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FACULTY OF ENGINEERING
AND ARCHITECTURE

DEPARTMENT OF ELECTROMECHANICAL, SYSTEMS AND METAL ENGINEERING
RESEARCH GROUP SUSTAINABLE THERMO-FLUID ENERGY SYSTEMS
APPLIED THERMODYNAMICS & HEAT TRANSFER

EXPERIMENTAL PERFORMANCE ANALYSIS OF AN SOFC AND PEM FUEL CELL UNIT FOR VARIOUS NATURAL GAS-HYDROGEN FUEL MIXTURES

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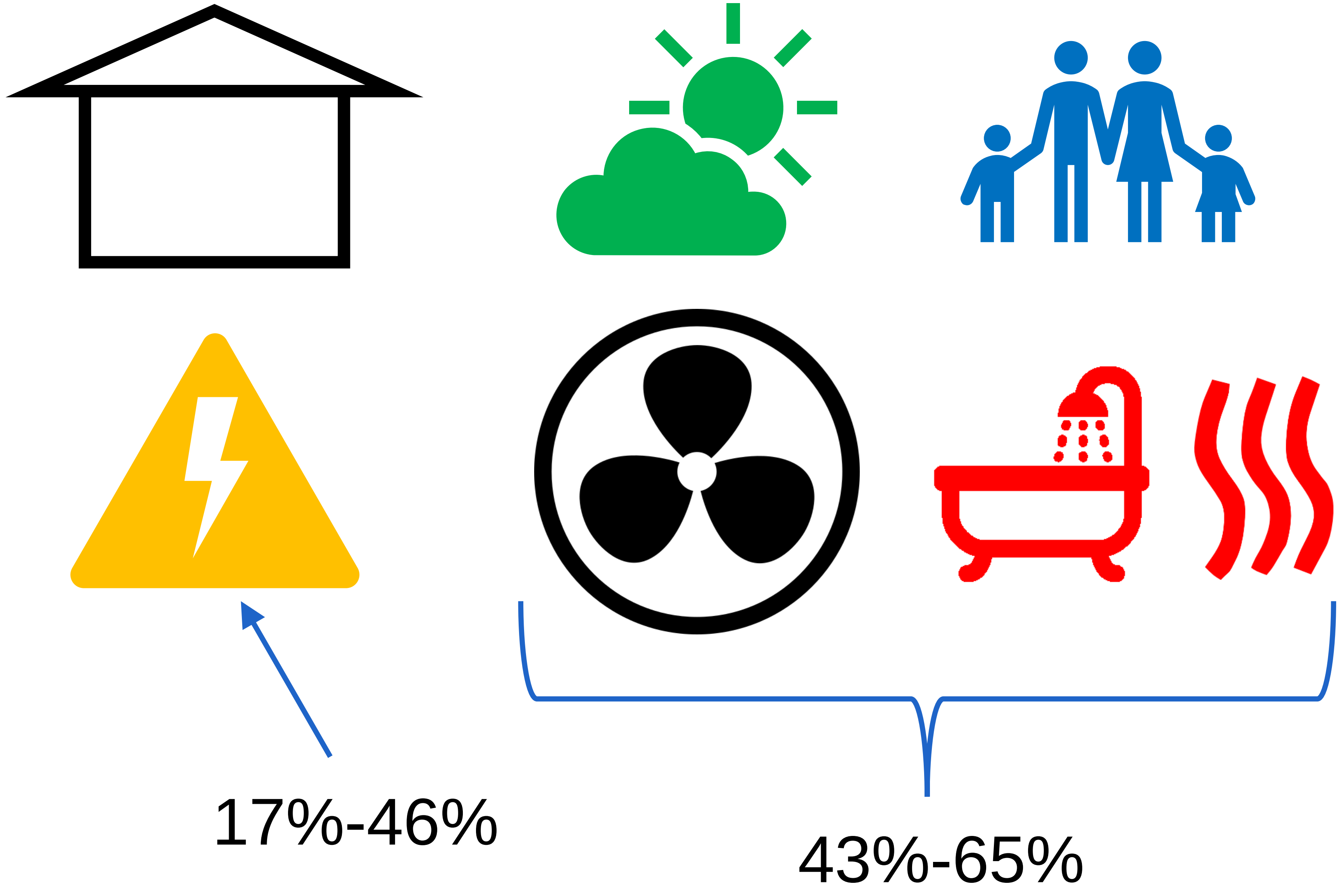
FLUXYS

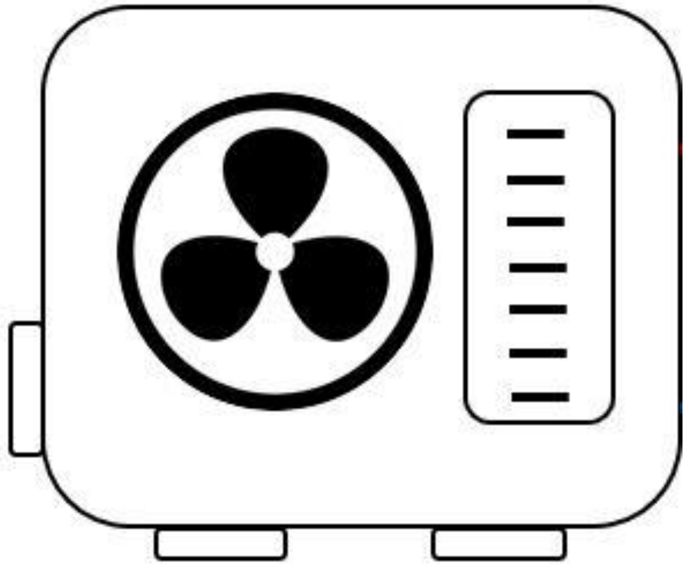
INTRODUCTION

- Residential buildings are responsible for the share of 25.71% of the total energy use in EU

- Gas Boilers the most used
- Renovation techniques
- Low temperature heating
- Electrically driven heat pumps



AIR SOURCED HEAT PUMPS (AHP)

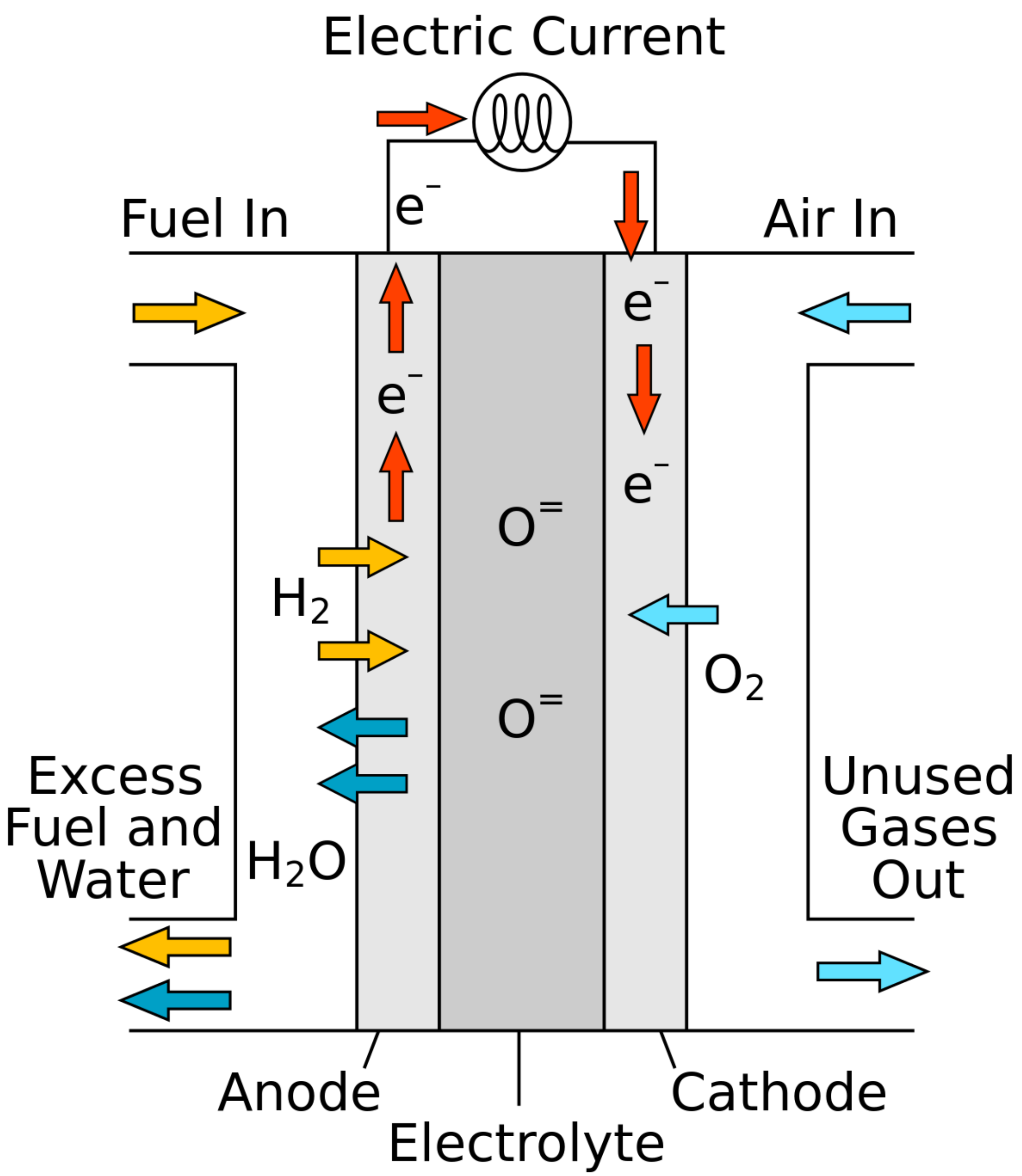


- Mostly in use due to price and practice
- Electricity may be generated by
  renewable sources → 0,024 kgCO_2/kWh
  → 0,217 kgCO_2/kWh (nat gas)
- In severe winter, the performance of AHP deteriorates while the space heating energy demand increases, back up heaters
  → overloading of the grid and voltage instabilities
  → insufficient generation from the renewable sources

SOFC & PEM FUEL CELL

- SOFC:
  - Slower start up, 5min-1h
  - 250-800 °C
  - Electrical efficiency 40-60%
- PEM:
  - Fast start up, 1sec
  - 60-80-250 °C
  - Electrical efficiency 30-40%

- Internal/external reformers:
  - Steam reformer (H_2O), partial oxidation
- Natural gas → Hydrogen (H_2)
- Use of the grid and securing provision of H_2



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MOTIVATION AND GOALS OF THE STUDY

– Future decarbonization plan will lead to the increase of H_2 share in the natural gas grid
– 5 Vol% is already officially approved
– In scientific literature there is a lack of experimental insights of the performance of these units for different fuels

– To examine the performance of the fuel cell units available on the market
– To reveal how much H_2 can perhaps be permitted in the grid in (near) future

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CHARACTERISTIC OF THE UNITS

Category	SOFC	PEM
Manufacturer	Solid power	Remeha
Electrical capacity	1.5 kW	700 W
Thermal capacity	850 W	1.5 kW
Yearly electricity yield	13 000 kWh	7500 kWh
Electrical power use	200 W	150 W
Energy label	A +++	A +++
Reformer type	Steam reformer	Steam reformer
Fuel	Natural gas	Natural gas

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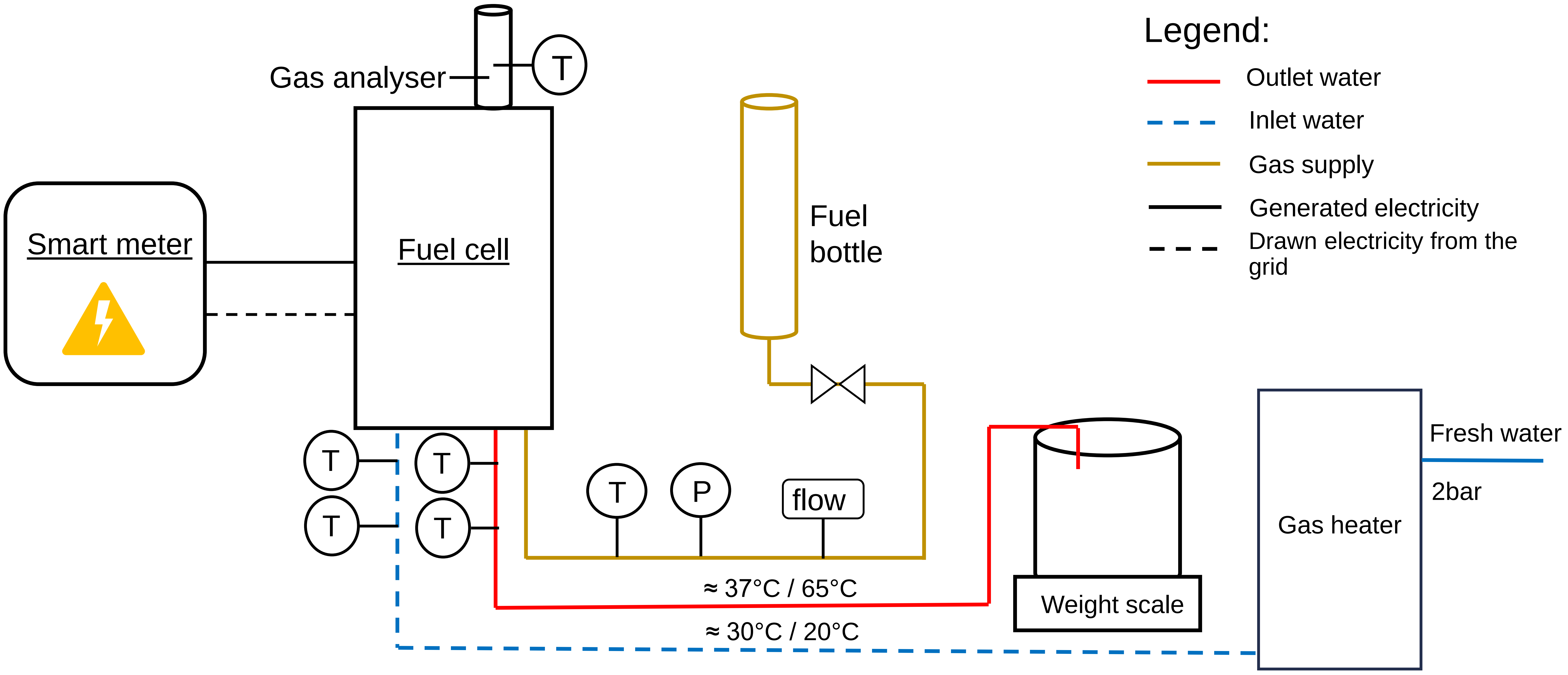
OVERVIEW OF THE SETUP



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MEASUREMENT CAMPAIGN

– SOFC, two phases:
  – Classified reformer adjustments
  – No adjustments

	Fuel mixture
G20*	100% CH_4
M1*	90% CH_4 + 10% H_2
M2*	80% CH_4 + 20% H_2
M3*	70% CH_4 + 30% H_2
M4	87% CH_4 + 13% C_3H_8
M5	57% CH_4 + 30% H_2 + 13% C_3H_8
M6	96% CH_4 + 4% CO_2
M7	66% CH_4 + 30% H_2 + 4% CO_2
M8	92.5% CH_4 + 7.5% N_2
M9	62.5% CH_4 + 30% H_2 + 7.5% N_2

– PEM, one phases:
  – No adjustments

	Fuel mixture	
G20	100% CH_4	I
M1	90% CH_4 + 10% H_2	I
M2	80% CH_4 + 20% H_2	I
M3	75% CH_4 + 25% H_2	II
M4	90% CH_4 + 10% C_3H_8	II
M5	63% CH_4 + **30%** H_2 + 7% C_3H_8	II
M6	96% CH_4 + 4% CO_2	III
M7	72% CH_4 + 25% H_2 + 3% CO_2	III
M8	92.5% CH_4 + 7.5% N_2	IV
M9	68.65% CH_4 + 25% H_2 + 6.35% N_2	IV

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KPI'S

Electrical efficiency:

$$\eta_{el} = \frac{\dot{W}_{el}}{\dot{V}_{gas\ flow} \cdot HHV}$$

Thermal efficiency:

$$\eta_{th} = \frac{\dot{m}_w \cdot c_p \cdot (T_{w,out} - T_{w,in})}{\dot{V}_{gas\ flow} \cdot HHV}$$

Total efficiency:

$$\eta_{FC} = \frac{\dot{W}_{el} + \dot{Q}_w}{\dot{Q}_{in}}$$

Marginal calculations*

Reference measurements

G20, M4, M6 and M8

$$\dot{Q}_{H2,M1,out} = \dot{Q}_{total,M1,out} - \dot{Q}_{CH4,M1,out}$$

$$\dot{E}_{H2,M1} = \dot{E}_{total,M1} - \dot{E}_{CH4,M1}$$

Efficiency of hydrogen share:

$$H_2[\%] = \frac{\dot{Q}_{H2,M1,out} + \dot{E}_{H2,M1}}{\dot{Q}_{H2,M1}}$$

*Based on LHV

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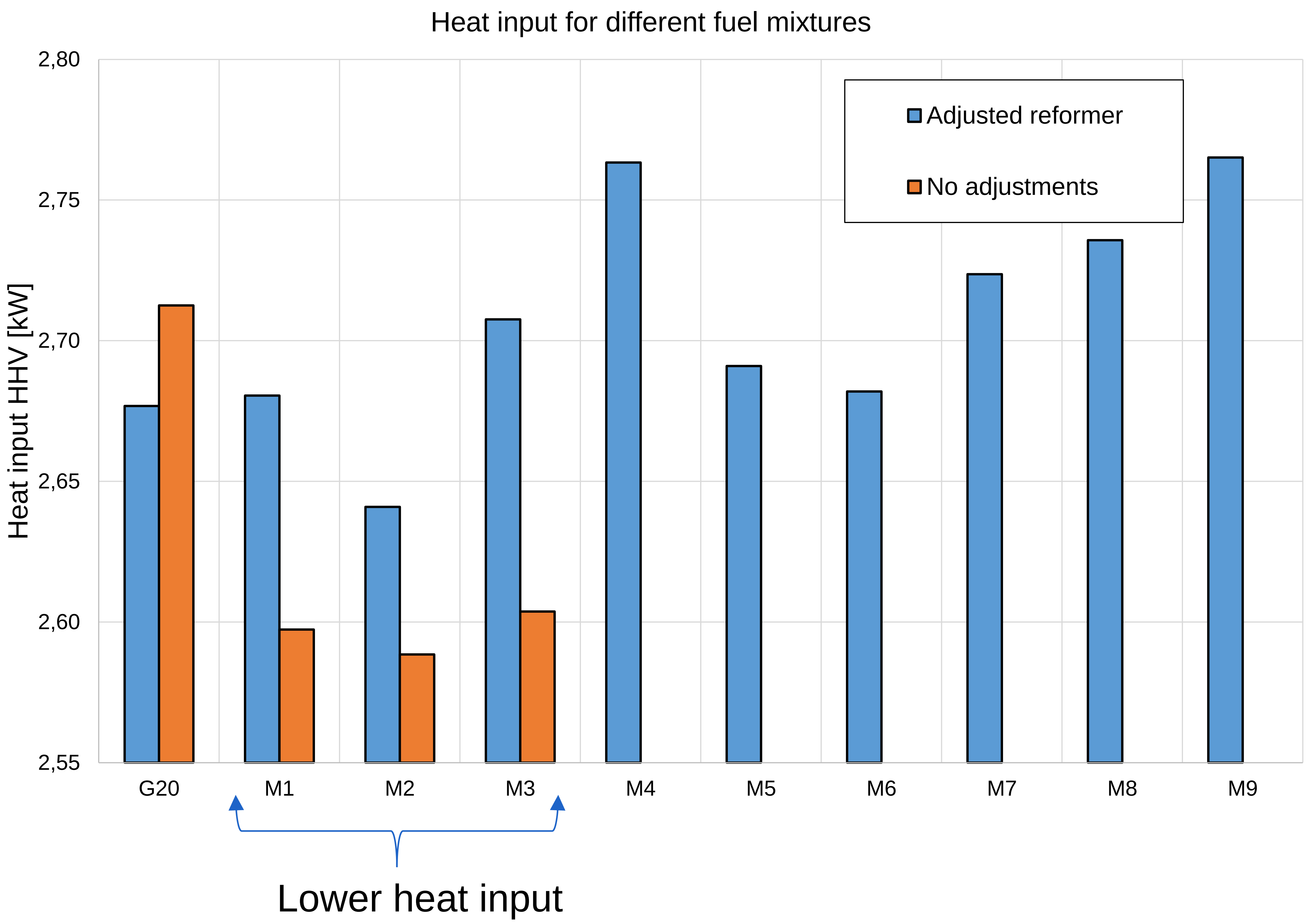
RESULTS SOFC

RESULTS **SOFC**, HEAT INPUT



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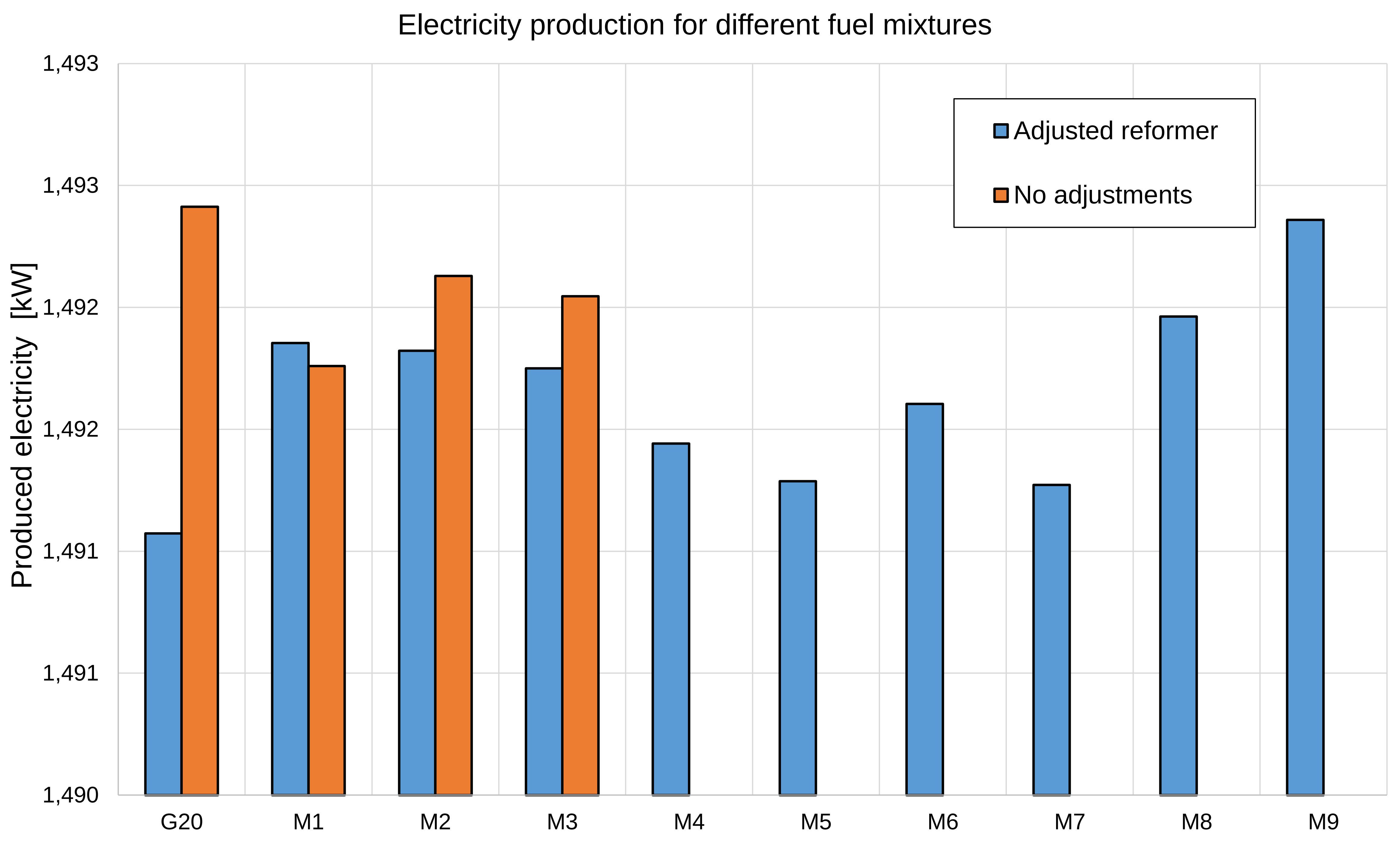
RESULTS **SOFC**, GENERATED ELECTRICITY



≈1.3 Wh

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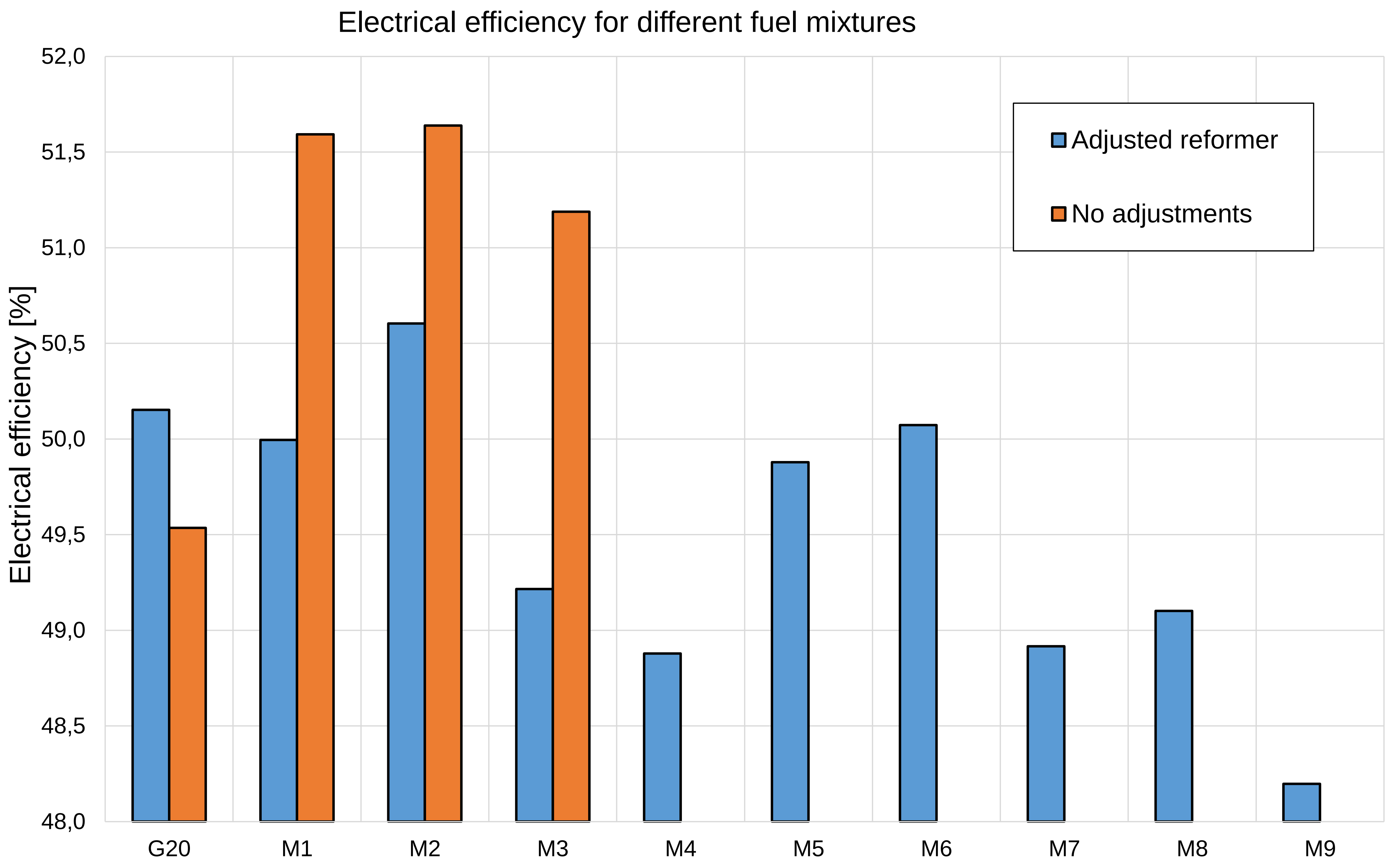
RESULTS **SOFC**, ELECTRICAL EFFICIENCY



≈ 50%

≈3.44 pp

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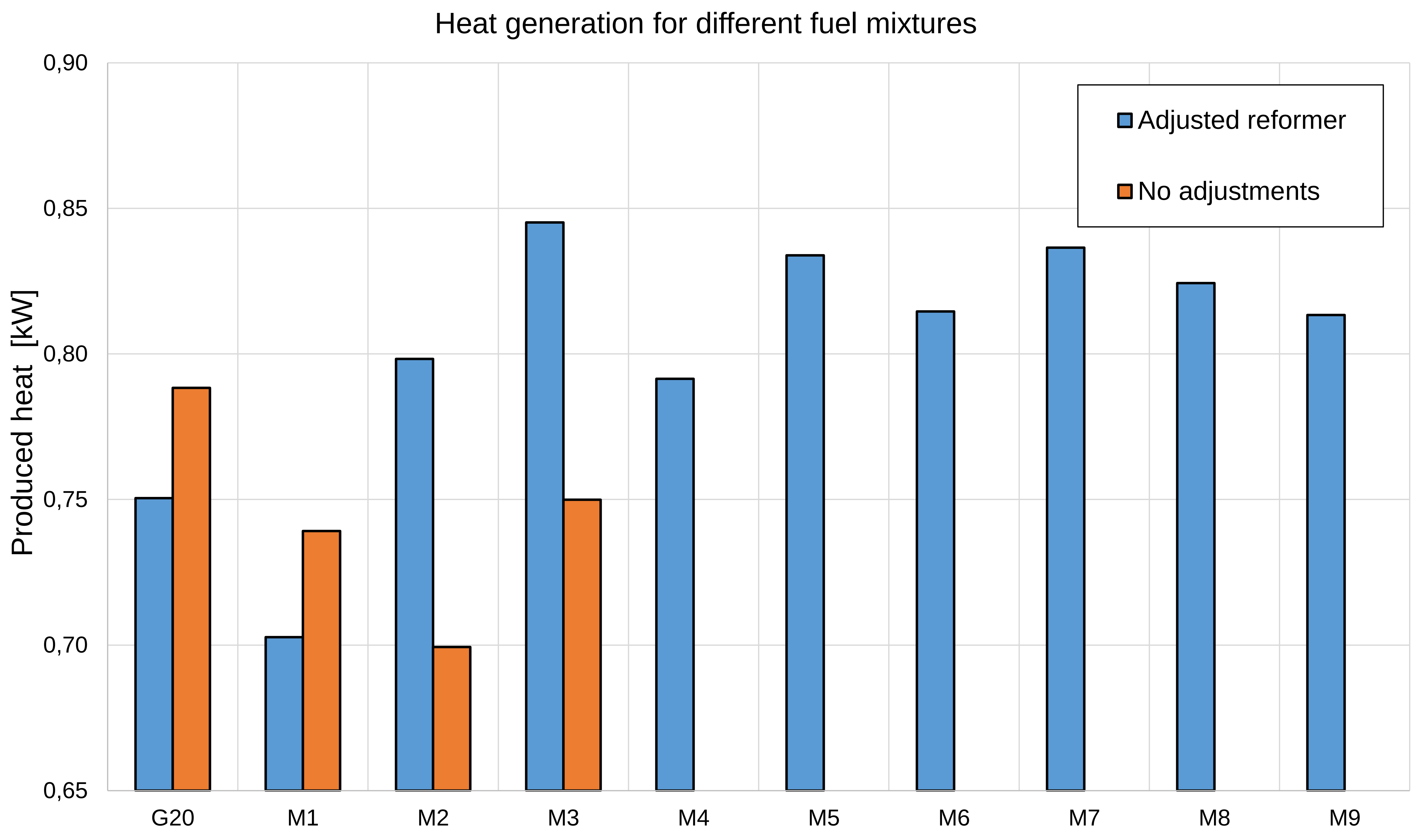
RESULTS **SOFC**, GENERATED HEAT



≈150 W

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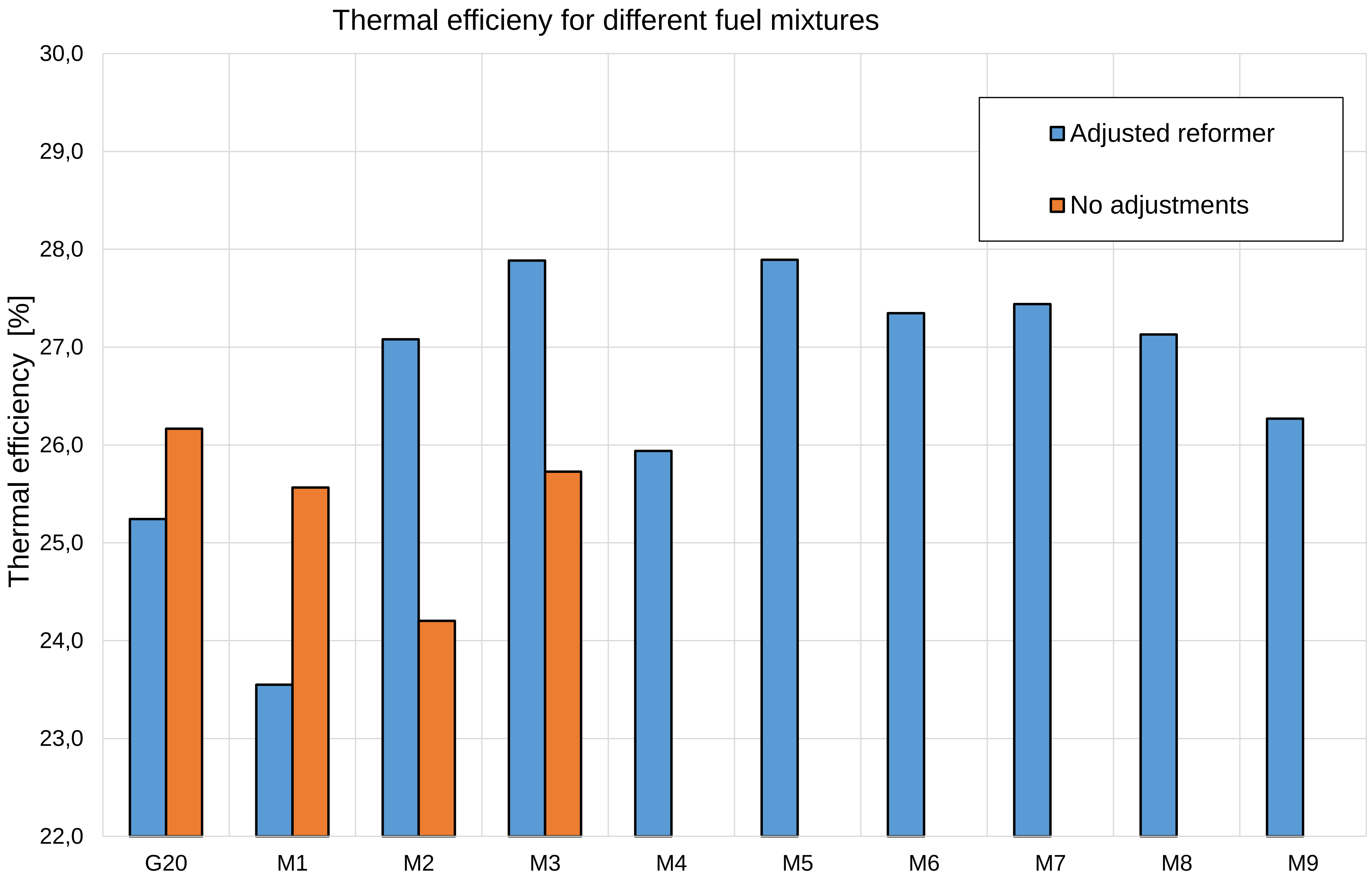
RESULTS **SOFC**, THERMAL EFFICIENCY



≈ 26%

≈ 4.34 pp

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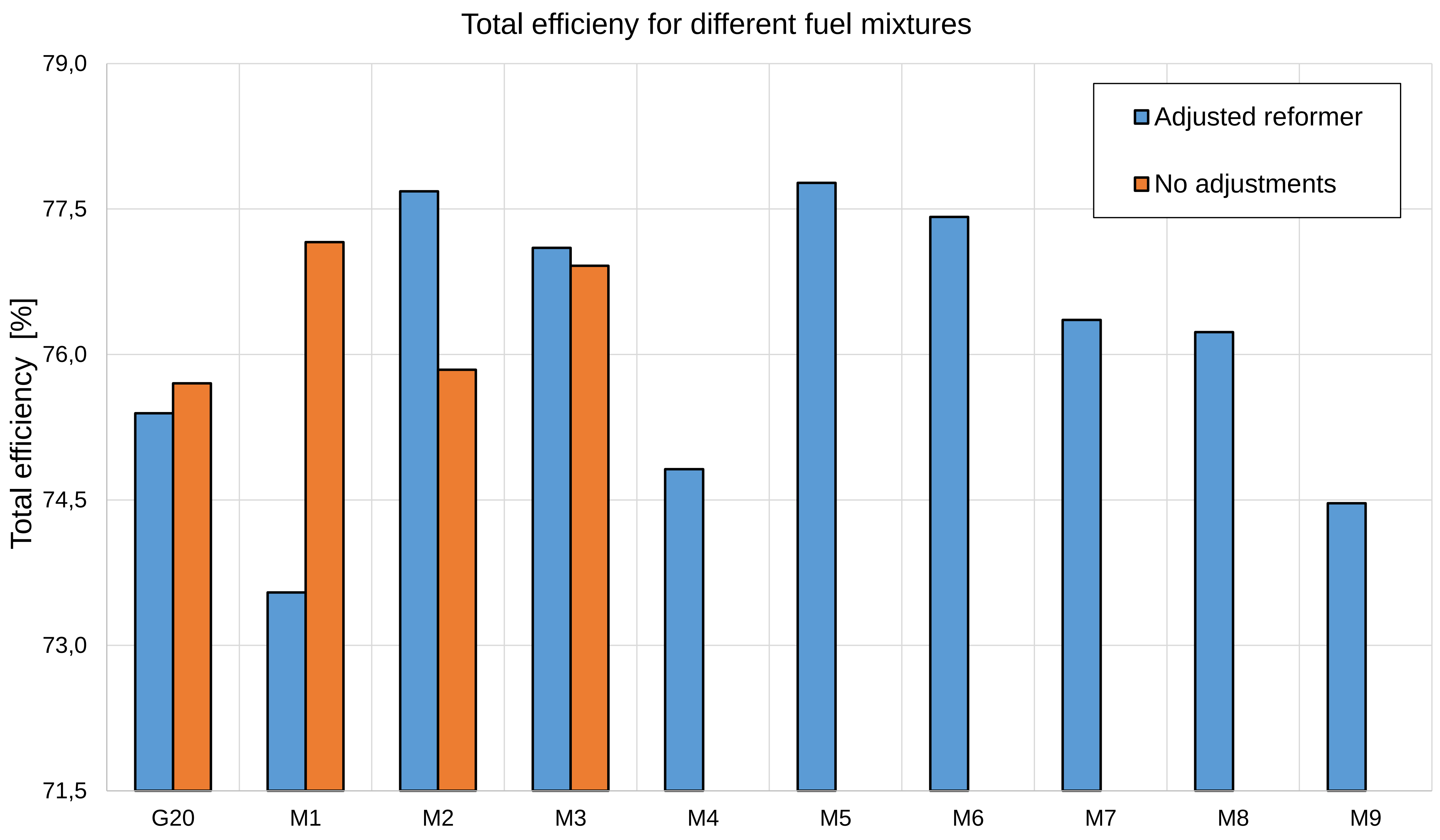
RESULTS **SOFC**, TOTAL EFFICIENCY



≈ 75%

First phase, ≈ 4.2 pp

Second phase, ≈ 1.5 pp

- Thermal output
- Fuel intake

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RESULTS PEM

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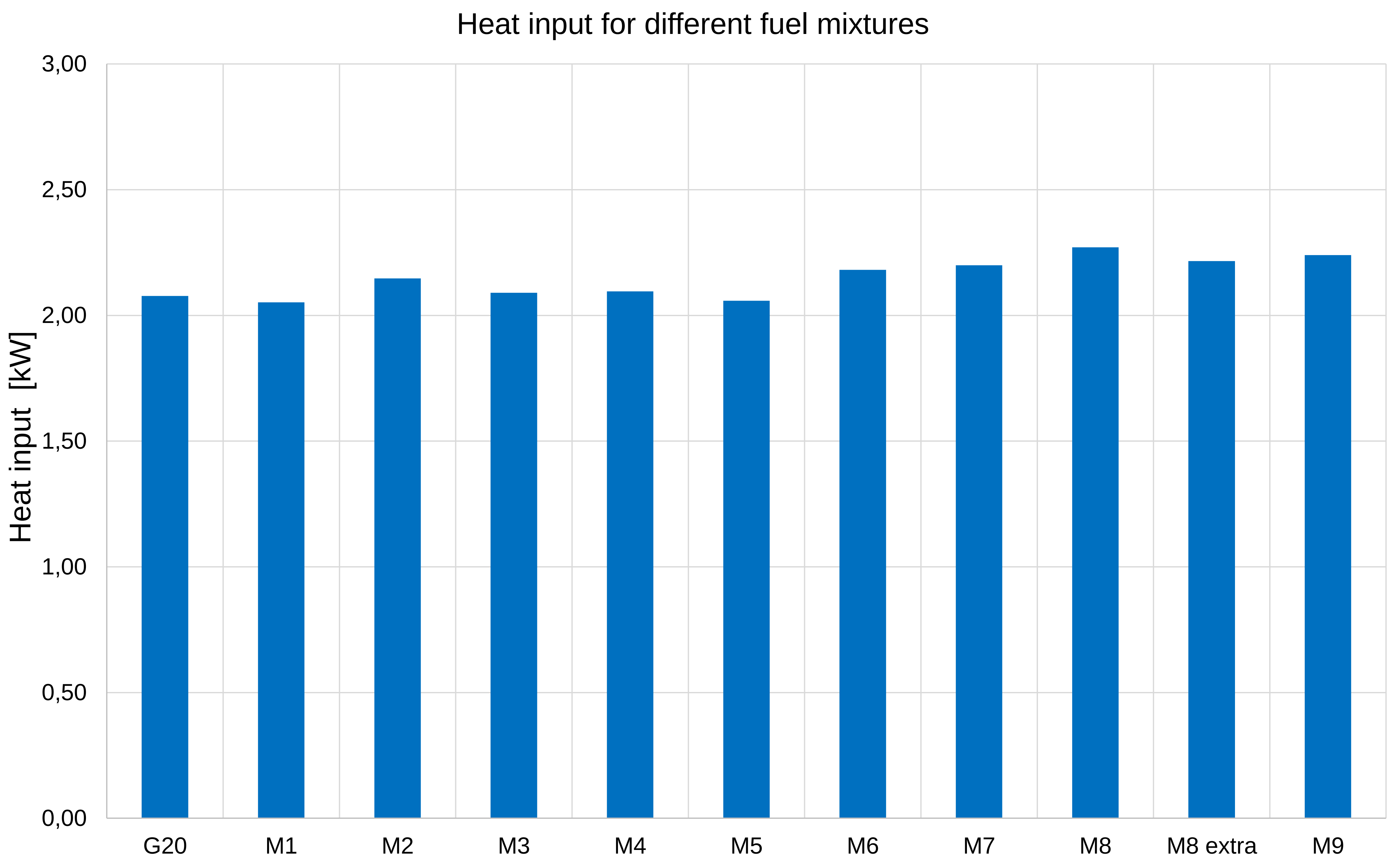
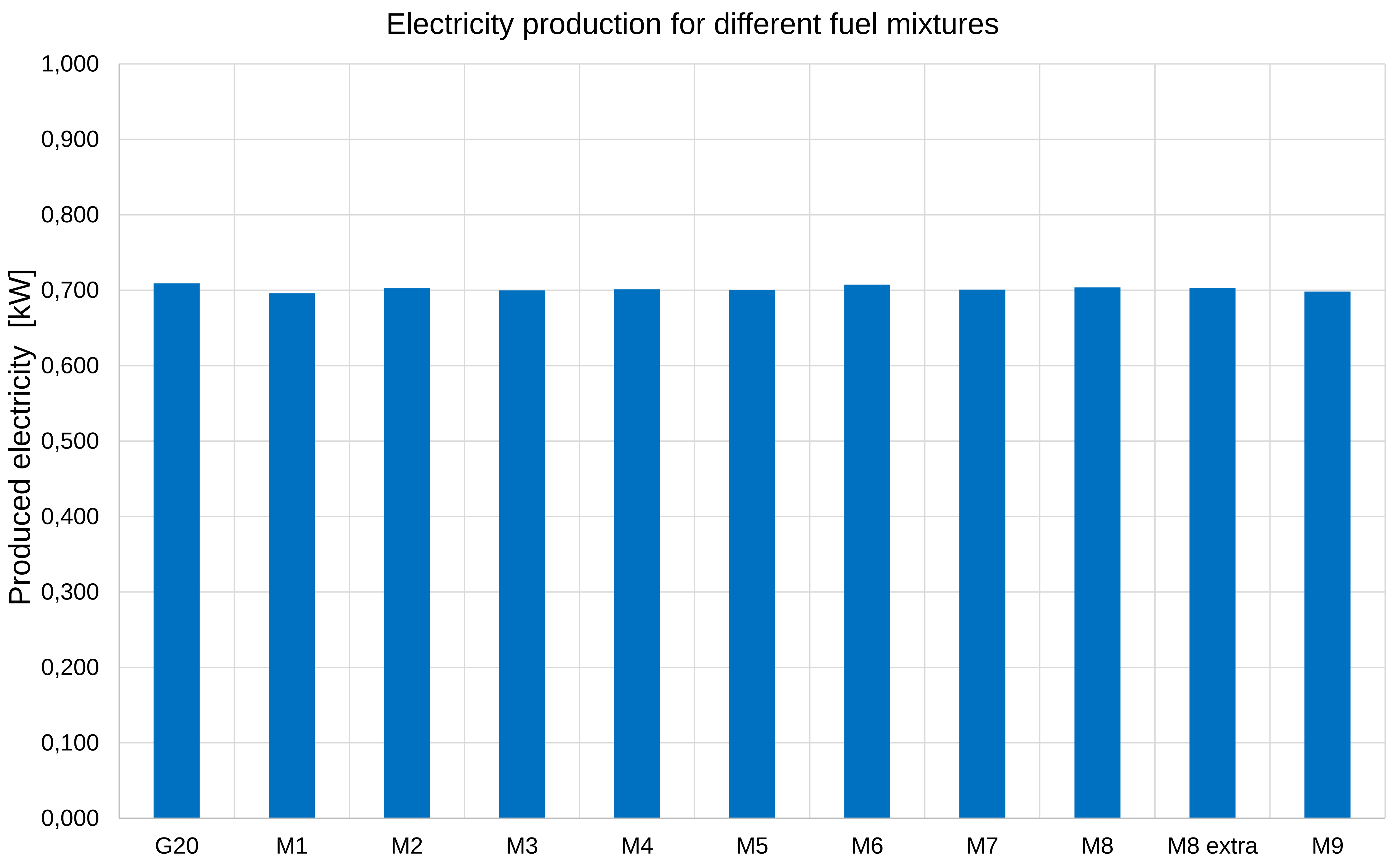
RESULTS **PEM**, HEAT INPUT



Fairly constant

220 W

RESULTS **PEM**, GENERATED ELECTRICITY



≈13 Wh

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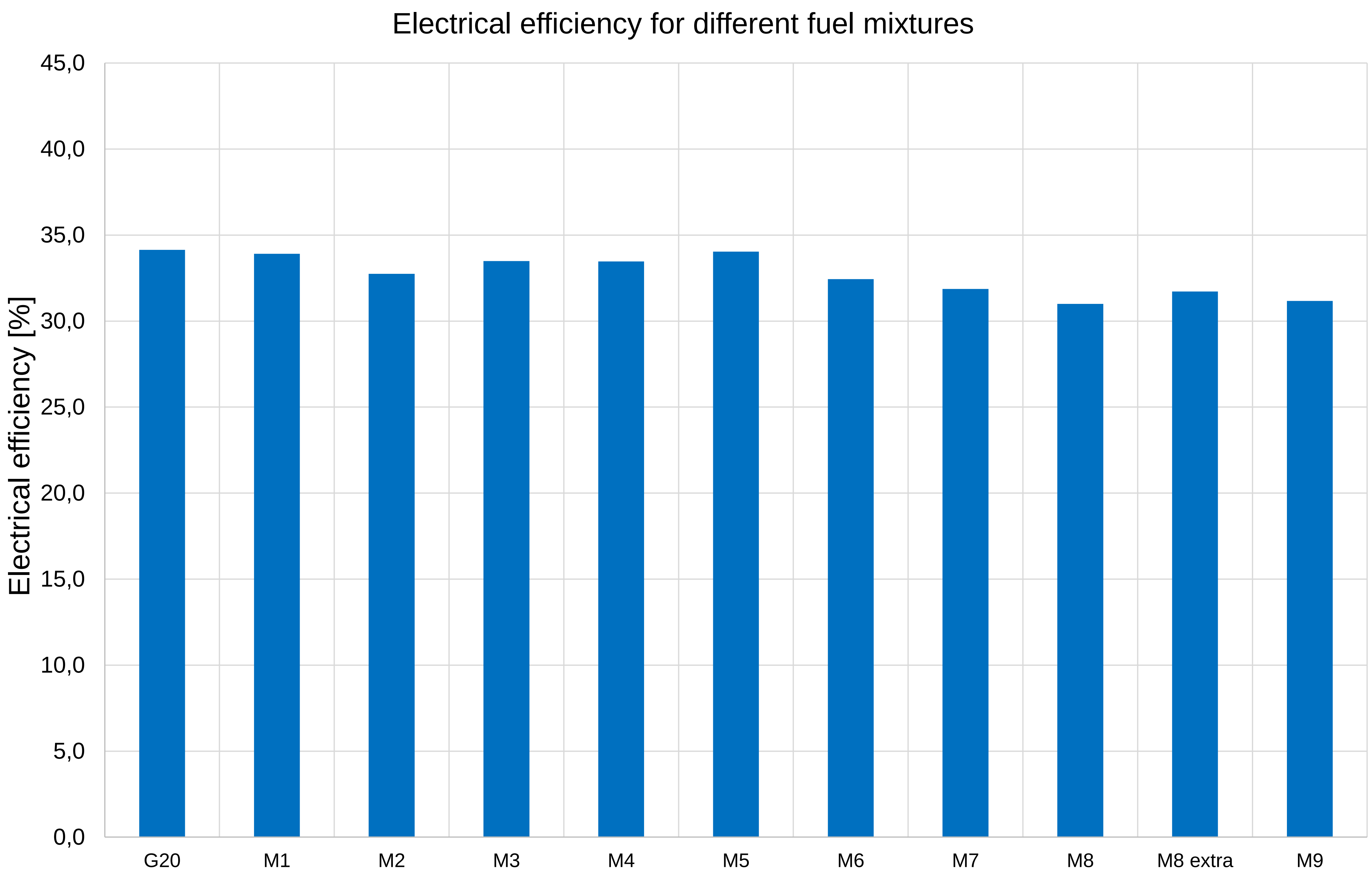
RESULTS **PEM**, ELECTRICAL EFFICIENCY



≈ 33%

≈ 50% SOFC

≈3.14 pp

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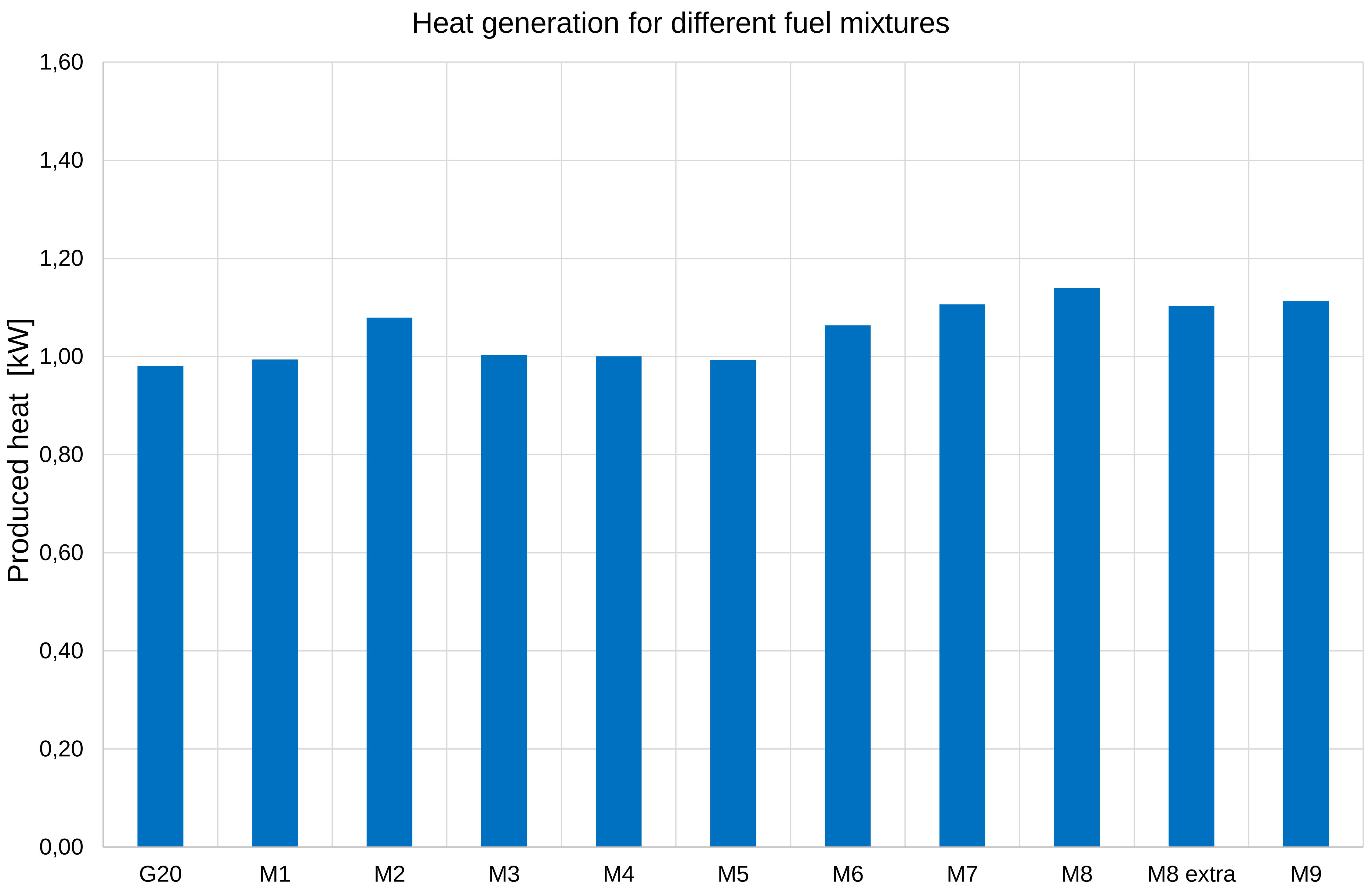
RESULTS **PEM**, GENERATED HEAT



≈160 W

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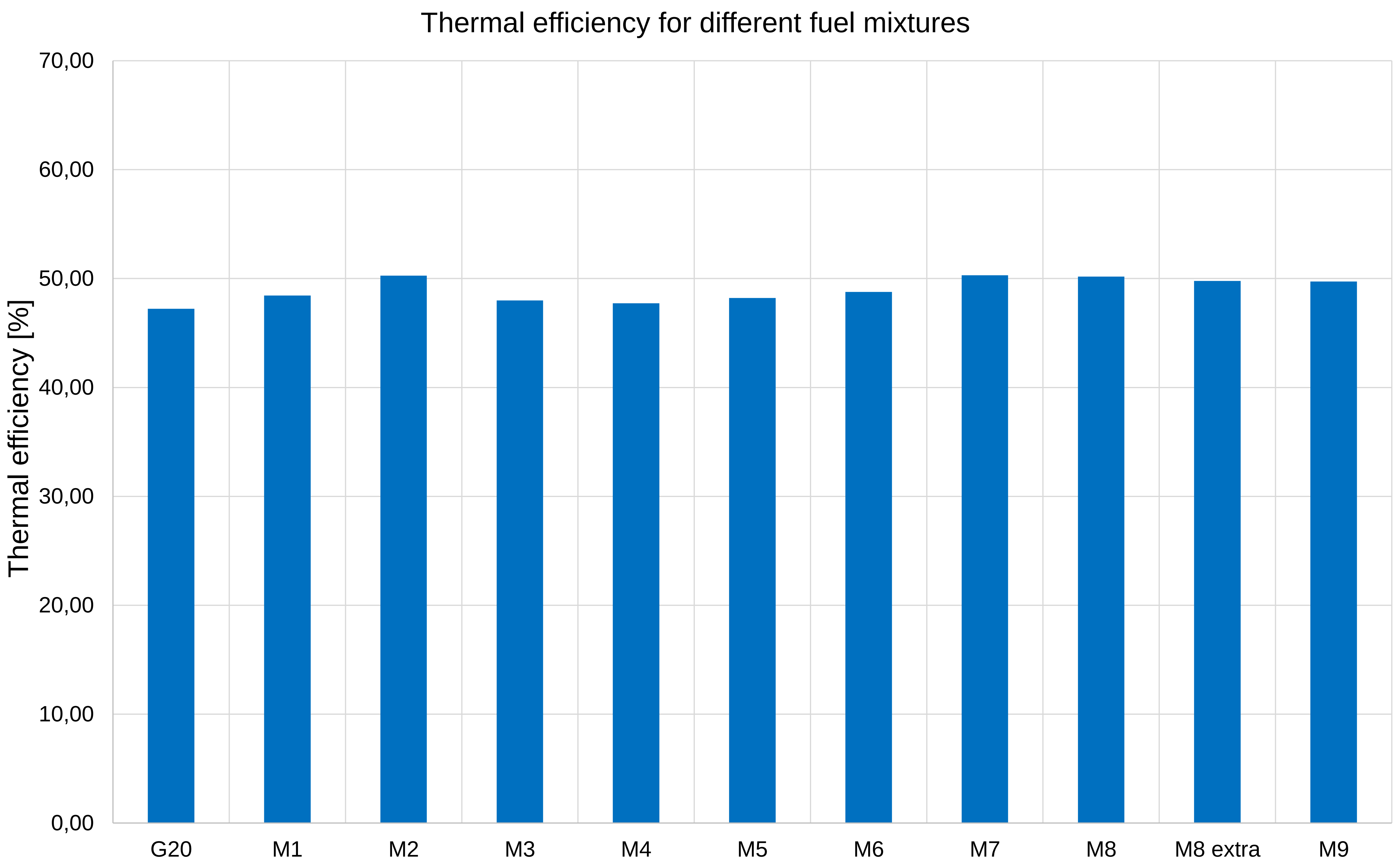
RESULTS **PEM**, THERMAL EFFICIENCY



≈ 48%

≈ 26% SOFC

≈ 3.07 pp

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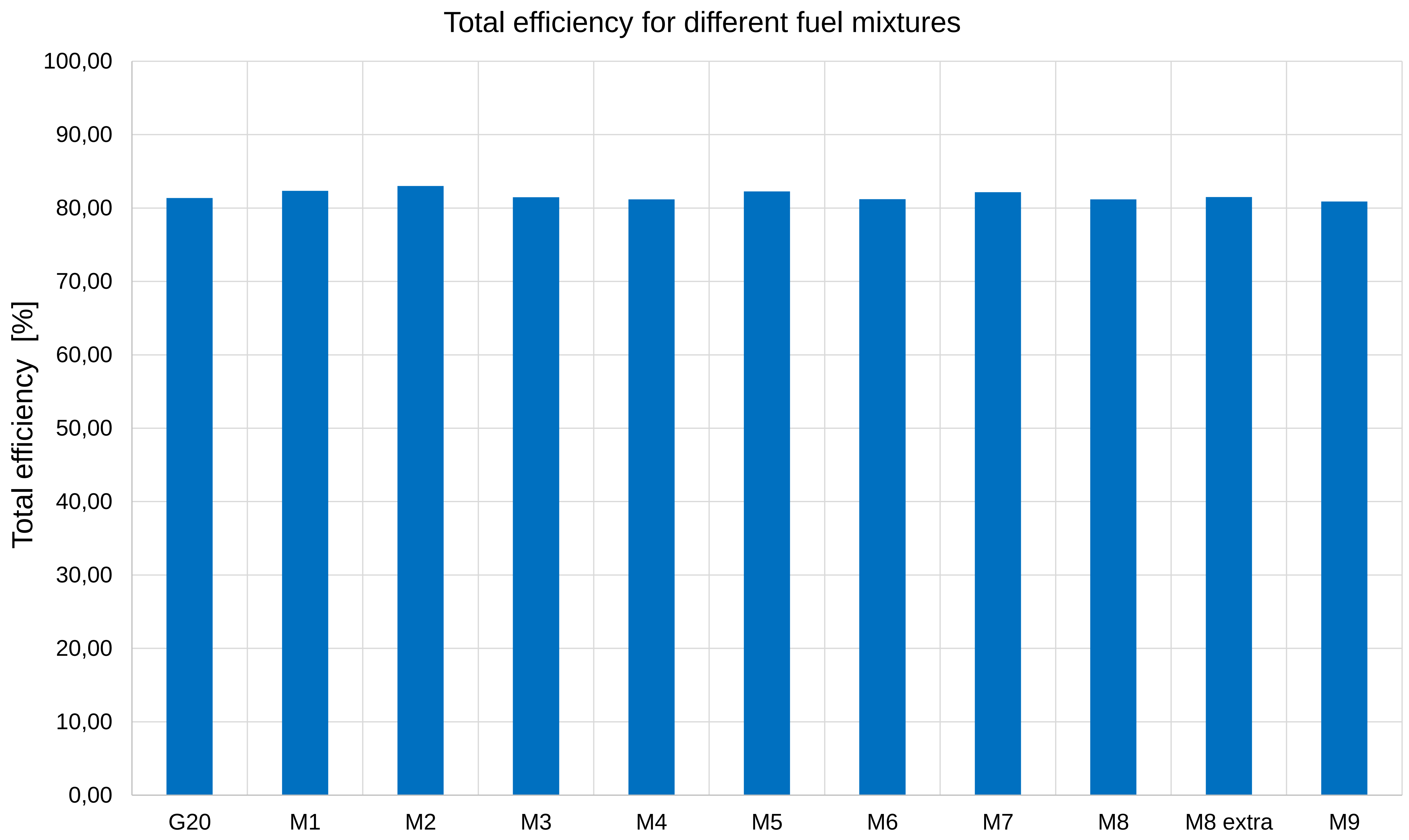
RESULTS **PEM**, TOTAL EFFICIENCY



≈ 82%

≈ 75%, SOFC

≈ 2.12 pp

MARGINAL CALCULATIONS

	Fuel mixture	SOFC Total yield H_2	PEM Total yield H_2
G20*	100% CH_4		
M1	90% CH_4 + 10% H_2	29.9%	130.9%
M2	80% CH_4 + 20% H_2	122.7%	123.2%
M3	70% CH_4 + 30%, 25% H_2	105.2%	97.8%
M4*	87% CH_4 + 13% C_3H_8		
M5	57% CH_4 + 30% H_2 + 13% C_3H_8	107.0%	107.6%
M6*	96% CH_4 + 4% CO_2		
M7	66% CH_4 + 30%, 25% H_2 + 4% CO_2	99.1%	106.8%
M8*	92.5% CH_4 + 7.5% N_2		
M9	62.5% CH_4 + 30%, 25% H_2 + 7.5% N_2	89.1%	92.9%

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CONCLUSION

– Fuel cells can be used to mitigate the shortage or overload of the electrical energy and aid the electrification plans

– 1.5kWel SOFC, 700Wel PEM

10 mixtures of natural gas and up to 30% H_2

⇨ Low impact on the efficiency of the tested FC units

⇨ Decarbonization of the current natural gas grid is to be promoted when fuel cells are used

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