



Energy research Centre of the Netherlands

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Policy Studies



Learning Curves for Fuel Cells

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Our fields of interest

Hydrogen...

- **production**
- **distribution**
- **storage**
- **end-use in fuel cells**



Are tools available to assess the potential of hydrogen end-use technologies?

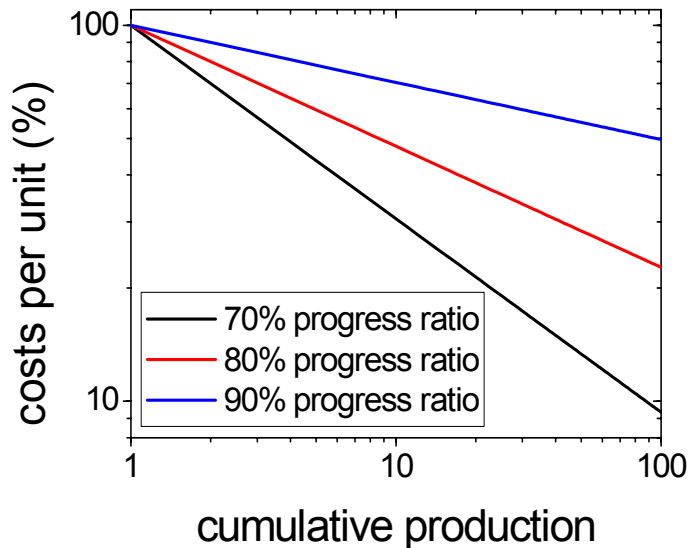
YES, learning curves!

Many fuel cell technologies are in their demonstration phase

→ can we detect learning prematurely?

Empirical

Methodology: Learning curves



Power law behavior:

$$c_x = c_0 \left(\frac{x}{x_0} \right)^{-\alpha}$$

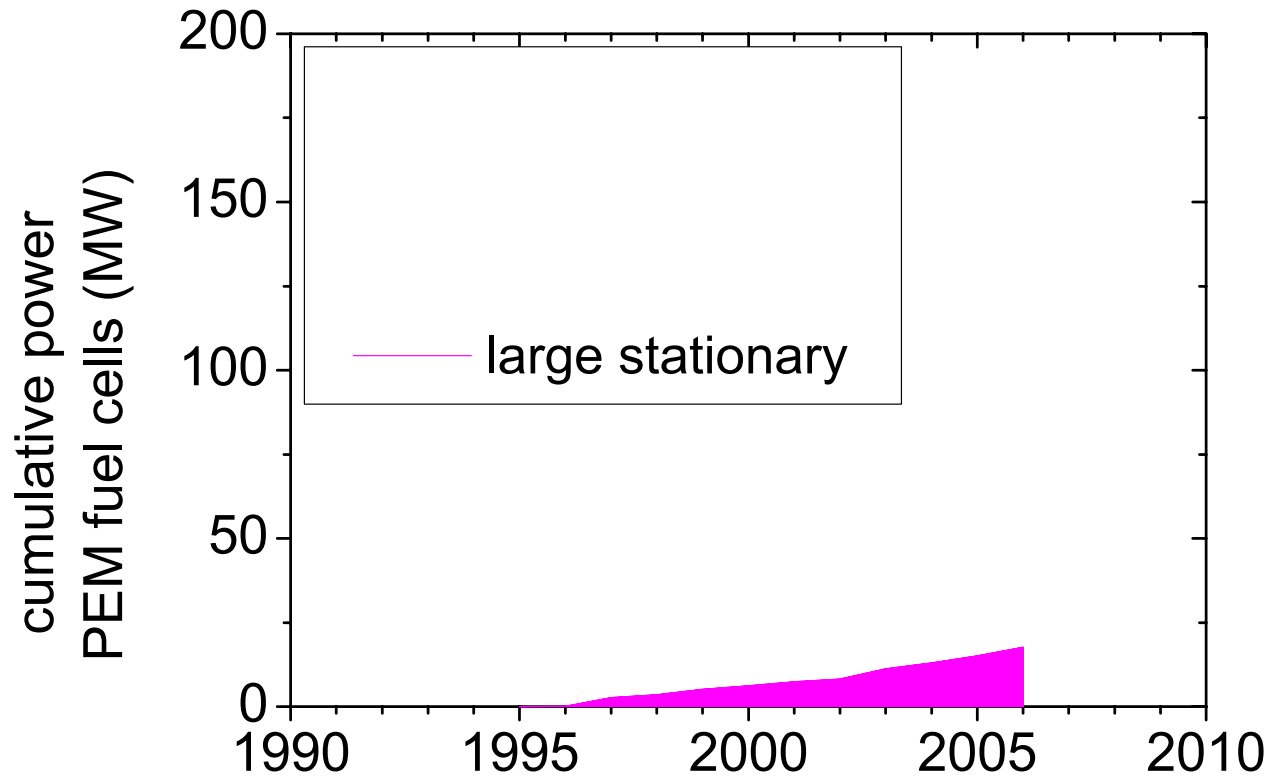
doubling of cumulated production

→ costs reduce with factor pr

$$pr = 1 - LR$$

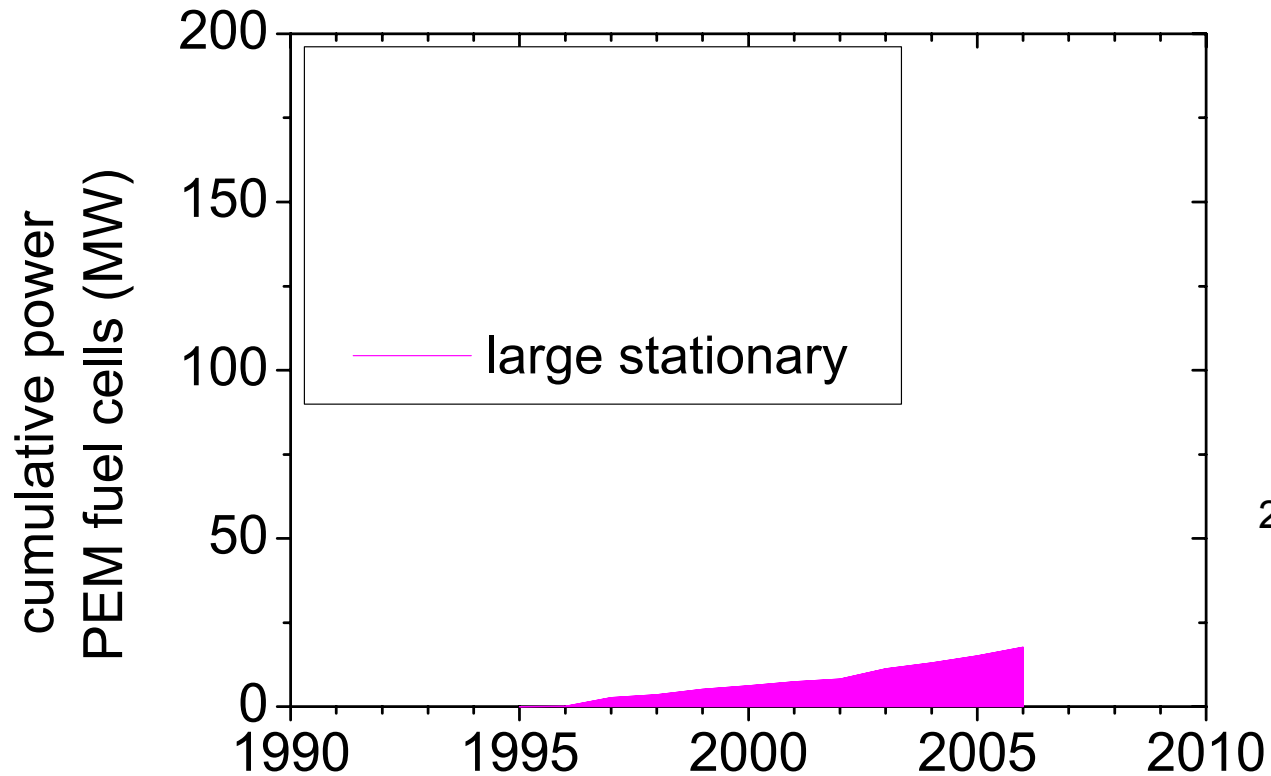
- c_0 = costs to produce x_0
- x_0 = unit of x
- x = cumulative production (unit number)
- c_x = costs to produce x^{th} unit
- α = learning index, progress ratio $pr = 2^{-\alpha}$

Global cumulative power of PEMFC

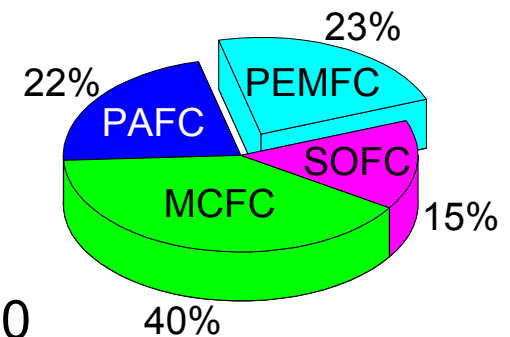


Cumulative No

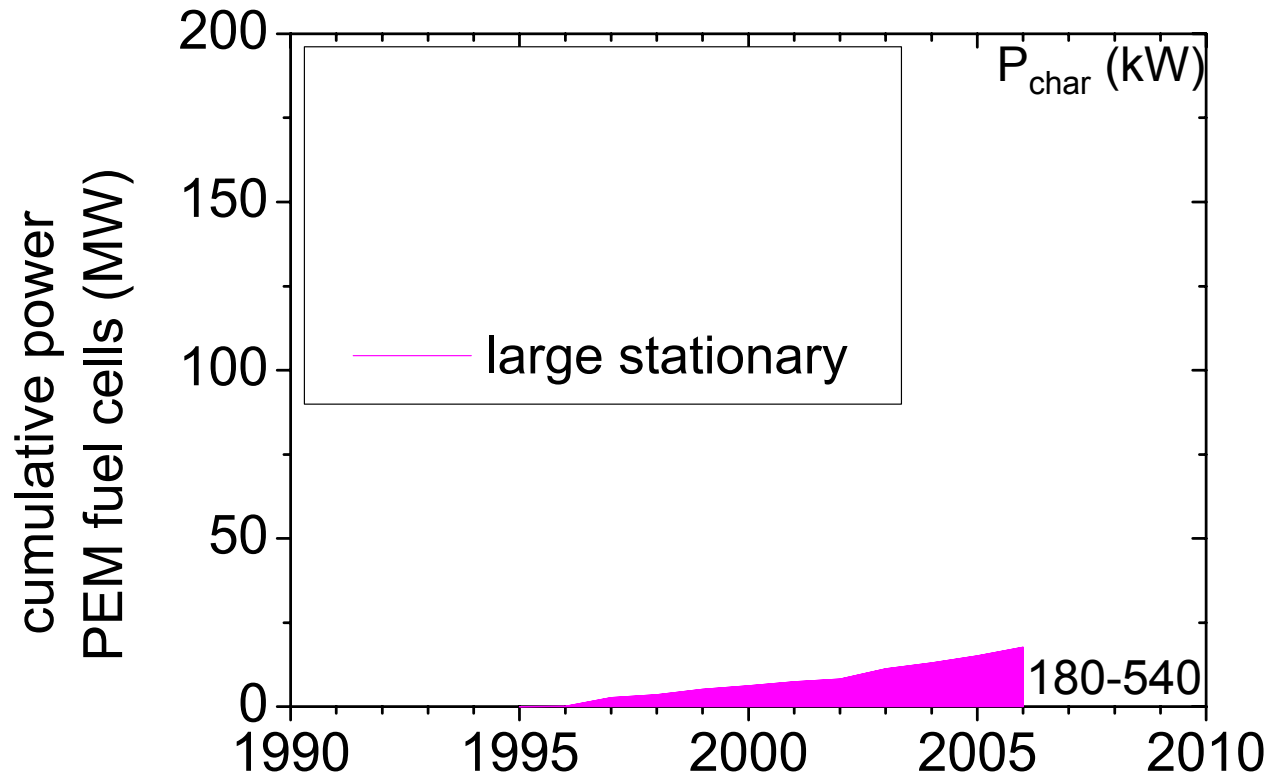
Global cumulative power of PEMFC



Cumulative No
X
PEMFC share



Global cumulative power of PEMFC



Cumulative No

X

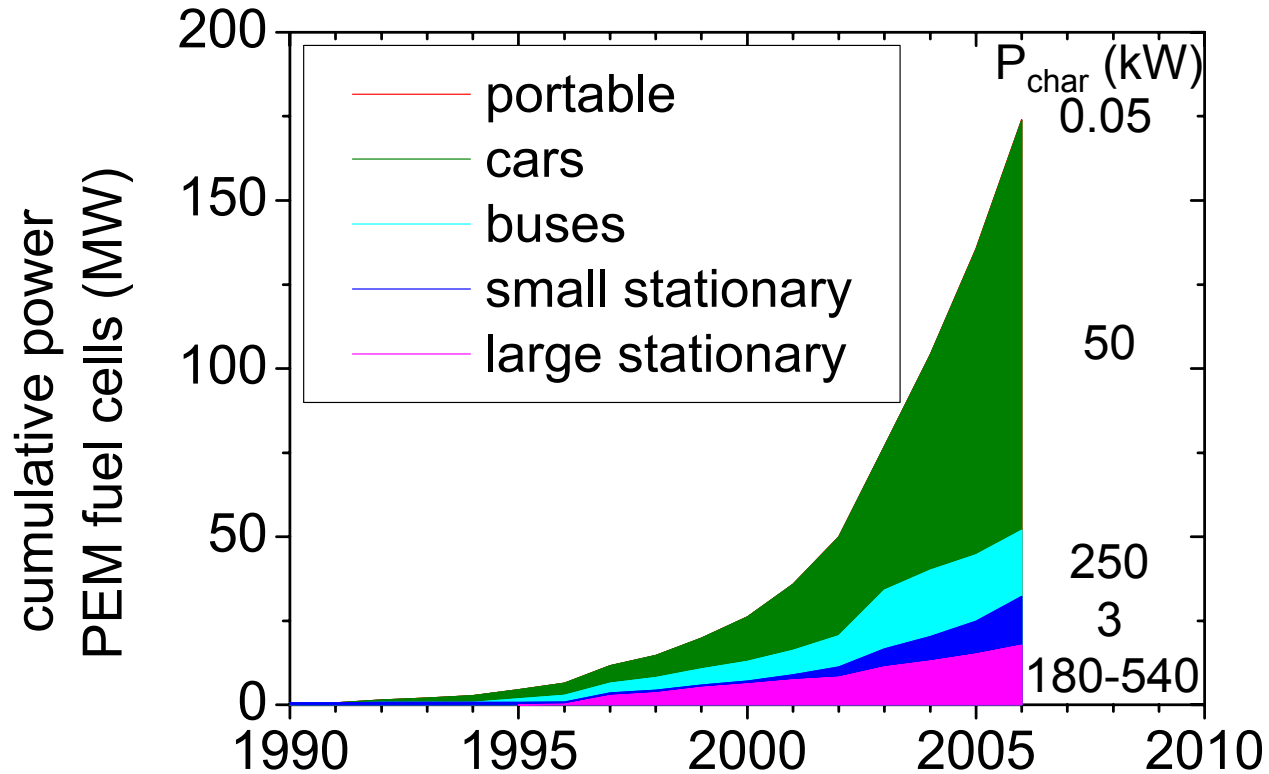
PEMFC share

X

$P_{characteristic}$

But more powerful FC simply consist of more cells!

Global cumulative power of PEMFC



Cumulative No

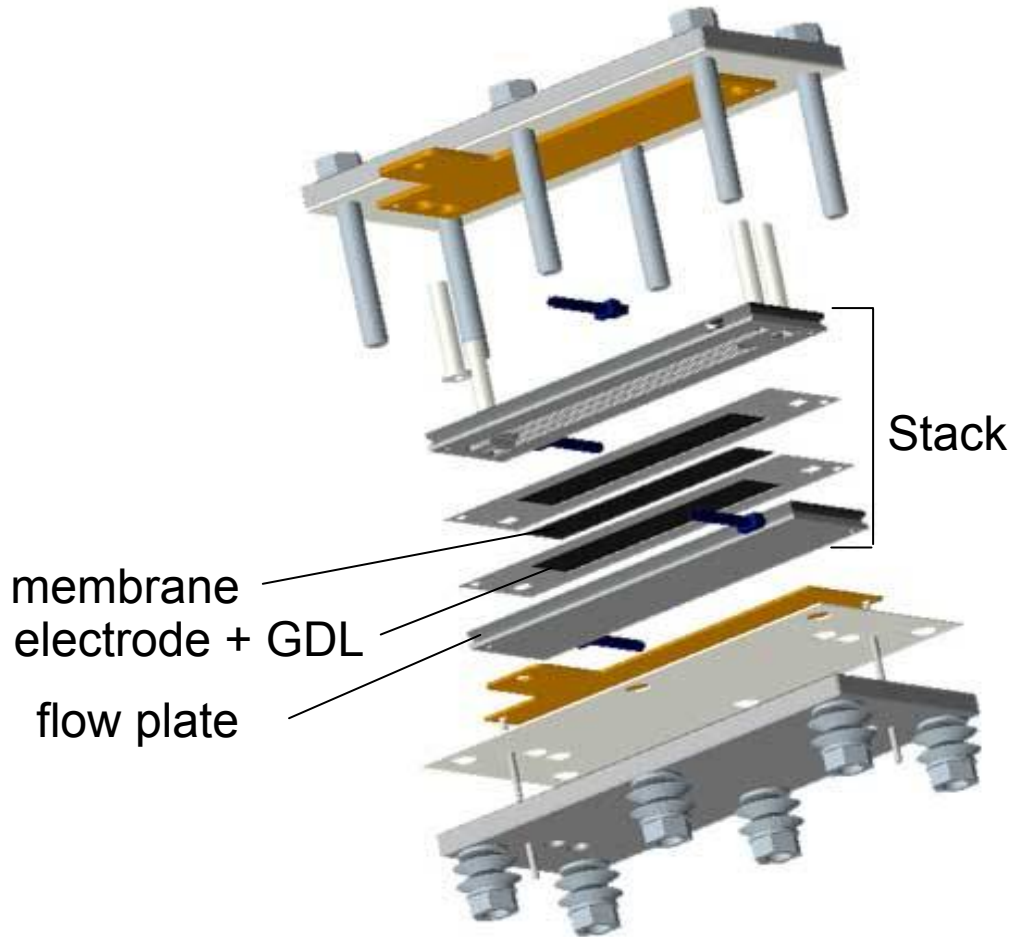
X

PEMFC share

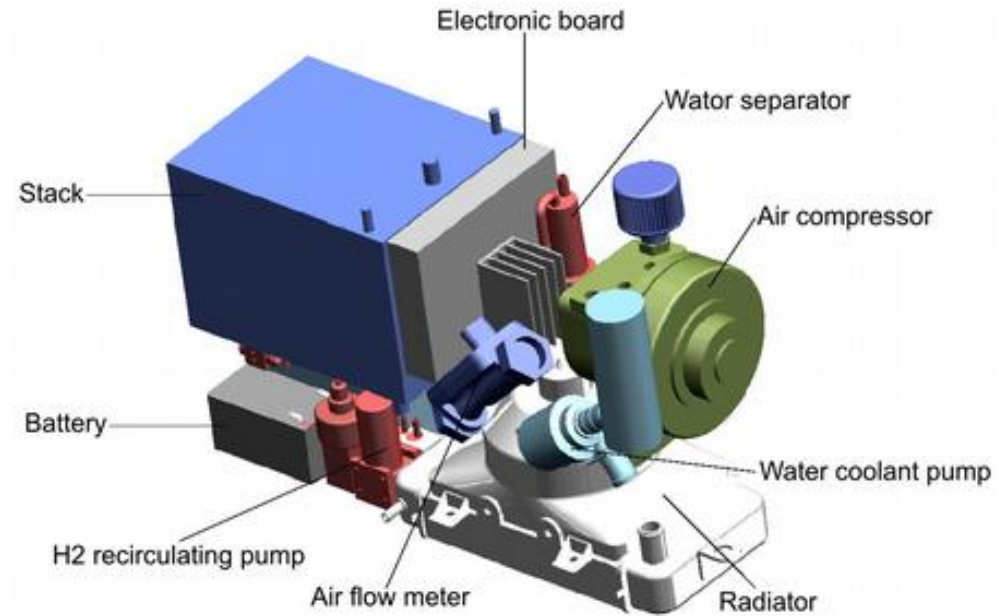
X

$P_{characteristic}$

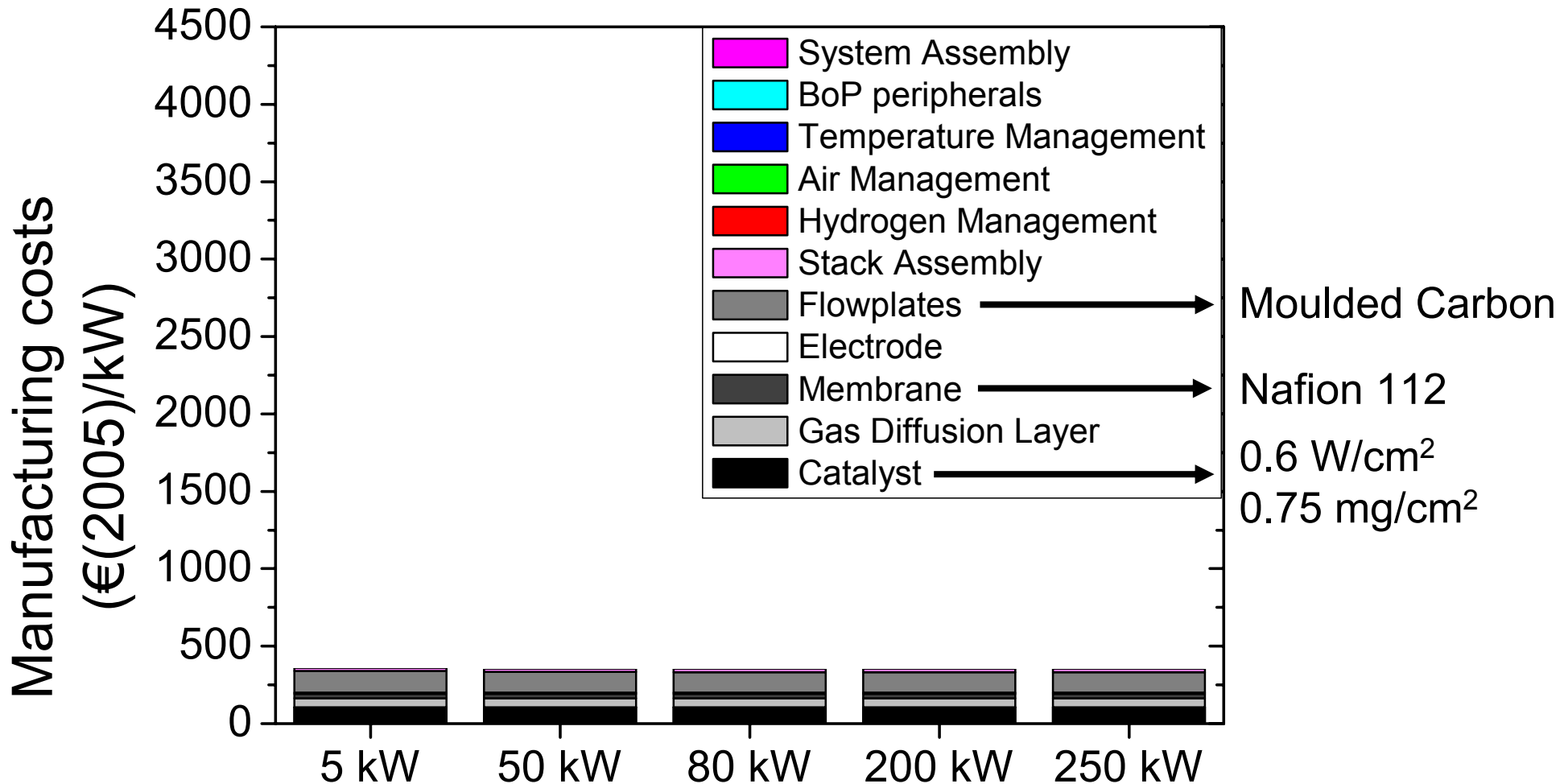
PEM fuel cell: how does it work?



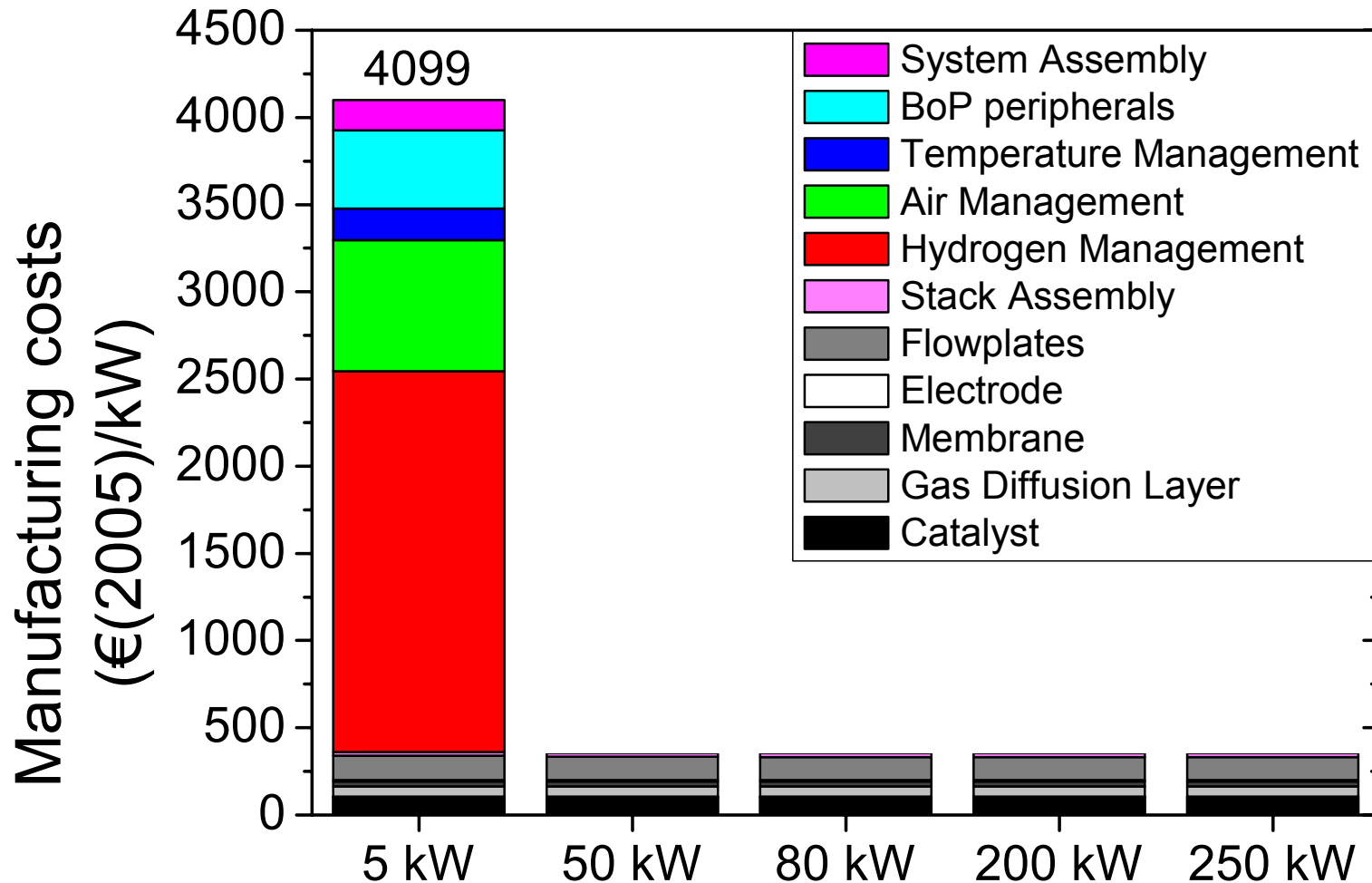
Fuel Cell System



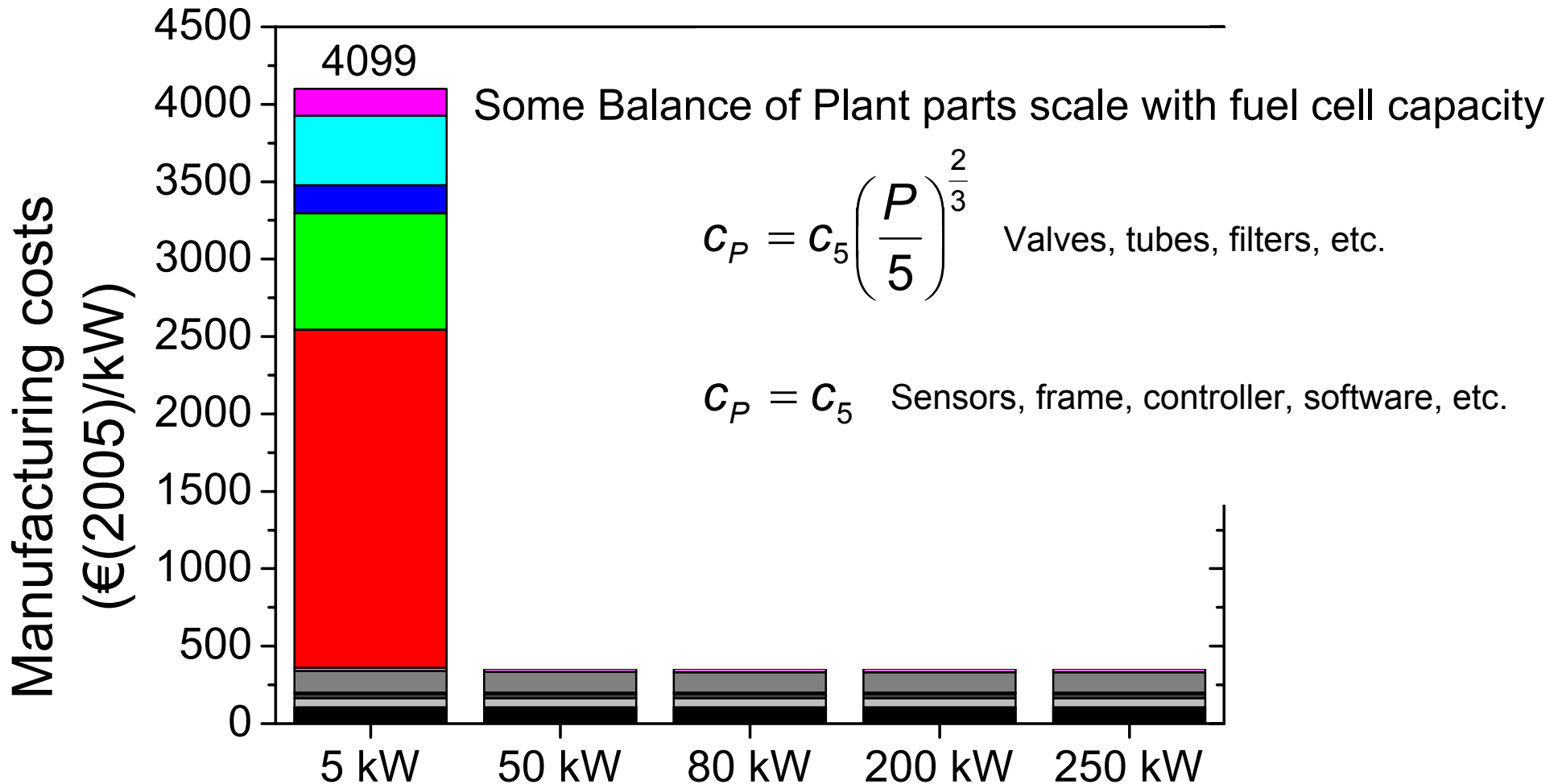
PEM fuel cell system costs



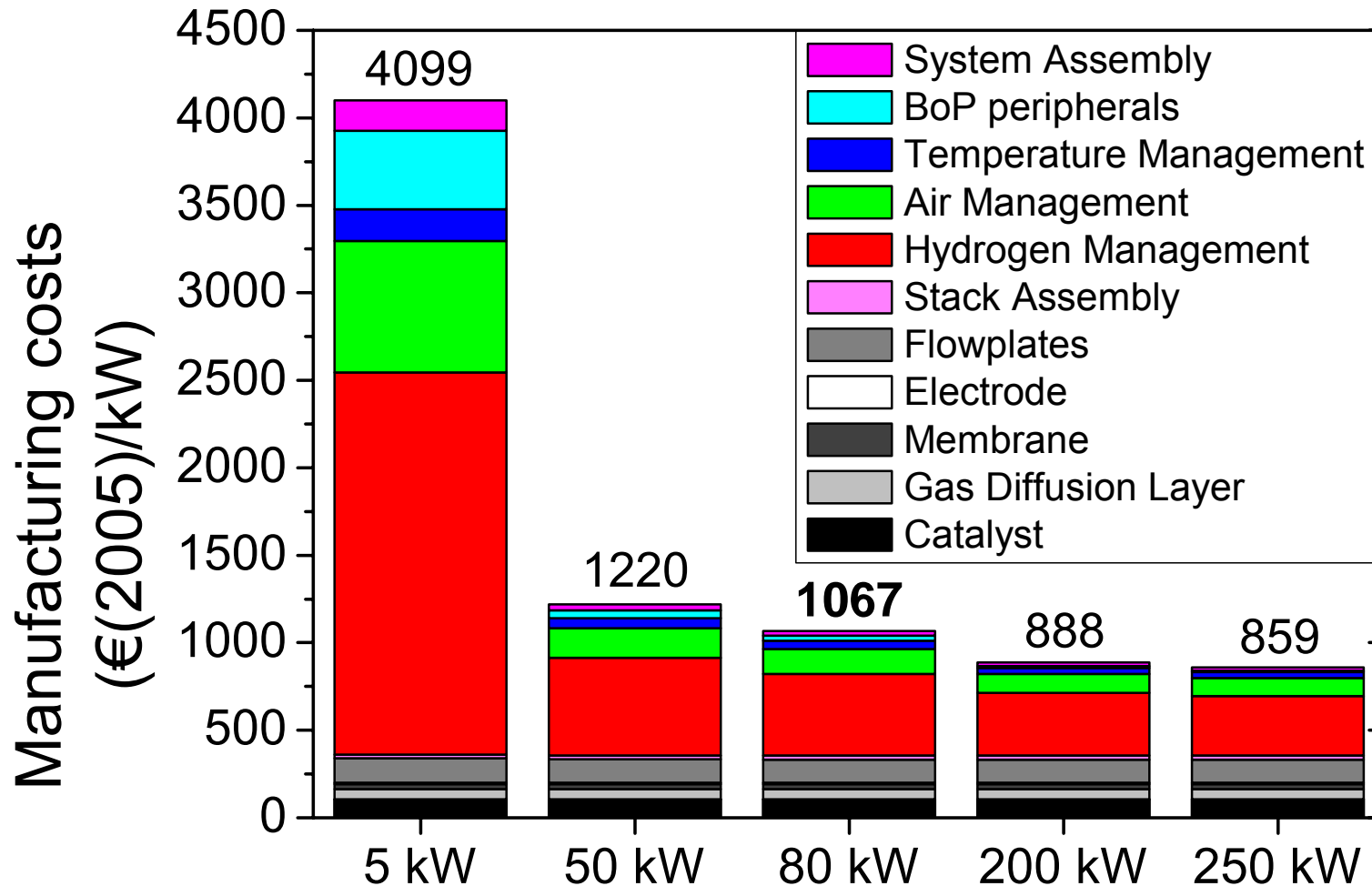
PEM fuel cell system costs



PEM fuel cell system costs

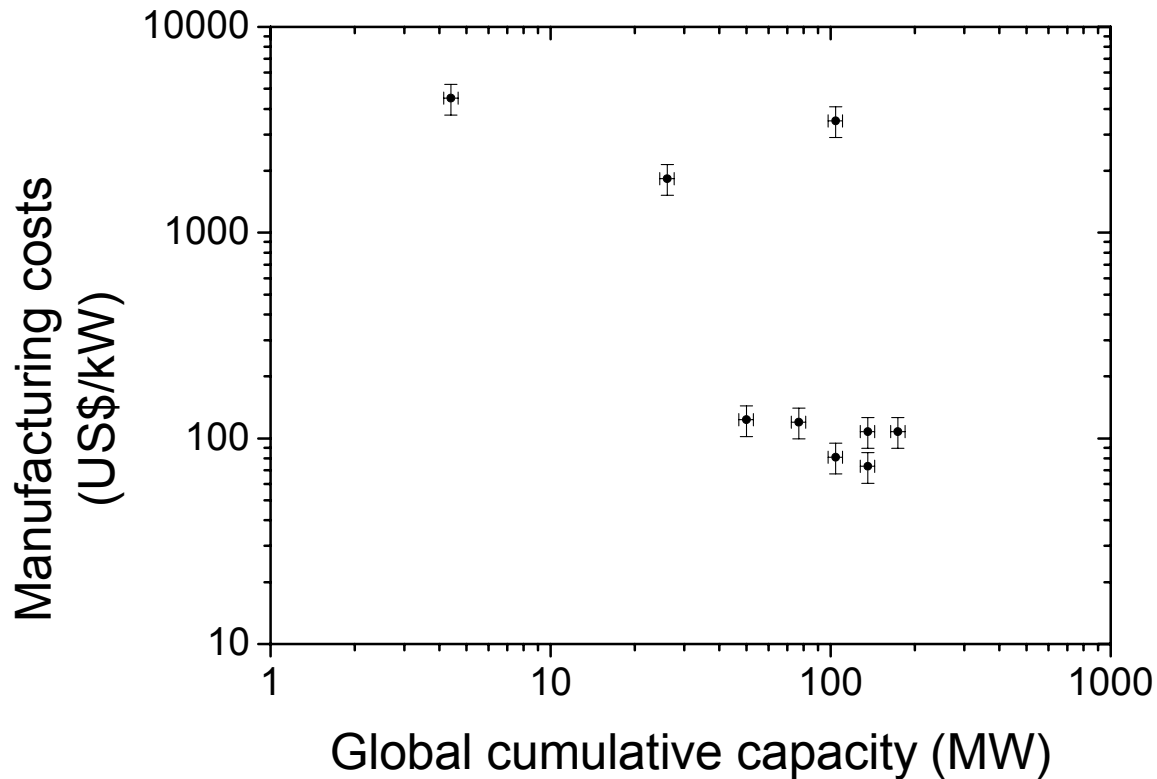


PEM fuel cell system costs



Learning curve PEMFC for transportation

running on pure hydrogen only, raw data

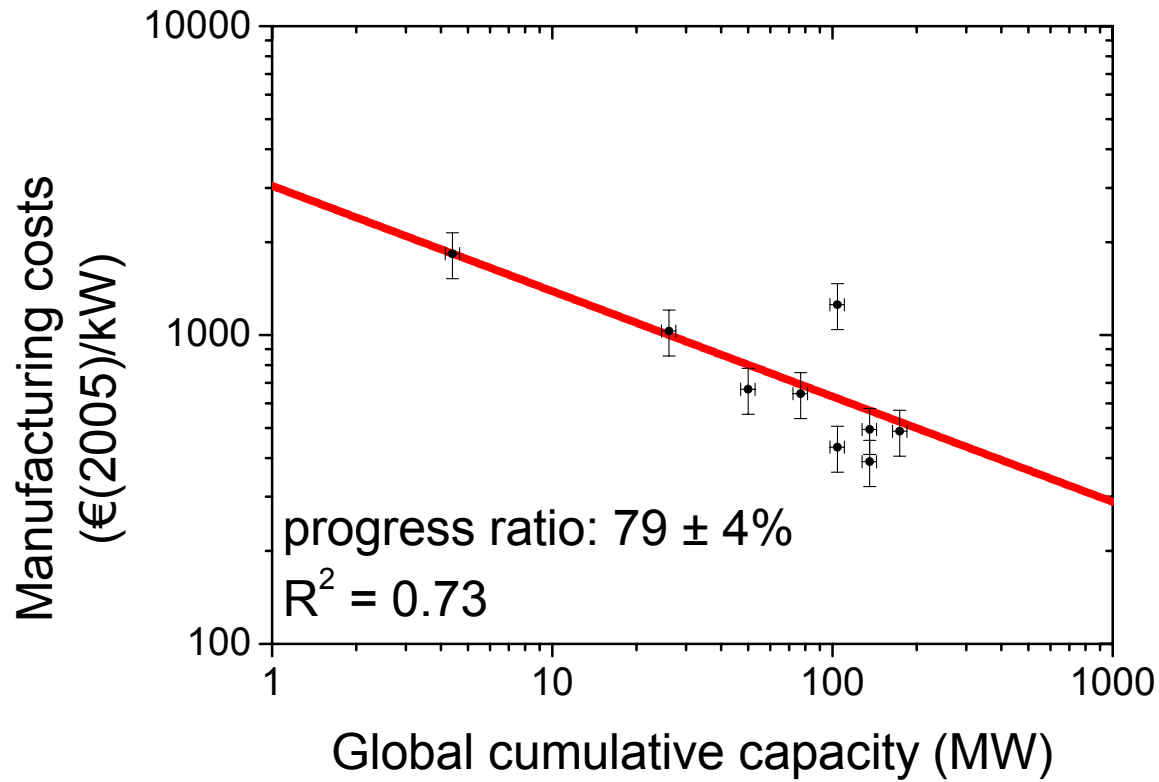


Corrections required:

- Inflation
- Economies-of-scale
- Pt market price

Learning curve PEMFC for transportation

running on pure hydrogen only, with all corrections

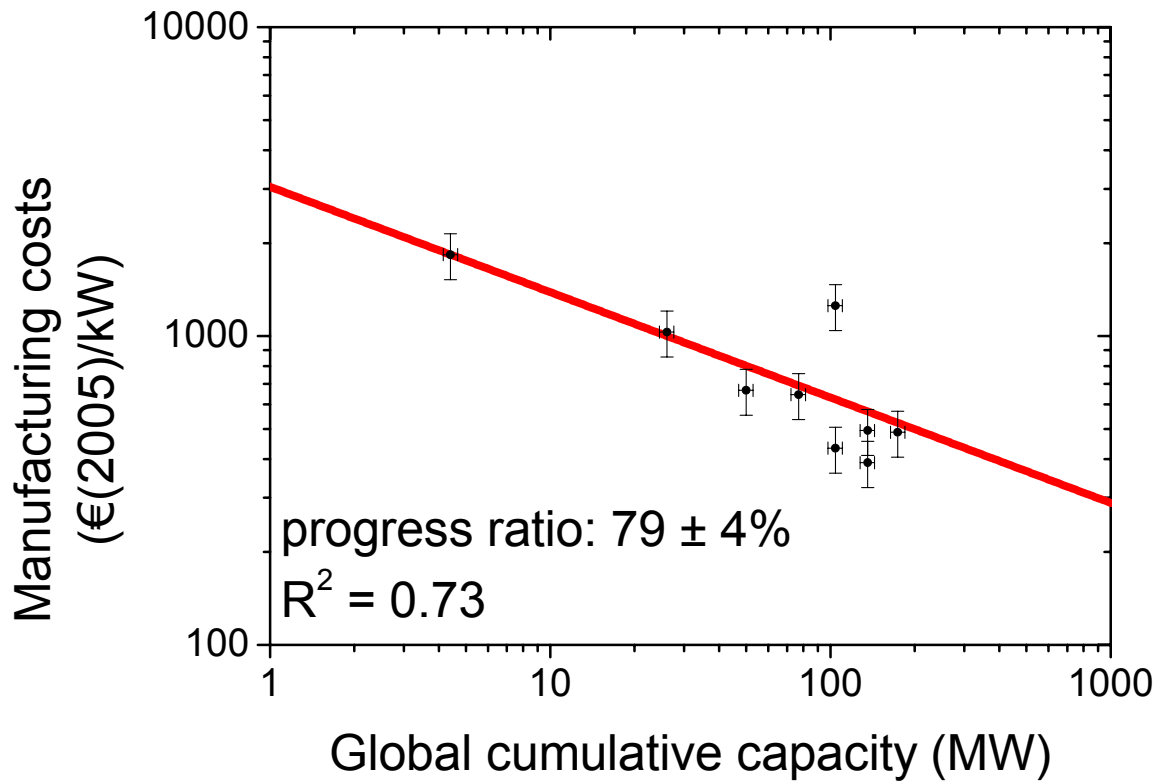


Corrections:

- Inflation
→ 2005
- Economies-of-scale
→ 500 units/yr
- Pt market price
→ 2005

Learning curve PEMFC for transportation

running on pure hydrogen only, with all corrections



Problems:

FC component market prices?

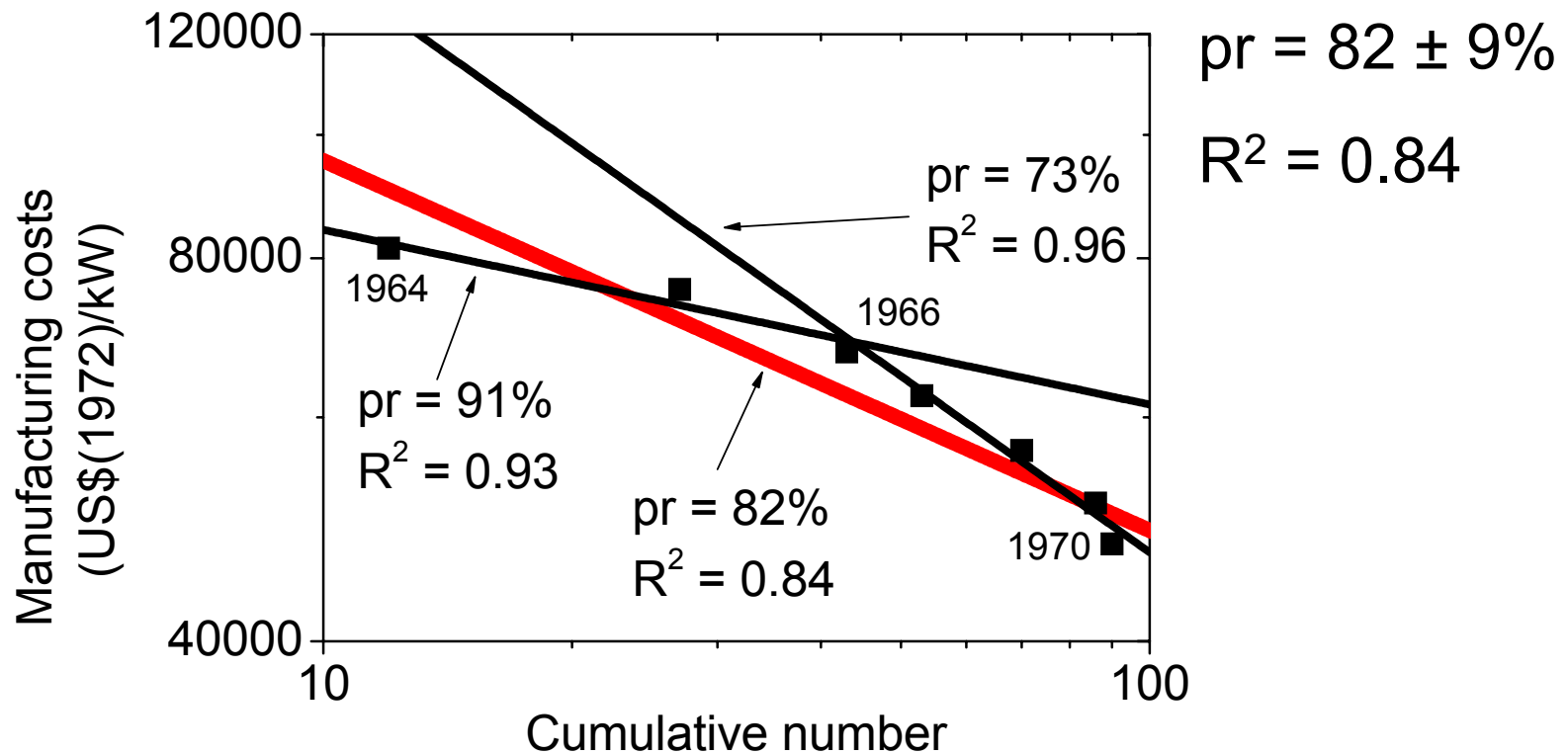
Definition of costs?
 What is accounted?
 For how much?

Econ. of scale over full costs justified?

Small technical differences

Apollo AFCs by Pratt & Whitney Aircraft

Learning curve



Technology Learning for Fuel Cells

Manufacturer	period	FC Type	PR	R ²
Global	1995-2006	PEMFC	79 ± 4%	0.73
P & W	1964-1970	AFC	82 ± 9%	0.84
UTC Power	1993-2000	PAFC	75 ± 3%	0.75
Ballard	2002-2005	PEMFC	70 ± 9%	0.83

Conclusions

- Can we detect learning prematurely for fuel cells?
- Yes!

- PEMFC global progress ratio = $79 \pm 4\%$
- 1067 €(2005)/kW for 80 kW PEMFC
Lower limit 95 €(2005)/kW

- R&D dominates current fuel cell developments and will remain important.
Short-medium term: learning-by-searching complements learning-by-doing