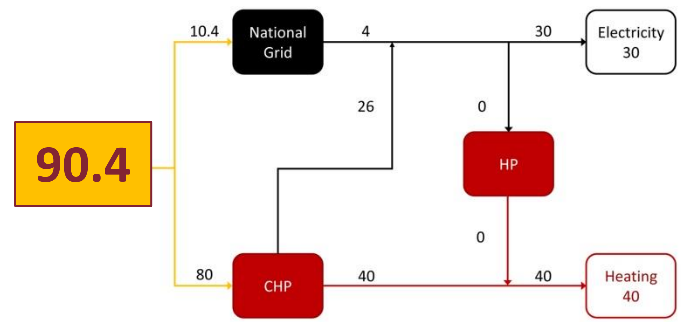
$$E_{fuel,Sys} = E_{fuel,CHP} + \frac{E_{el,GRID}}{\eta_{GRID}} \quad (4)$$

Energy System and Grid Priority

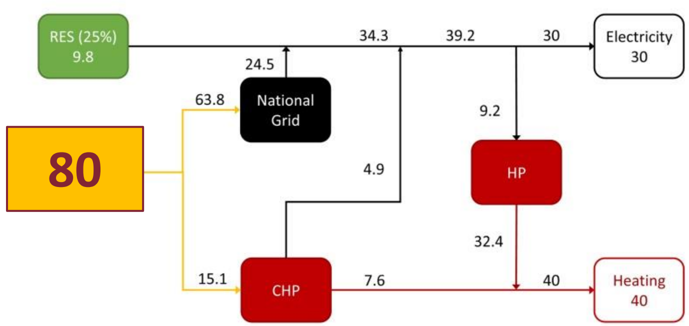
Energy System with Grid Priority



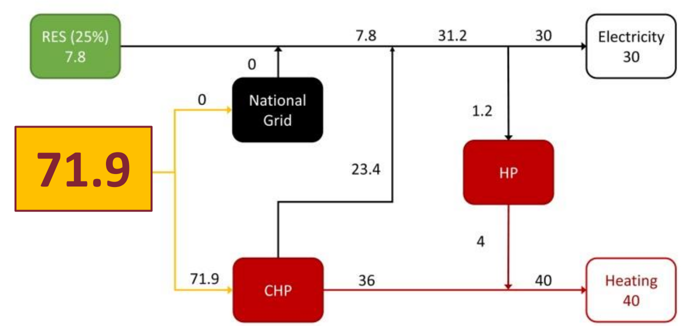
Optimized Energy System



Energy System with Grid Priority and 25% RES



Optimized Energy System and 25% RES



Centralized vs Distributed Generation

4DH
4th Generation District Heating Technologies and Systems

- **Transmission Cost is avoided**
- **Transmission Losses are reduced**
- **Off-Grid solutions mitigate market price volatility**
- **Fossil-fuel supply is more expensive**
- **Security is an issue at big scale**
- **Higher rated efficiency but higher investment**

✓ **Transition from Pro-sumers to Energy Hub**

Analysis Parameters

Grid Efficiency η_2 = 0.385

Demand Power to Heat Ratio 0.75 (30 – 40)

Heat Pump COP COP= 3.5

CHP Efficiency of Distributed Generation

- **Electrical** 0.325 **Thermal** 0.5

Efficiency Improvement due to H2 addition to NG

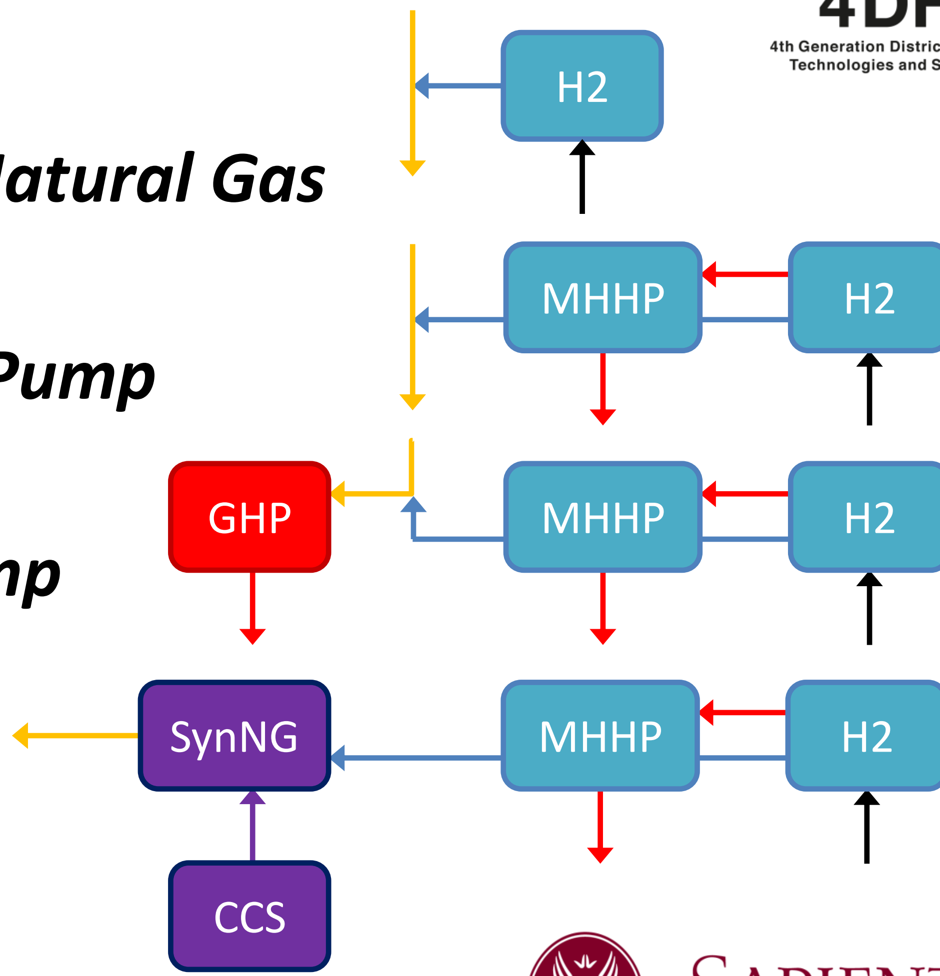
- **Electrical** 0.345 **H2 vol. fraction** 20%

Research Question 1

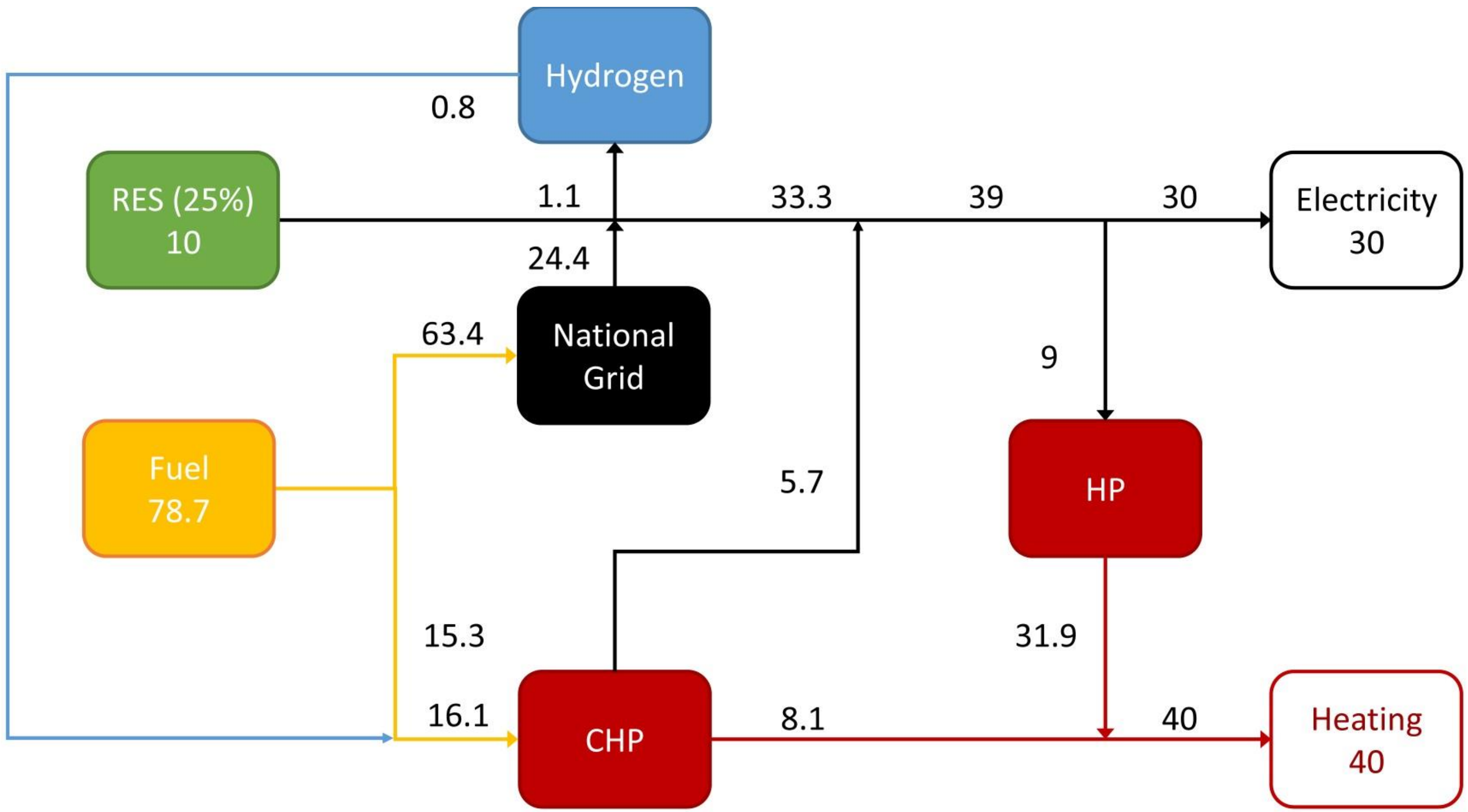
What Renewable Hydrogen Technology could be involved in linking Heat and Electricity but considering the use in well-proven technologies?

Hydrogen Technologies

- **H2NG**
  Hydrogen enriched Natural Gas
- **MHHP**
  Metal Hydride Heat Pump
- **GHP**
  Gas-engine Heat Pump
- **SCH4**
  Synthetic Methane

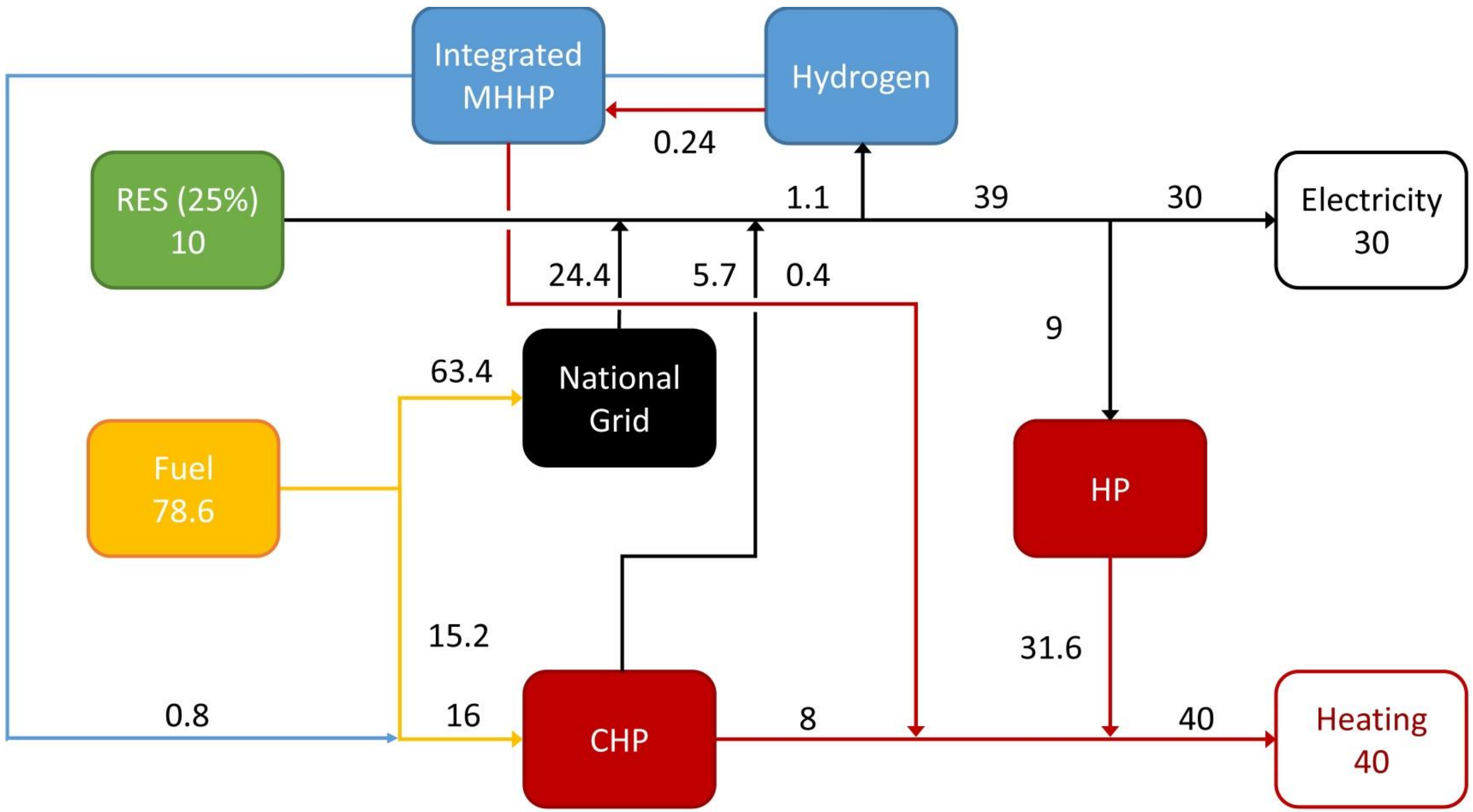


H2NG Hydro-methane mixtures



MHHP Metal Hydride Heat Pump

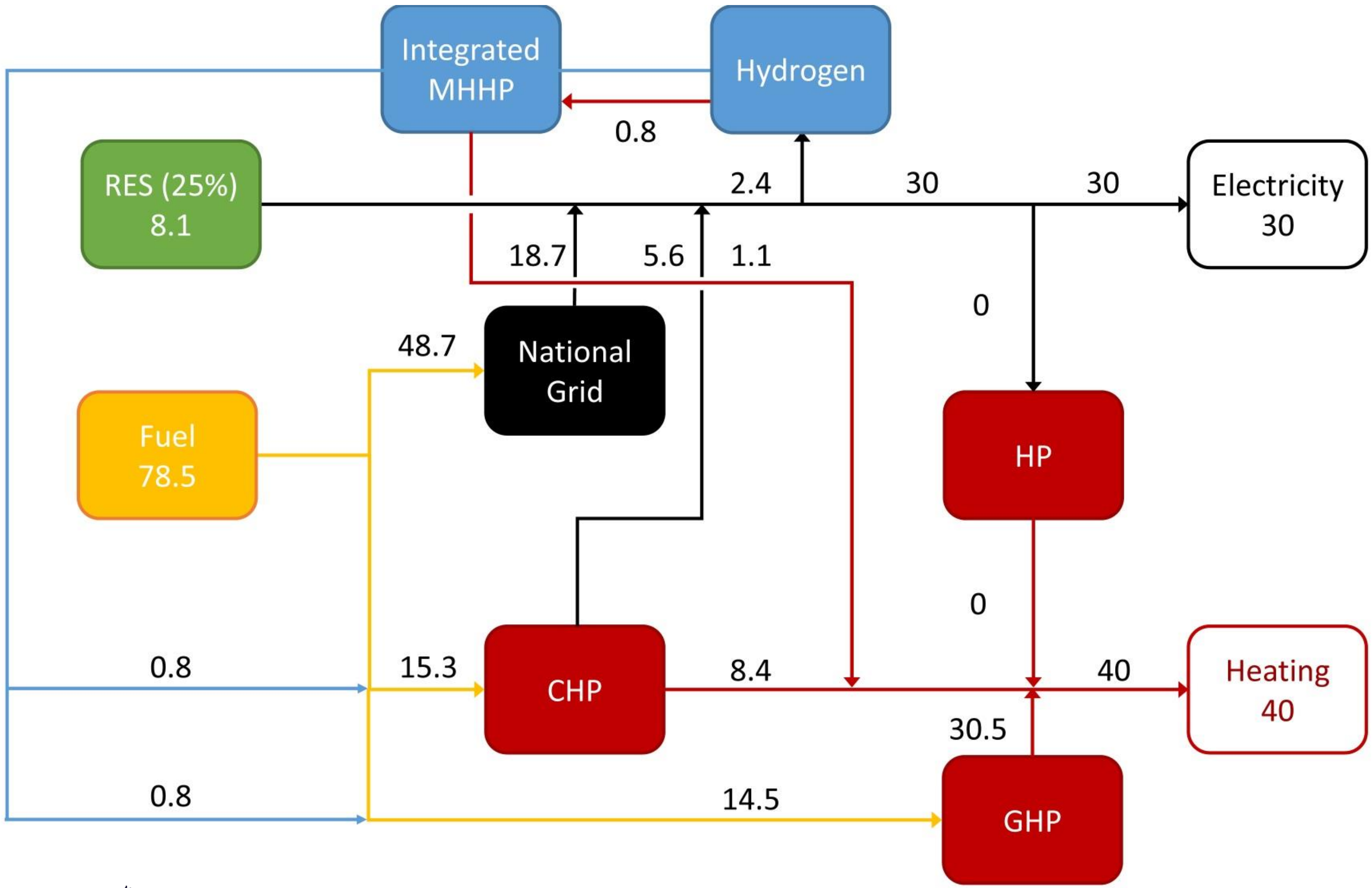
4DH
4th Generation District Heating Technologies and Systems



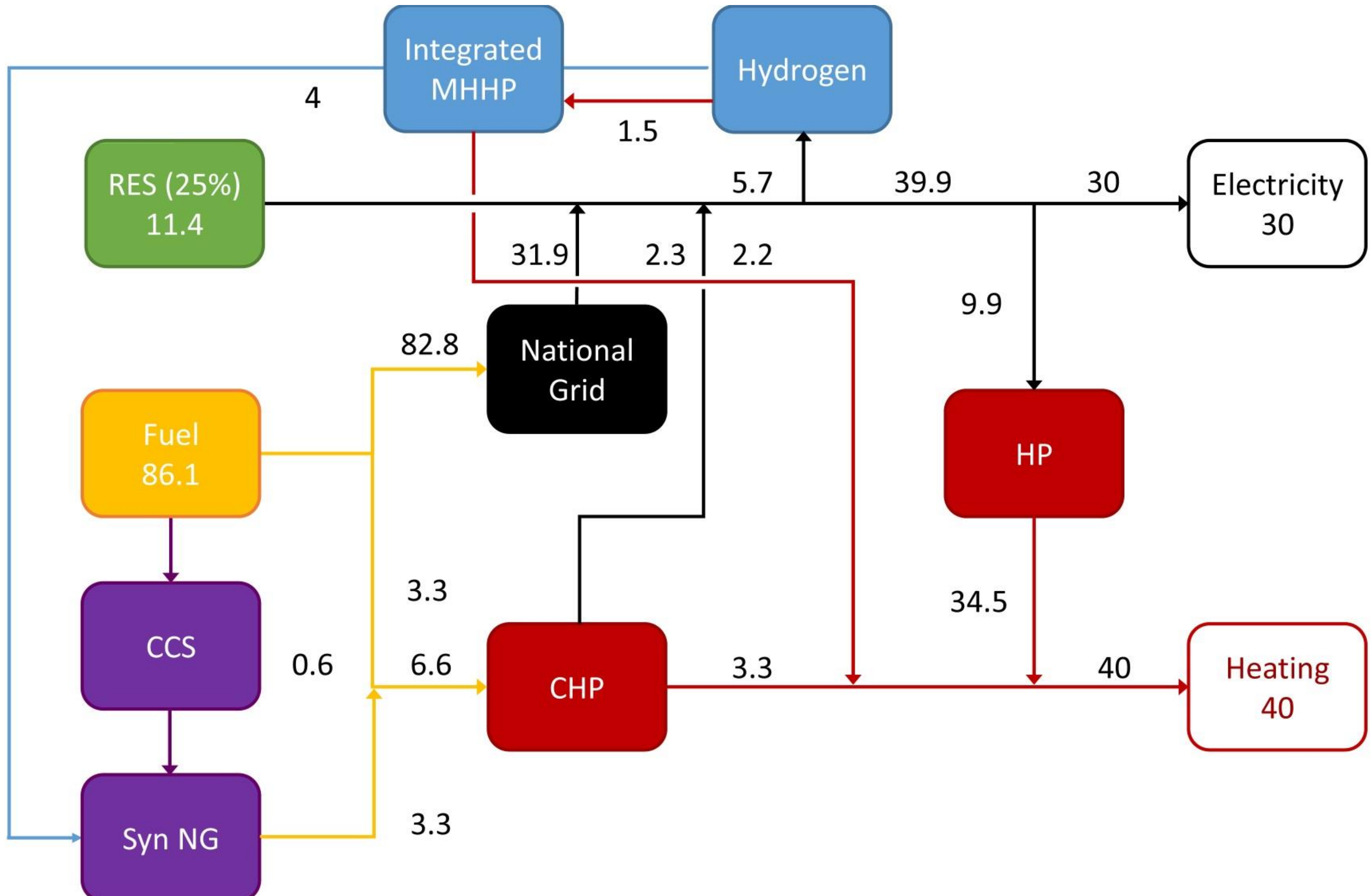
AALBORG UNIVERSITY DENMARK

SAPIENZA UNIVERSITÀ DI ROMA

GHP Gas-engine Heat Pump



SCH4 Synthetic Methane

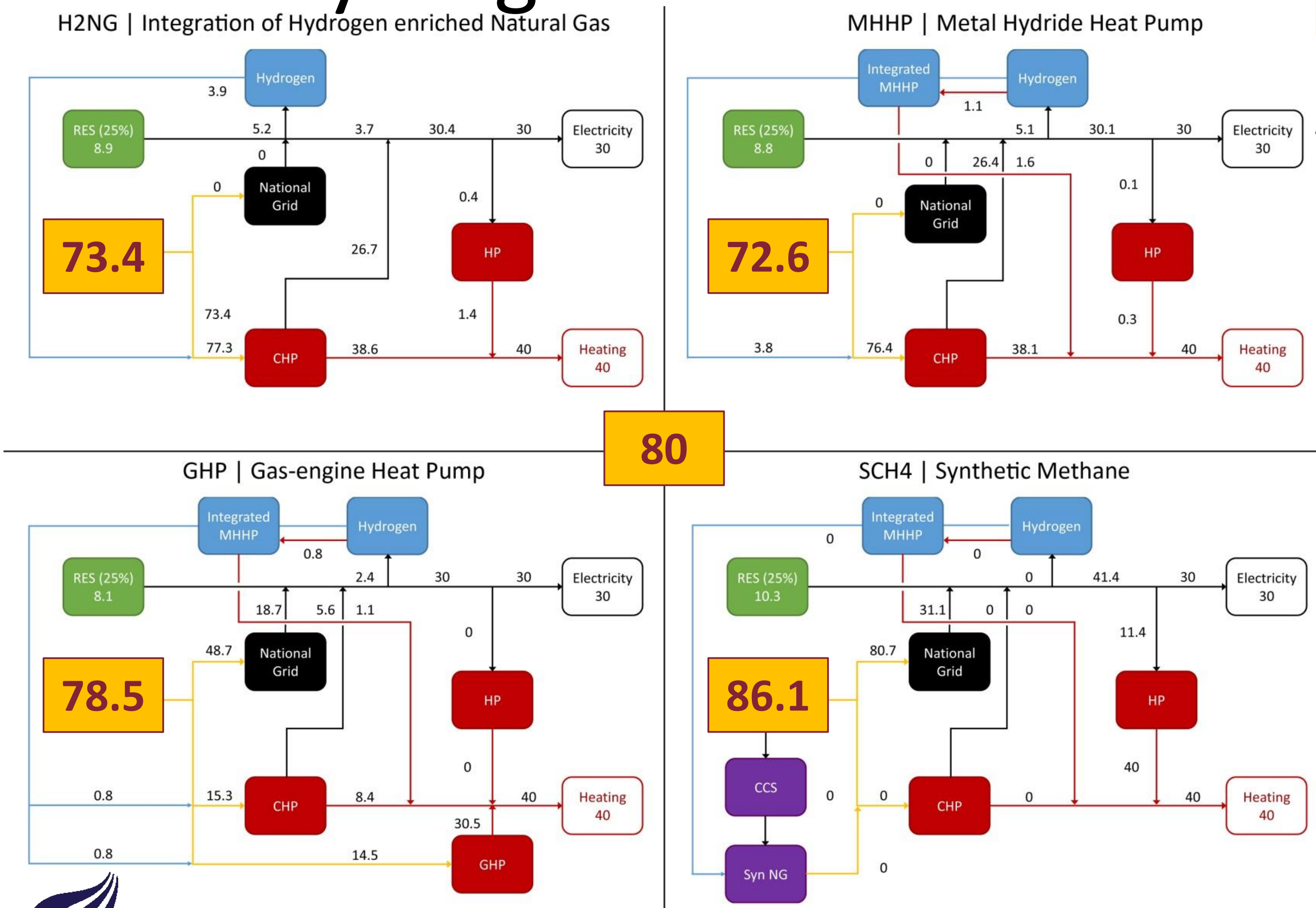


Research Question 2

What kind of contribution, in terms of Primary Energy Saving, could be provided by Hydrogen Technologies when the share of RES increases at 30%, 40% and 50% in the energy mix?

4DH
4th Generation District Heating Technologies and Systems

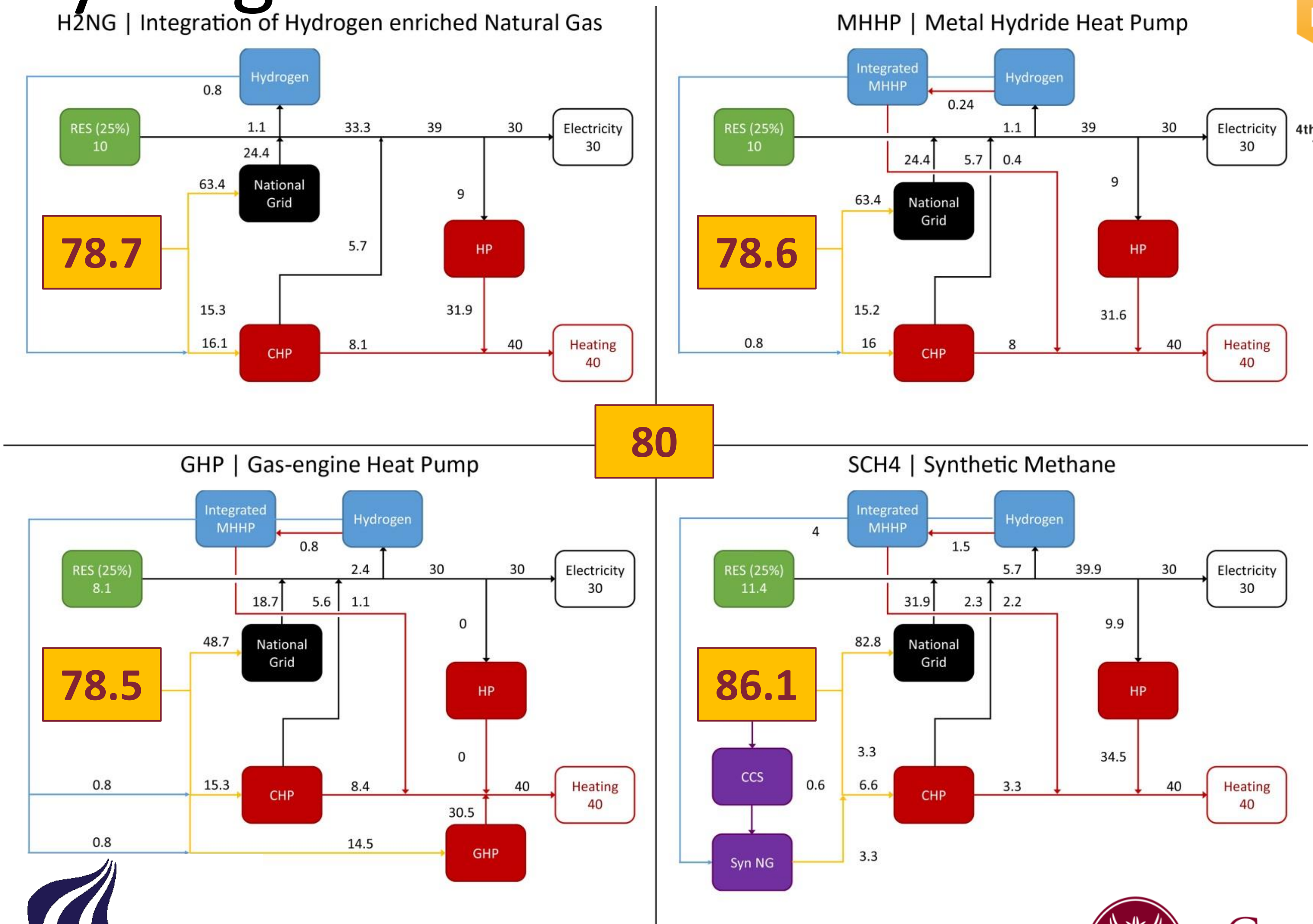
Hydrogen - 25% RES



AALBORG UNIVERSITY DENMARK

SAPIENZA UNIVERSITÀ DI ROMA

Hydrogen - 25% RES – Grid locked



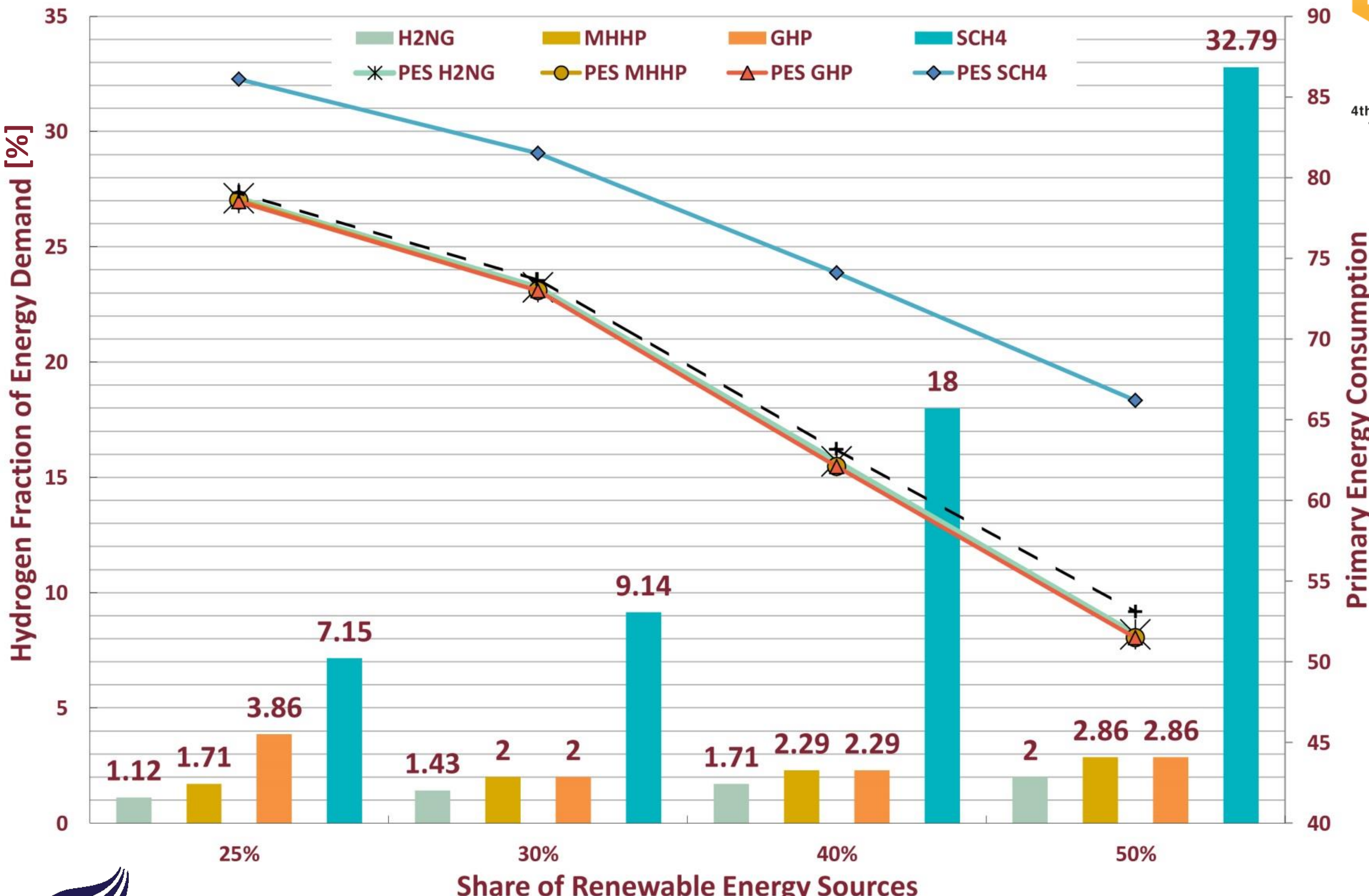
AALBORG UNIVERSITY DENMARK

International Conference on Smart Energy Systems and
4th Generation District Heating, Copenhagen, 25-26 August 2015

4DH 4th Generation District Heating Technologies and Systems

SAPIENZA UNIVERSITÀ DI ROMA

Energy Scenario 30% - 40% - 50%



AALBORG UNIVERSITY
DENMARK

SAPIENZA
UNIVERSITÀ DI ROMA

4DH
4th Generation District Heating Technologies and Systems

Conclusions

- **MHHP+H2NG is the best solution to reduce PE**
- **Grid to DG Relation is crucial for PES and safety**
- **GHP works only at 25% in optimized layout**
- **SCH4 requires more PE than BAU and other H2s**
- **Further studies about SCH4 for CO2 reduction**
- **Studies by a dynamic model (e.g. EnergyPLAN)**

✓ **Transition solutions towards Hydrogen Economy**

Acknowledgement

This research was partially supported by "*Progetto Avvio alla Ricerca 2014*" a research grant funded by Sapienza University of Rome (n. 000328_2014_NASTASI)

Principal Investigator: Benedetto Nastasi.

4DH
4th Generation District Heating Technologies and Systems

Thank you for your attention!

DIPARTIMENTO
DI INGEGNERIA ASTRONAUTICA
ELETTRICA ED ENERGETICA

SAPIENZA
UNIVERSITÀ DI ROMA

For any suggestion or further information please contact:

benedetto.nastasi@outlook.com