ECN

Energy research Centre of the Netherlands

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Koen Schoots

Fuel Cell Economics

Koen Schoots[1]

Francesco Ferioli[1]

Gert Jan Kramer[2]

Rodrigo Rivera[1]

Geert Verbong[2]

Bob van der Zwaan[1,3,4]

[1] Energy research Center of the Netherlands, Amsterdam, The Netherlands

[2] Eindhoven University of Technology, The Netherlands

[3] Columbia University, New York City, NY, USA

[4] John Hopkins University, Bologna, Italy

Nederlandse Organisatie voor Wetenschappelijk Onderzoek

Fuel Cell Economics

How do costs develop?

What factors play a role?

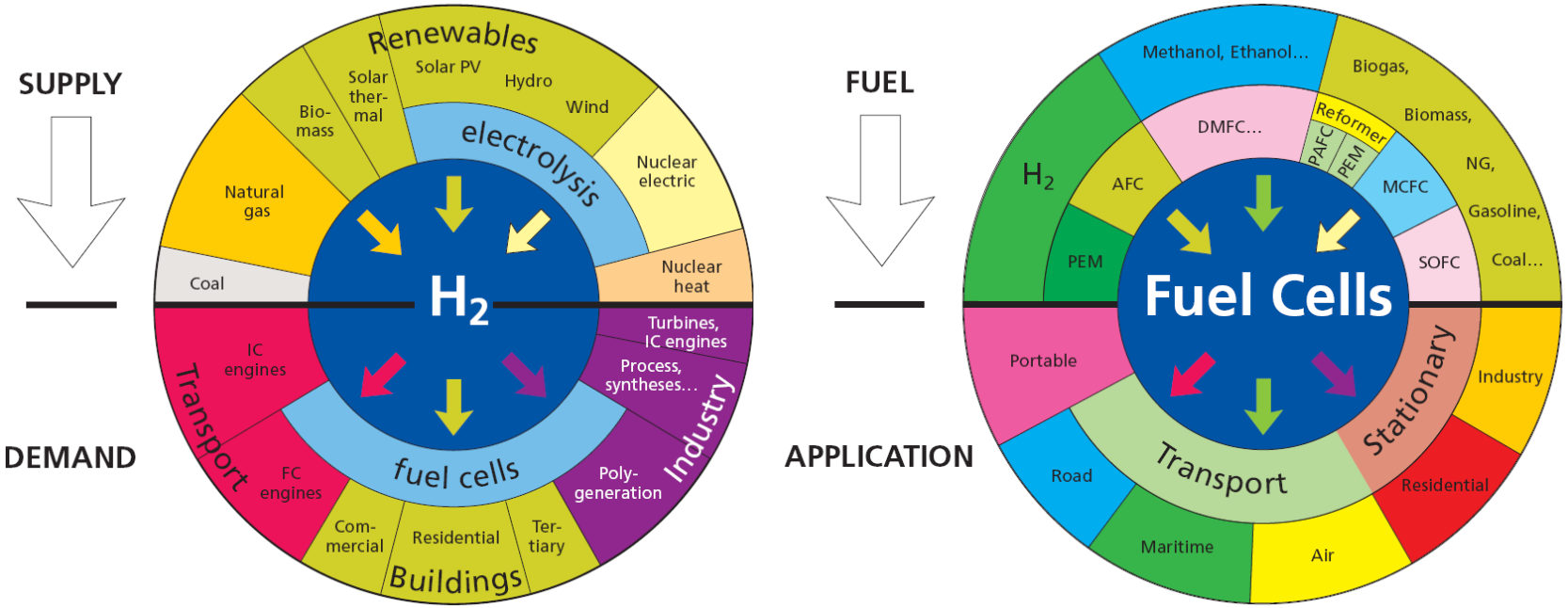
Limitations to fuel cell cost reductions?

schoots@ecn.nl


United States
Atlantis

Future role: security-of-supply

Many sources and many applications



A future role: cleaning up transport sector

Long ranges possible

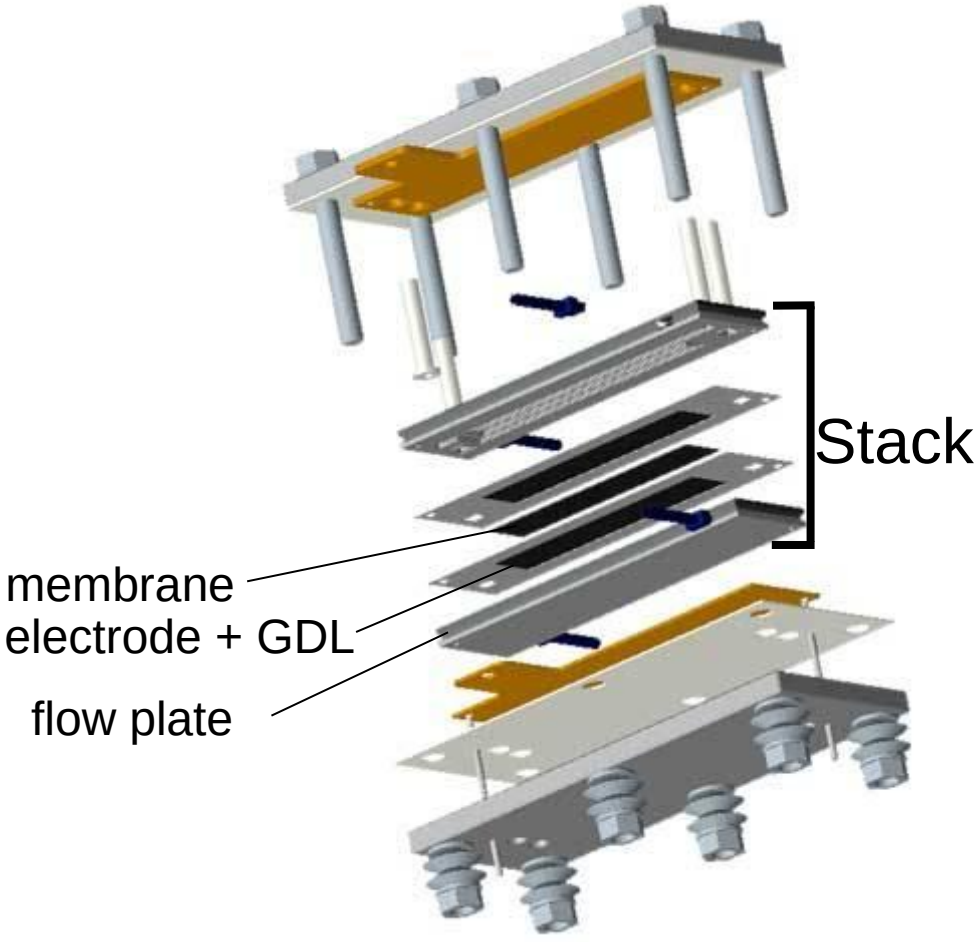
Increase local air quality

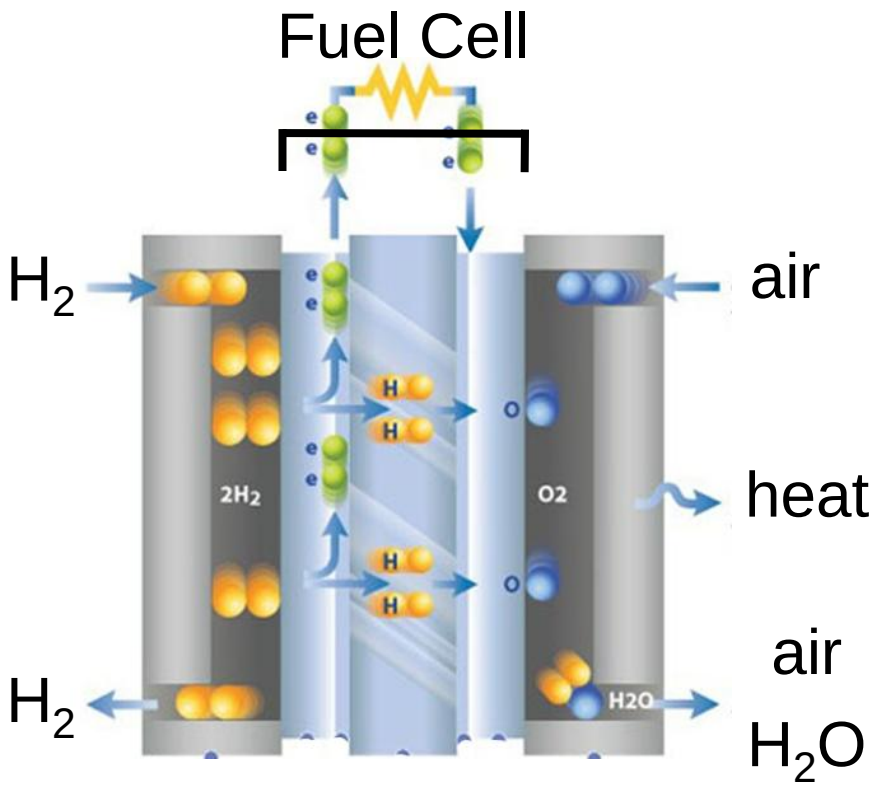
But

Costs still high

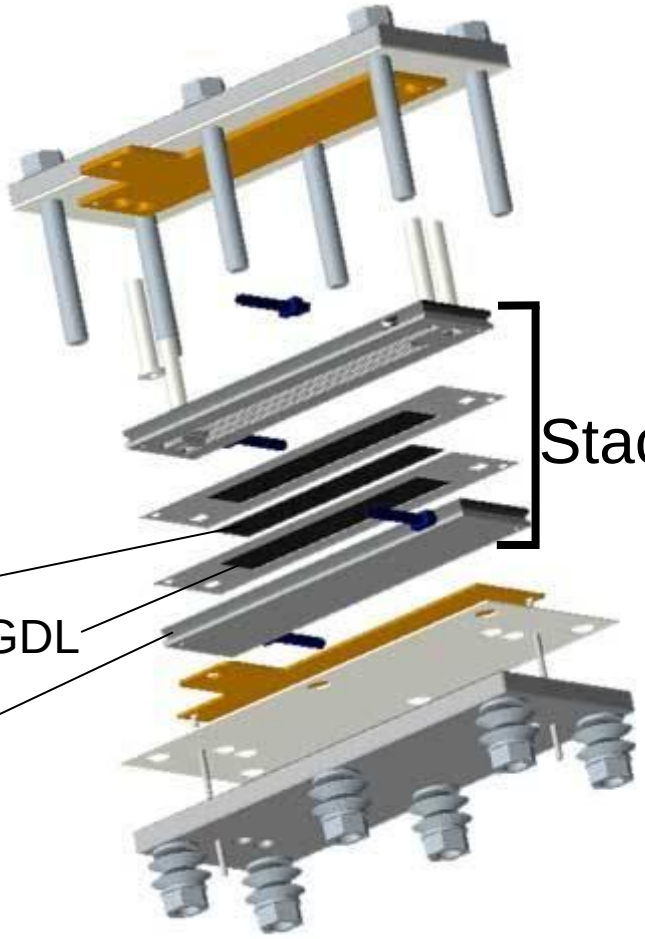
Market & infrastructure development uncertain

PEM fuel cell, stack and system

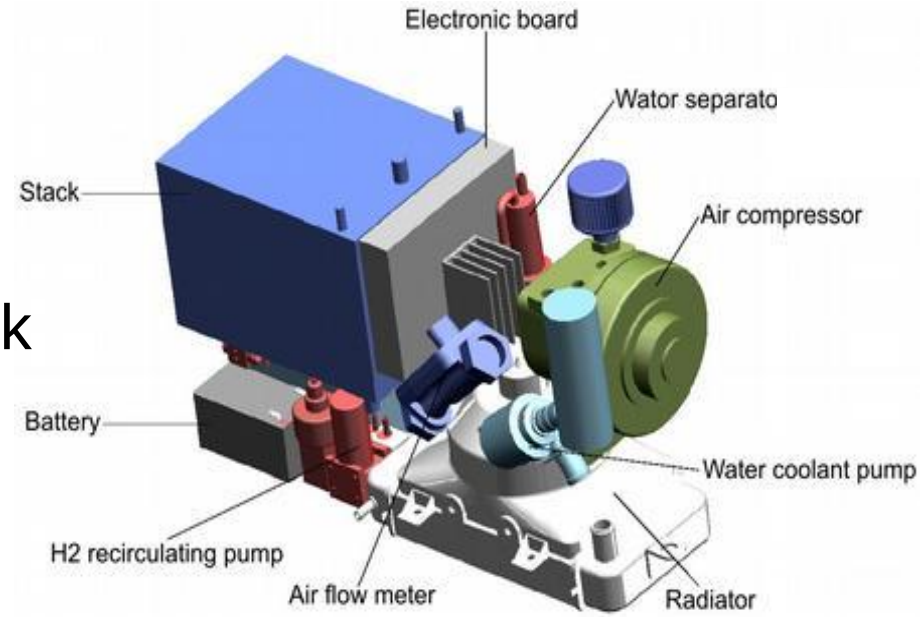




PEM fuel cell, stack and system

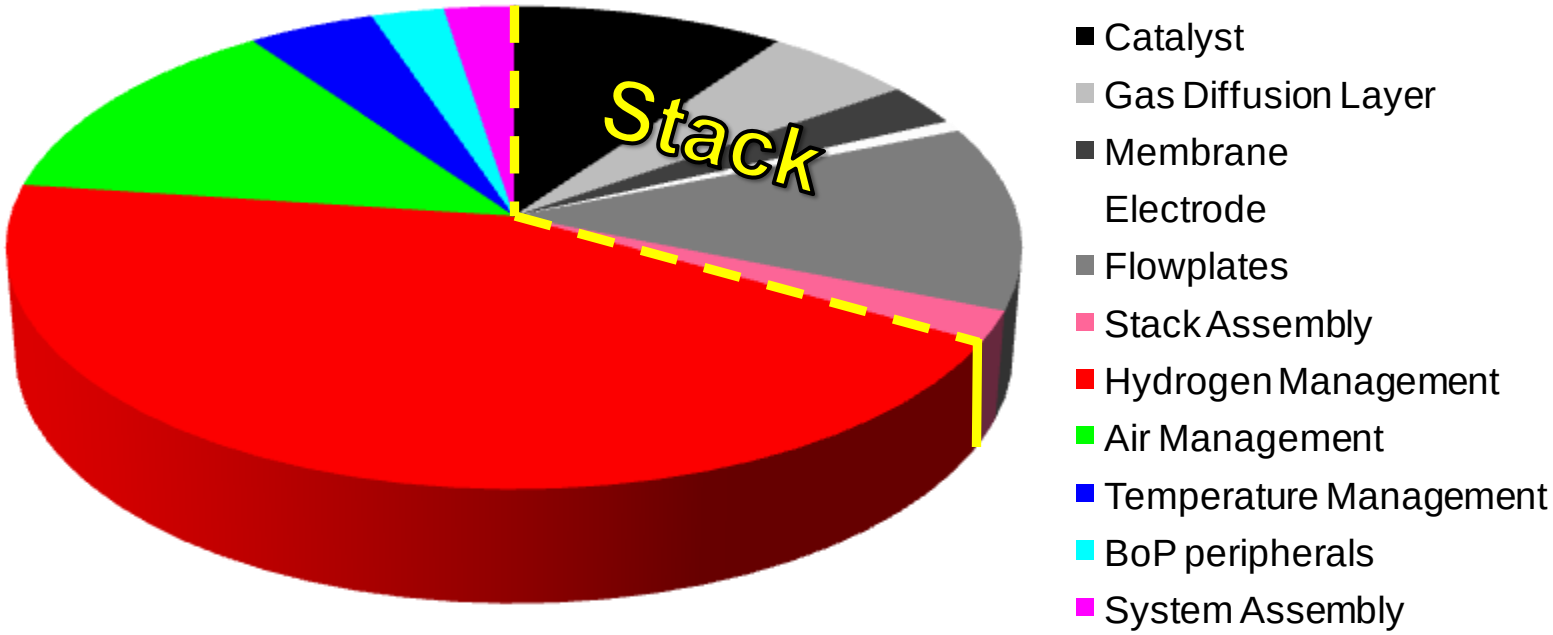


Fuel Cell System



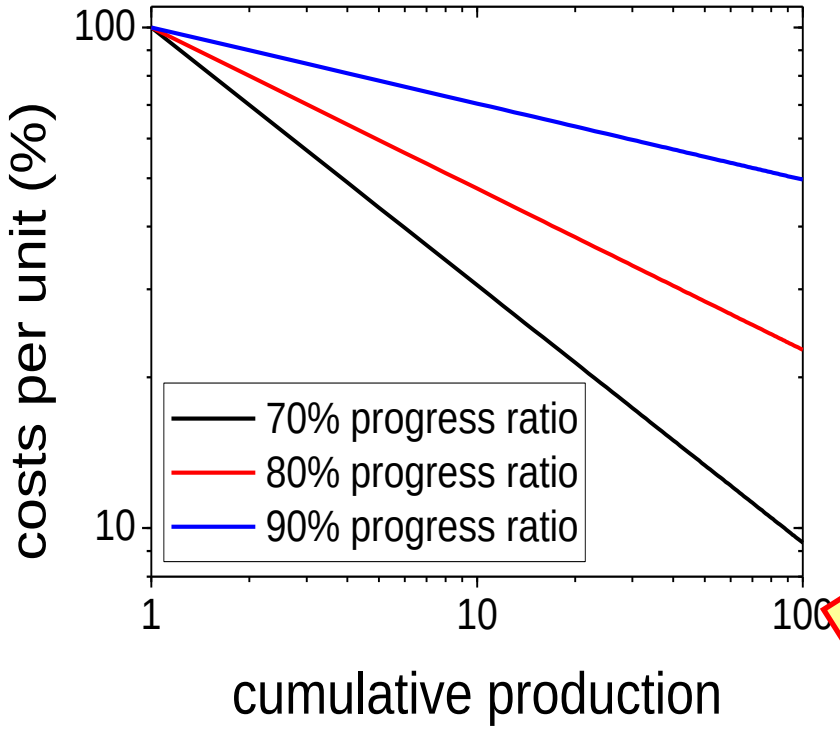
80 kW PEM fuel cell system costs

1067 €(2005)/kW



Learning curve basics

Each doubling of cumulated production: → costs reduce with the same factor

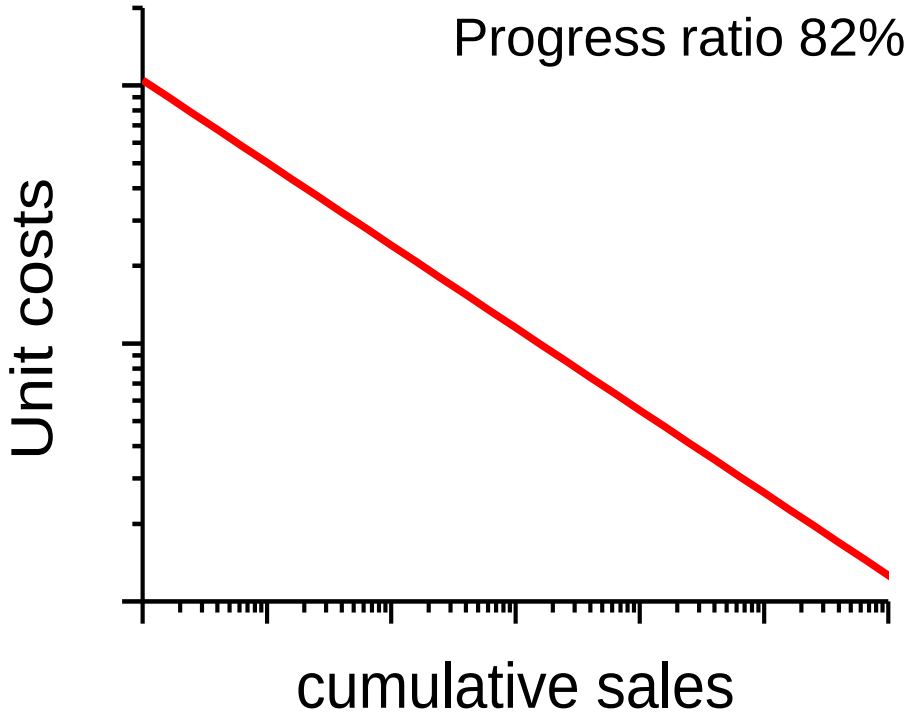


Progress ratio = 1- *Learning rate*

In practice pr = 81 ± 8%

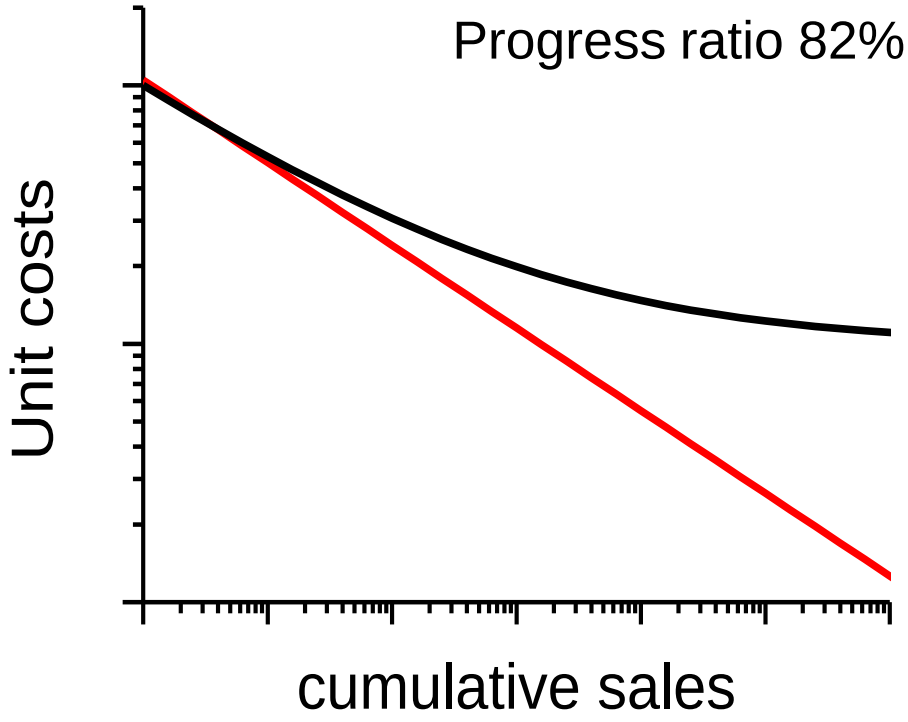
Empirical

Component learning



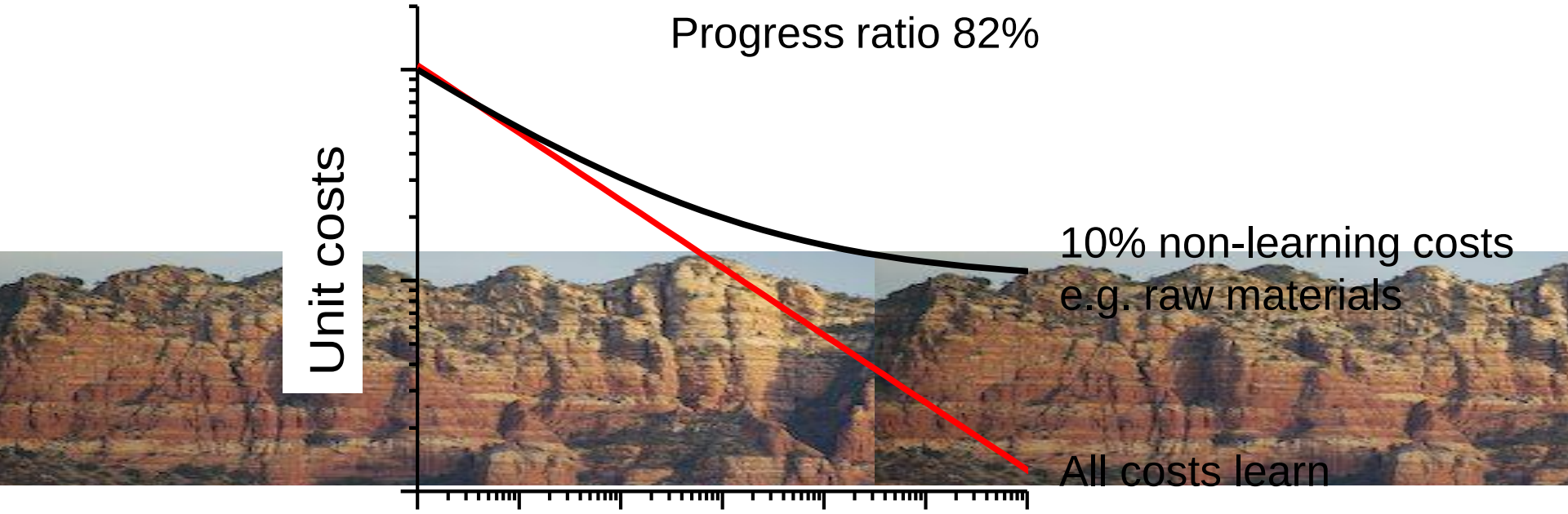
$$c(P) = c_0 \left(\frac{P}{P_0} \right)^{-\alpha}$$

Component learning



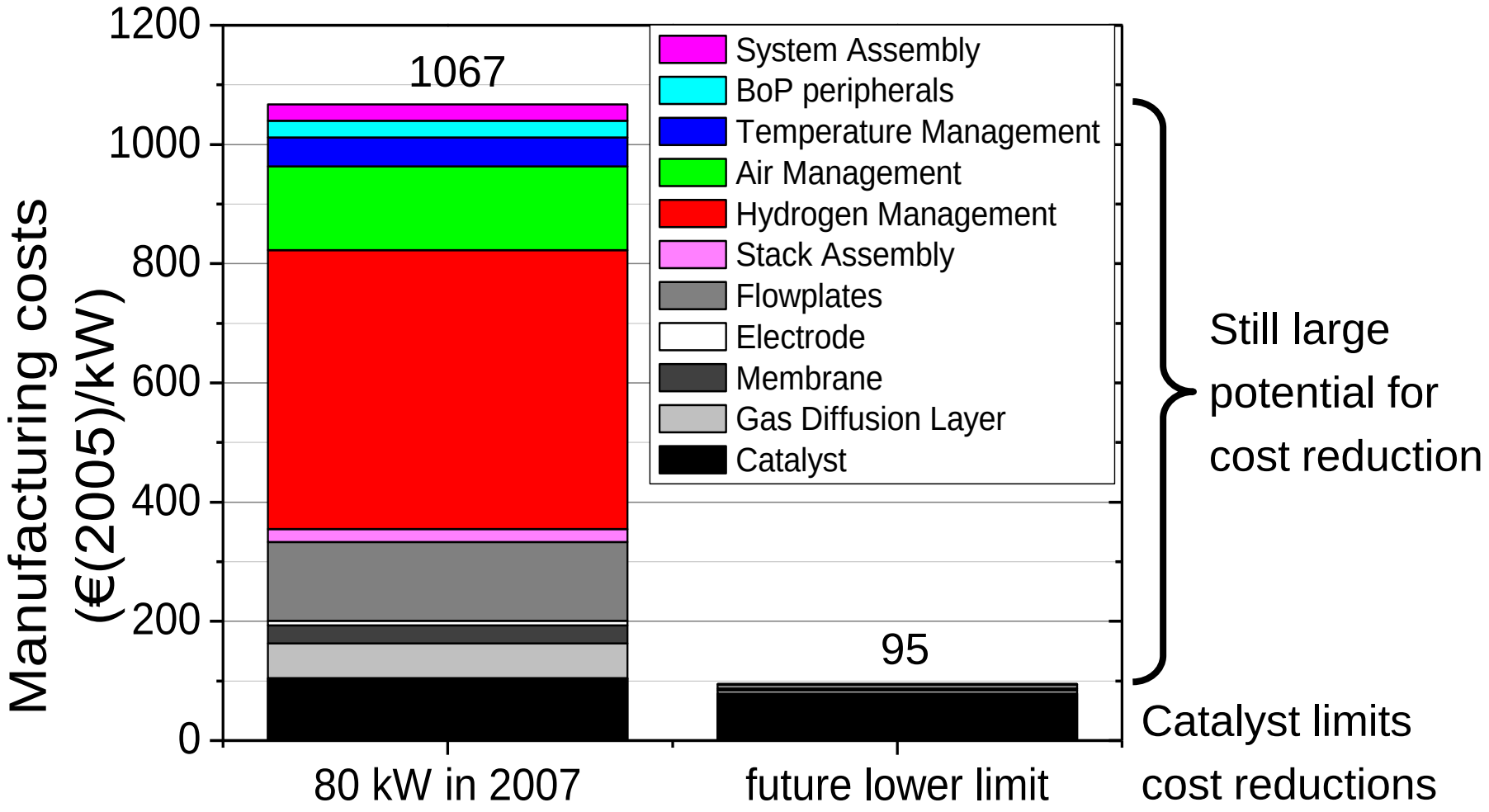
$$c(P) = (1-\varepsilon)c_0\left(\frac{P}{P_0}\right)^{-\alpha} + \varepsilon c_0$$

The rock bottom

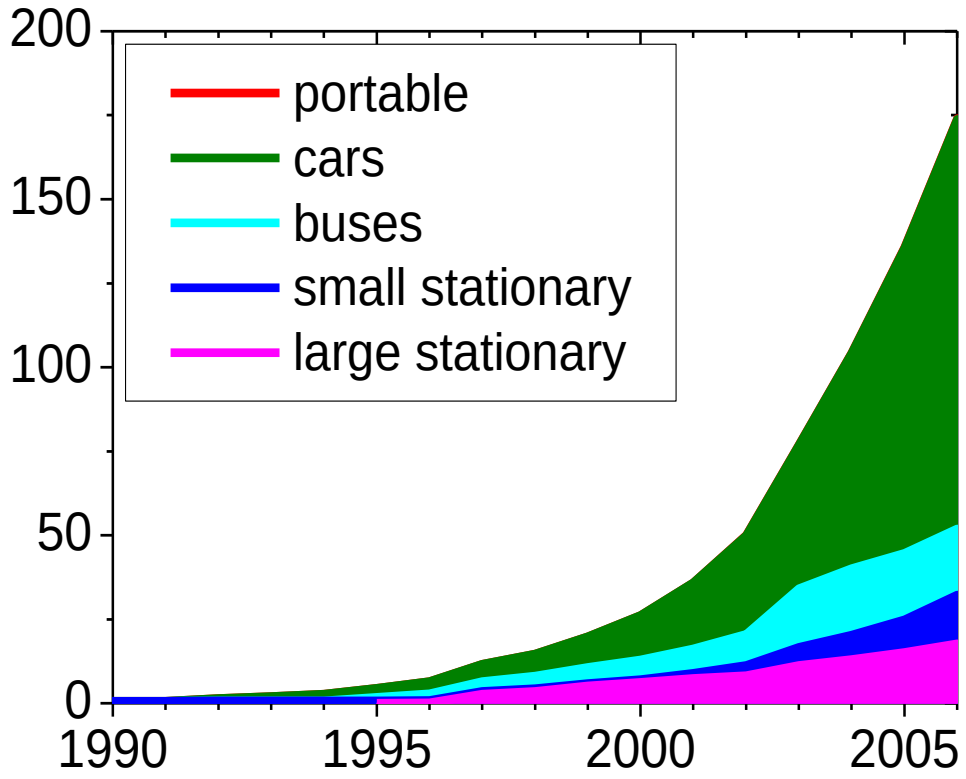


$$c(P) = (1-\varepsilon)c_0\left(\frac{P}{P_0}\right)^{-\alpha} + \varepsilon c_0$$

80 kW PEM fuel cell system costs: the lower limit

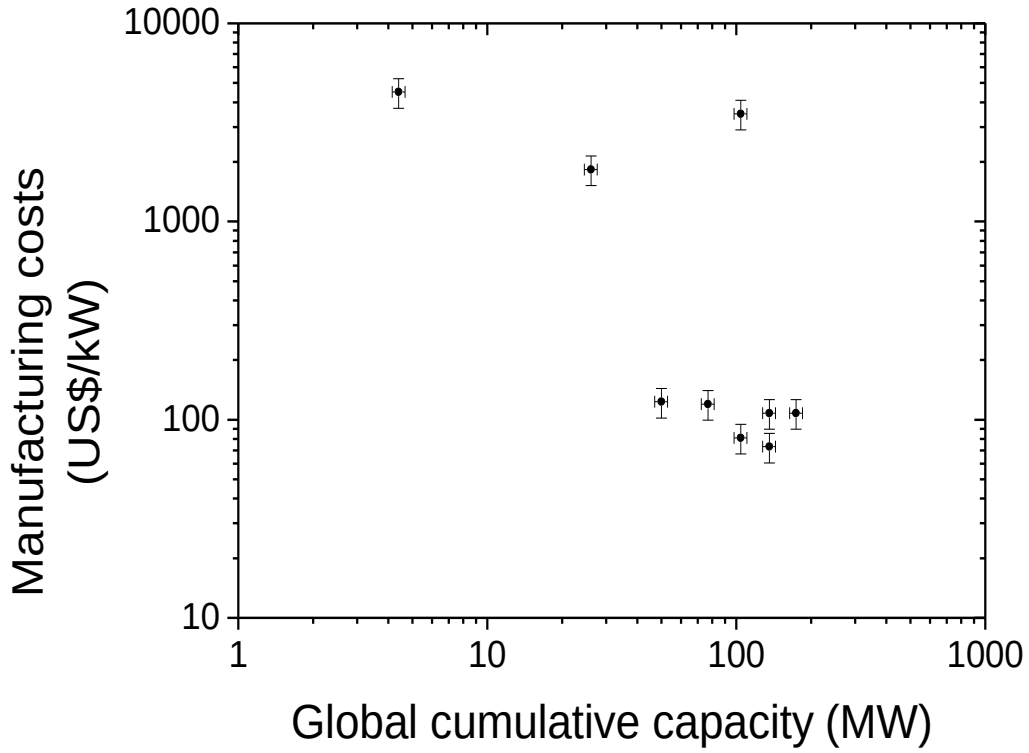


Global cumulative power of PEMFC (MW)



Learning curve PEMFC for transportation

running on pure hydrogen only, raw data



Corrections required:

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

Economies-of-scale

- Learning-by-doing vs. economies-of-scale
- Different mechanisms
  - l-b-d: cost reductions through gaining experience
  - e-o-s: cost reductions through scale benefits
- Different time dependency
  - l-b-d: time dependent
  - e-o-s: time independent

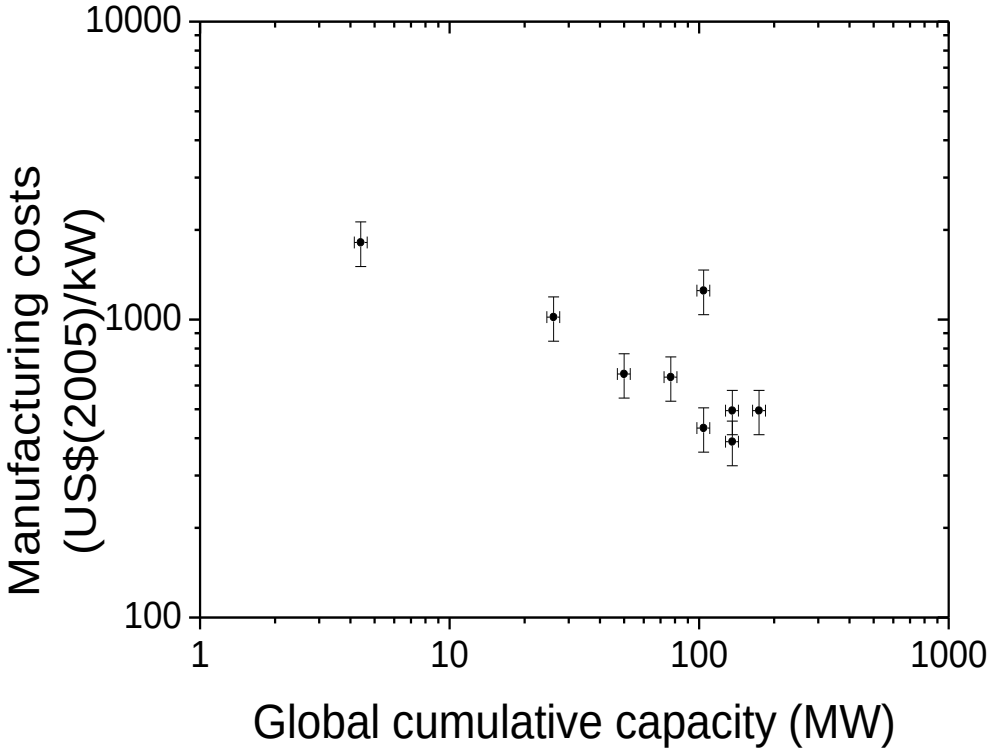
$$C = C_{lit}\left(\frac{S_{lit}}{S_{ref}}\right)^{1-\lambda}$$

S_{ref} = 500 *units/yr*

λ = 0.69

Learning curve PEMFC for transportation

running on pure hydrogen only

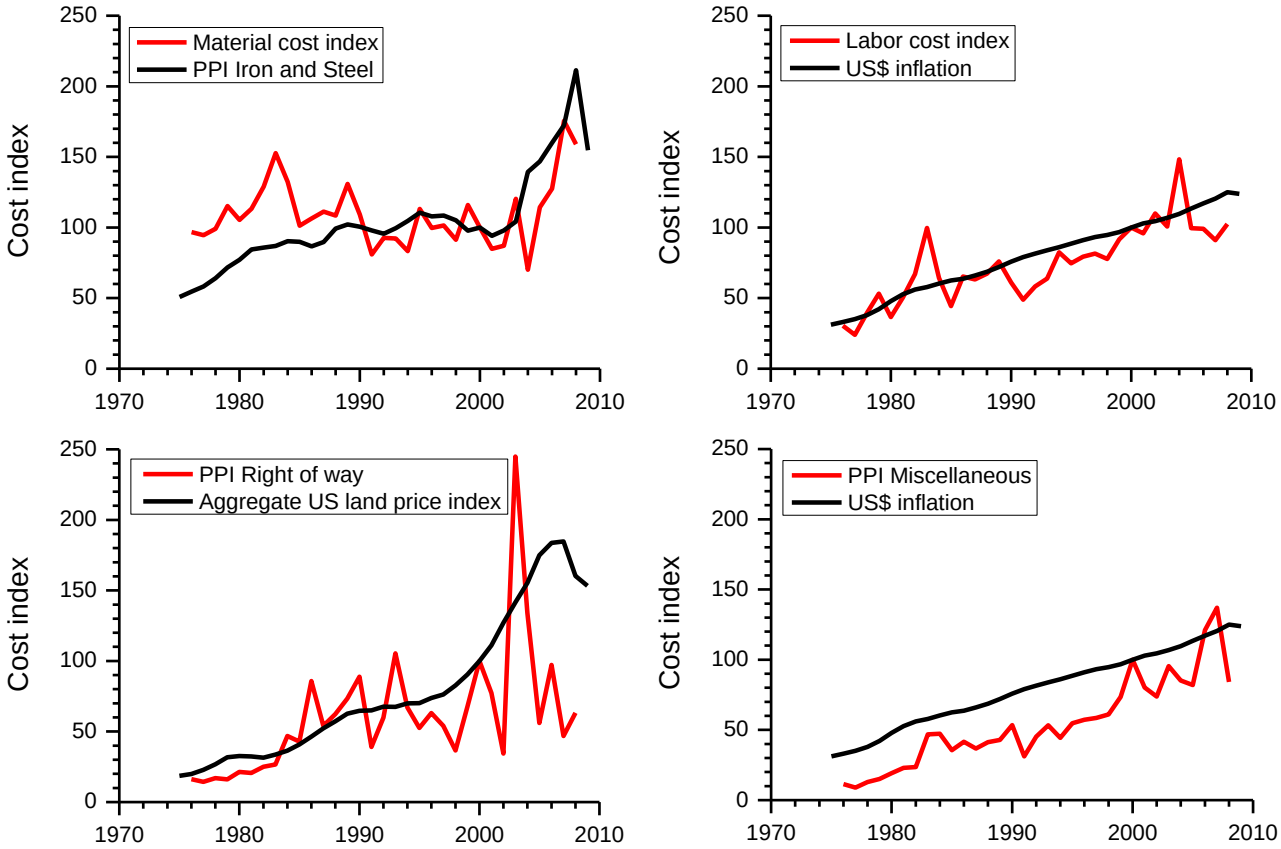


Corrections:

- Inflation
  → 2005
- Economies-of-scale
  → 500 units/yr

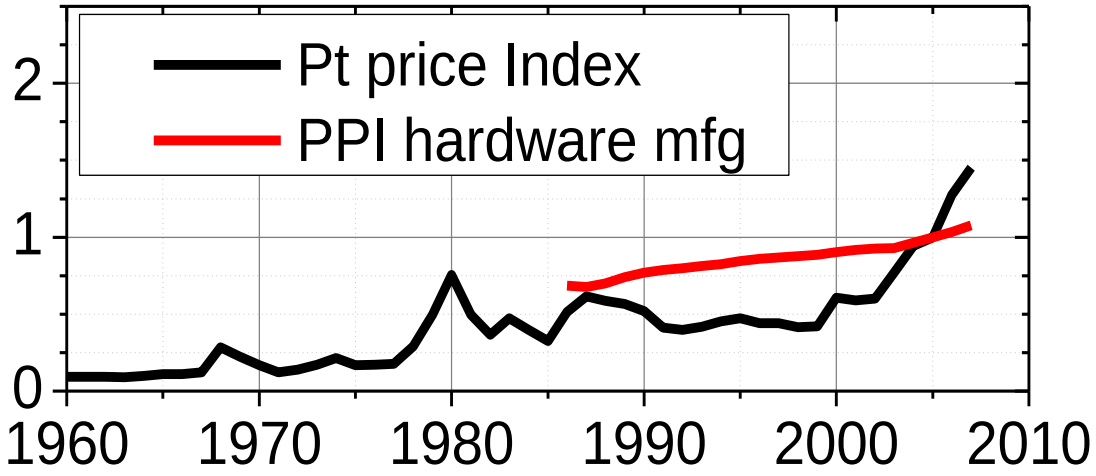
Not all costs subject to learning

Example: CH_4 pipeline components follow market prices

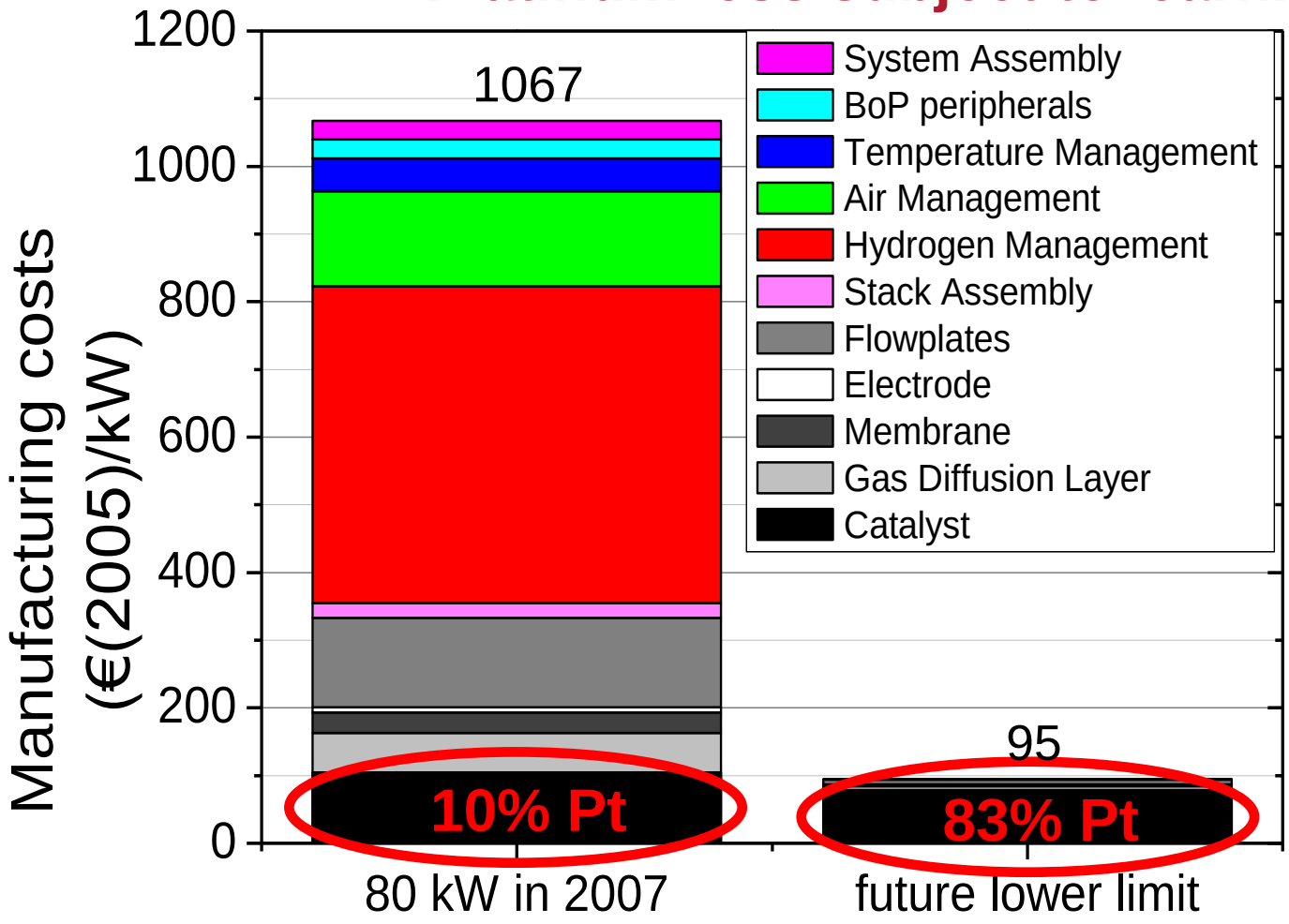


Platinum price development

Platinum does not follow price index fuel cell

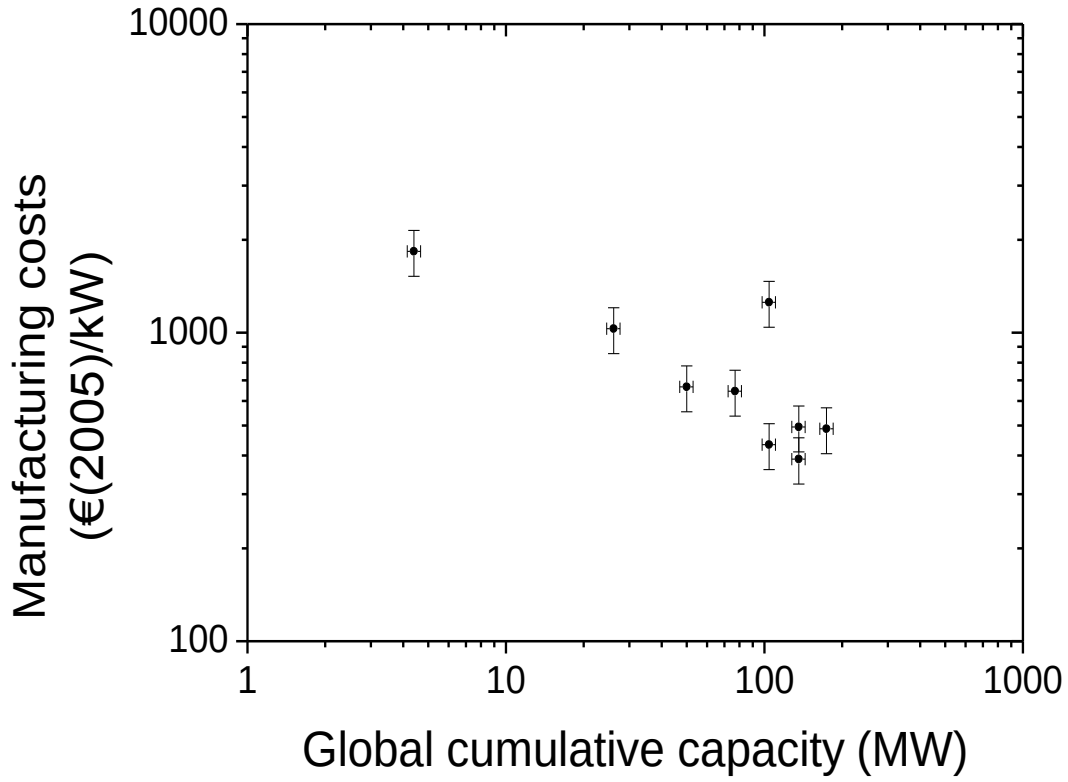


Platinum less subject to learning



Learning curve PEMFC for transportation

running on pure hydrogen only, with all corrections

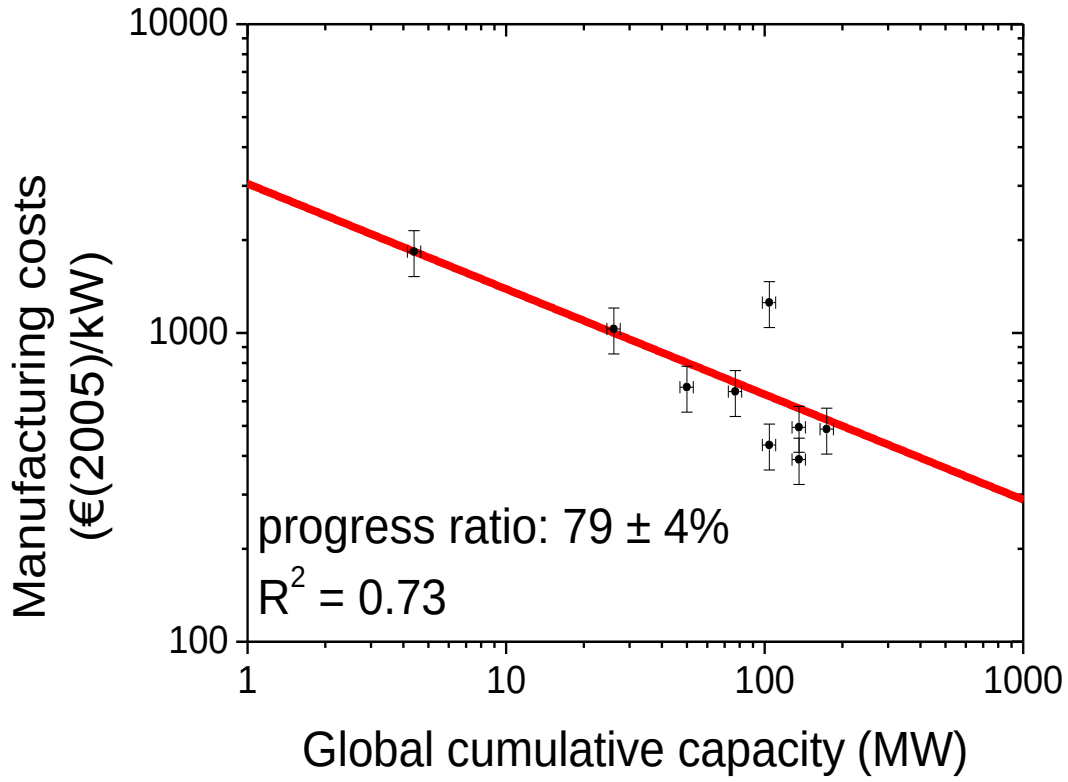


Corrections:

- 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



Corrections:

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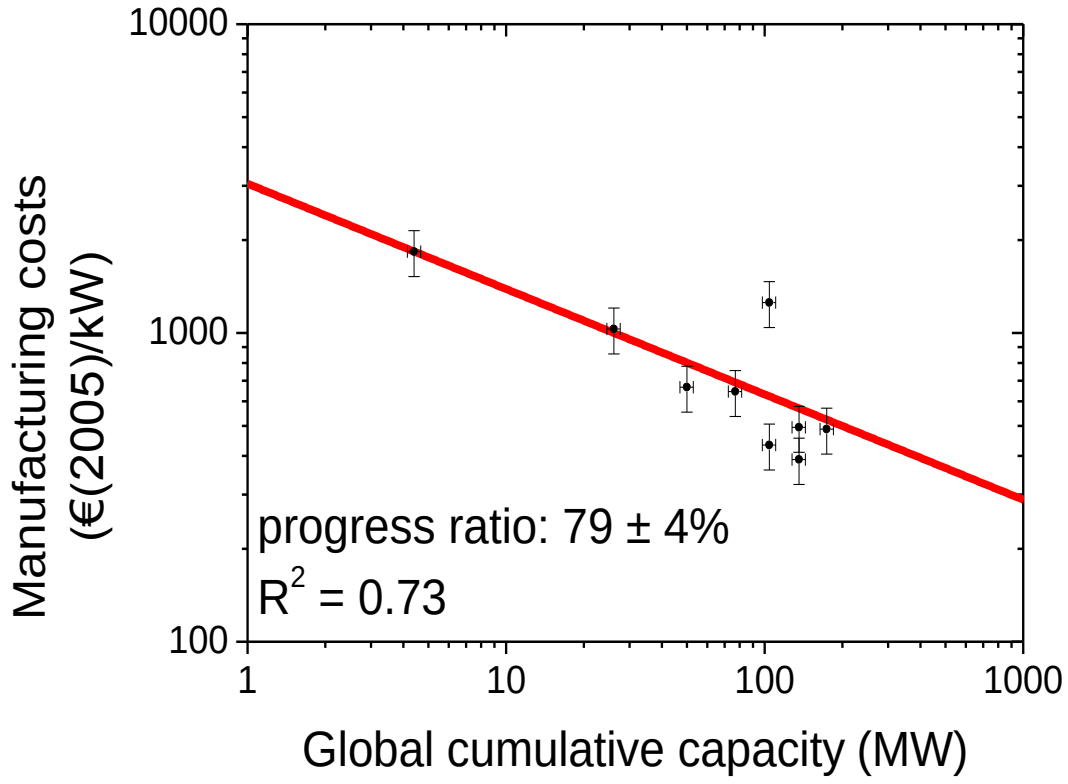
Learning curve PEMFC for transportation

running on pure hydrogen only, with all corrections



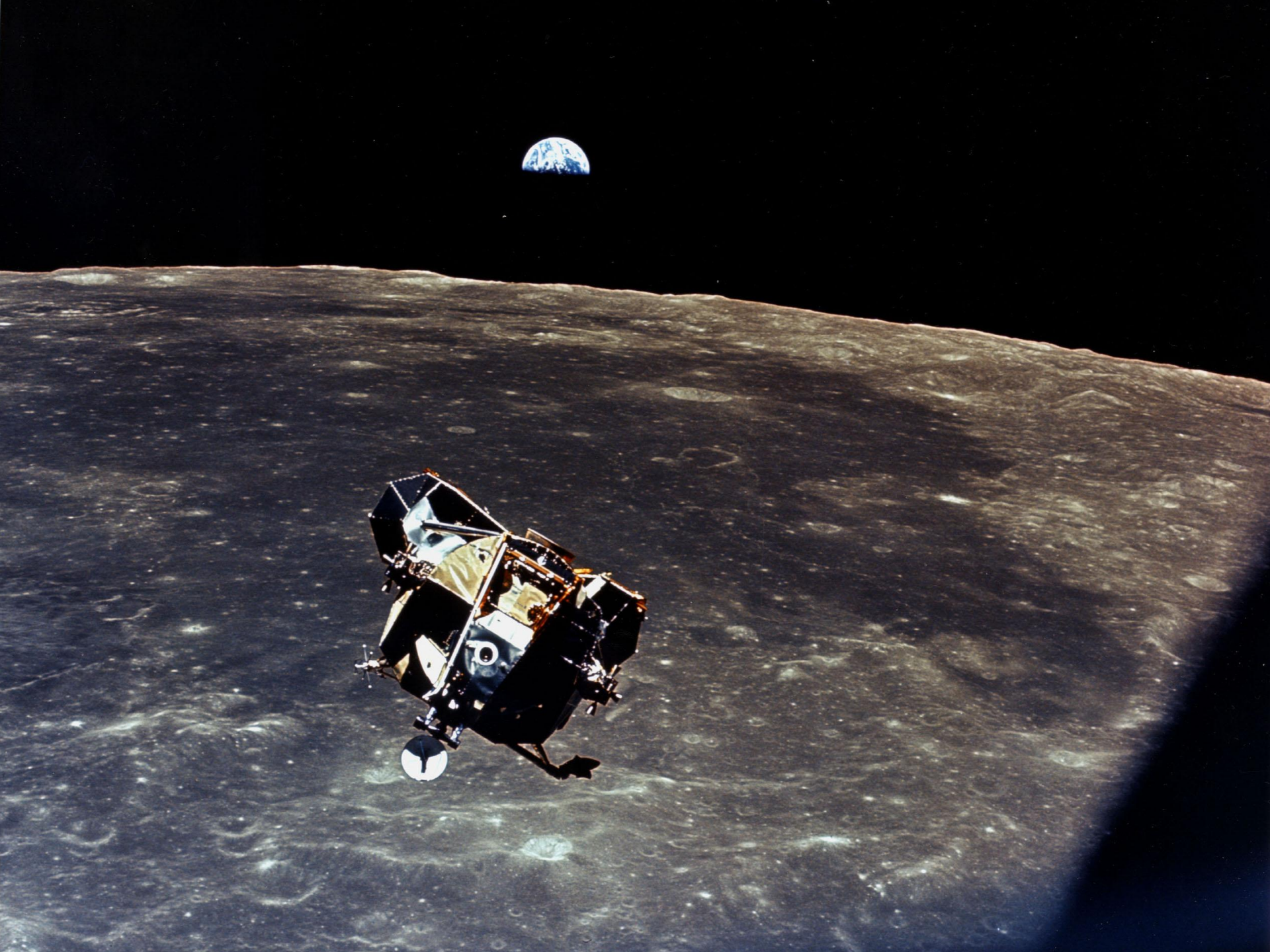
Data scattering:

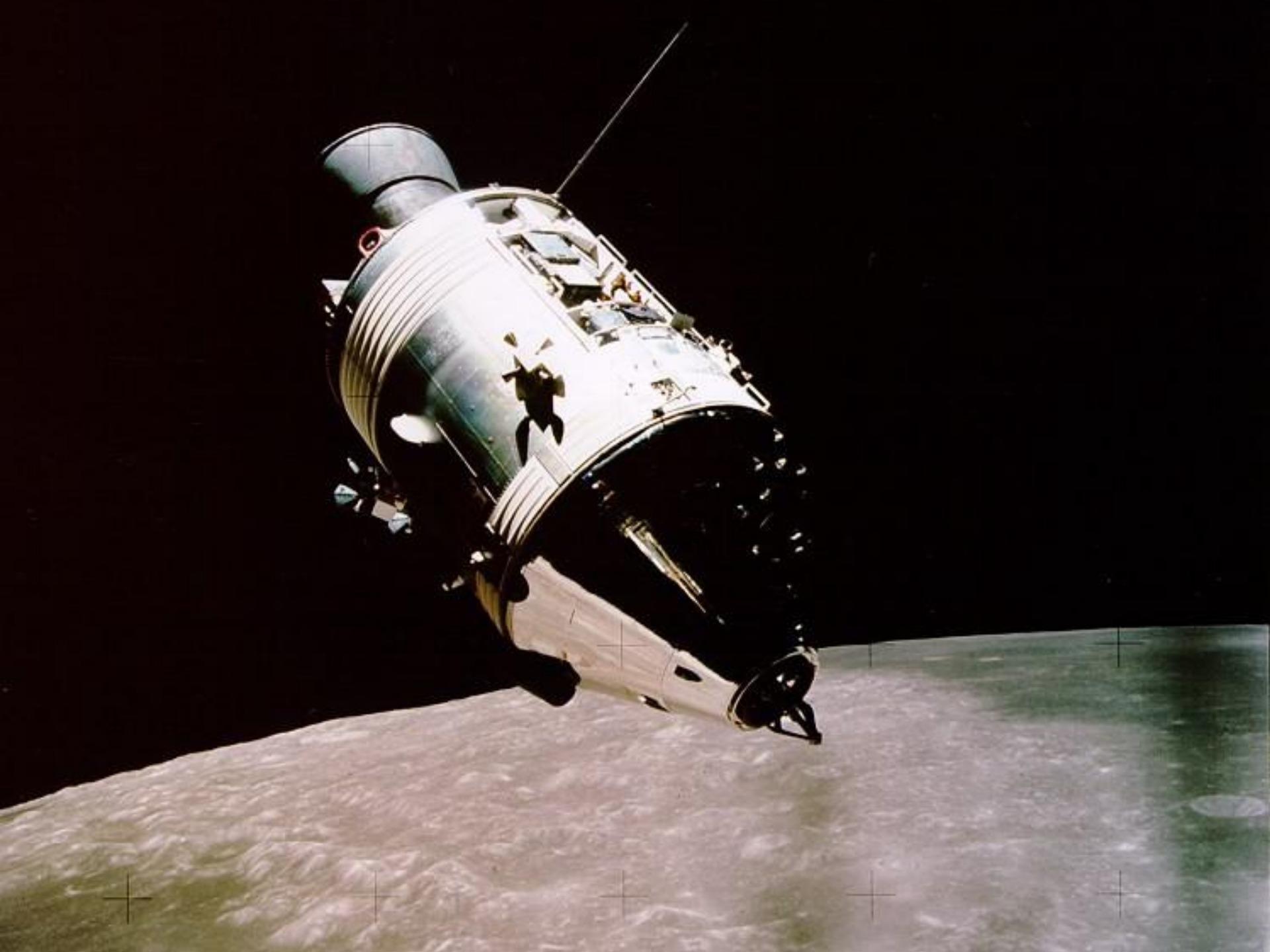
Econ. of scale over full costs justified?

FC component market prices?

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

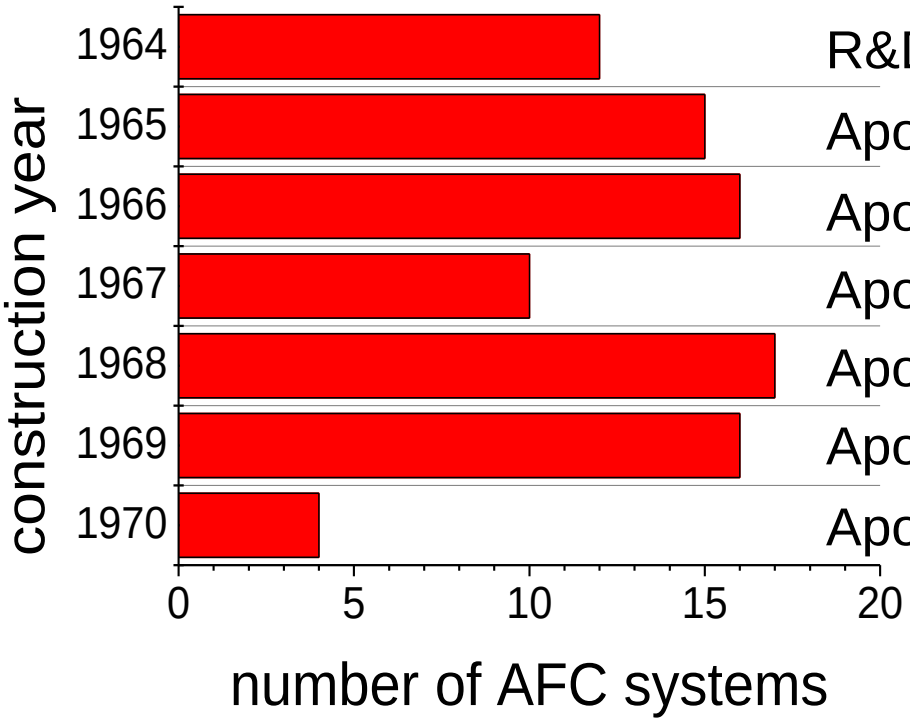
Small technical differences





Apollo AFCs by Pratt & Whitney Aircraft

Annual production



R&D, qualification, testing, Apollo AS201

Apollo AS202, 1 and 4

Apollo 6-9

Apollo 10-11

Apollo 12-15

Apollo 16-19

Apollo 20

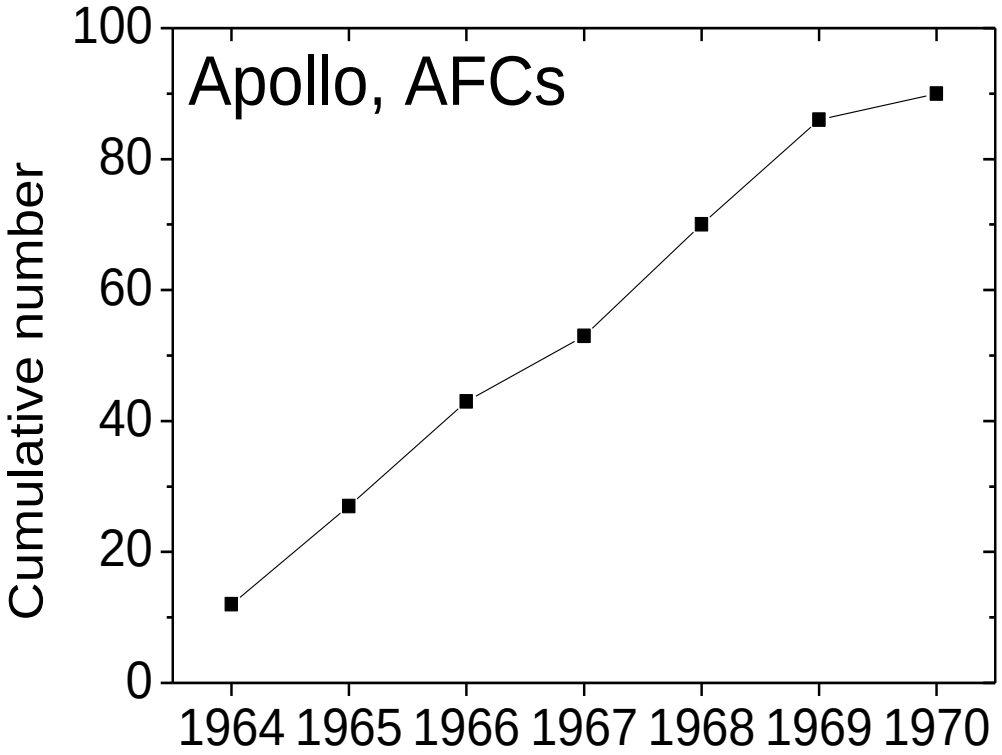
Per mission:

- 3 units in CSM
- 1 or 2 units spare

Missions are linked to the year of *construction* of the spacecraft.

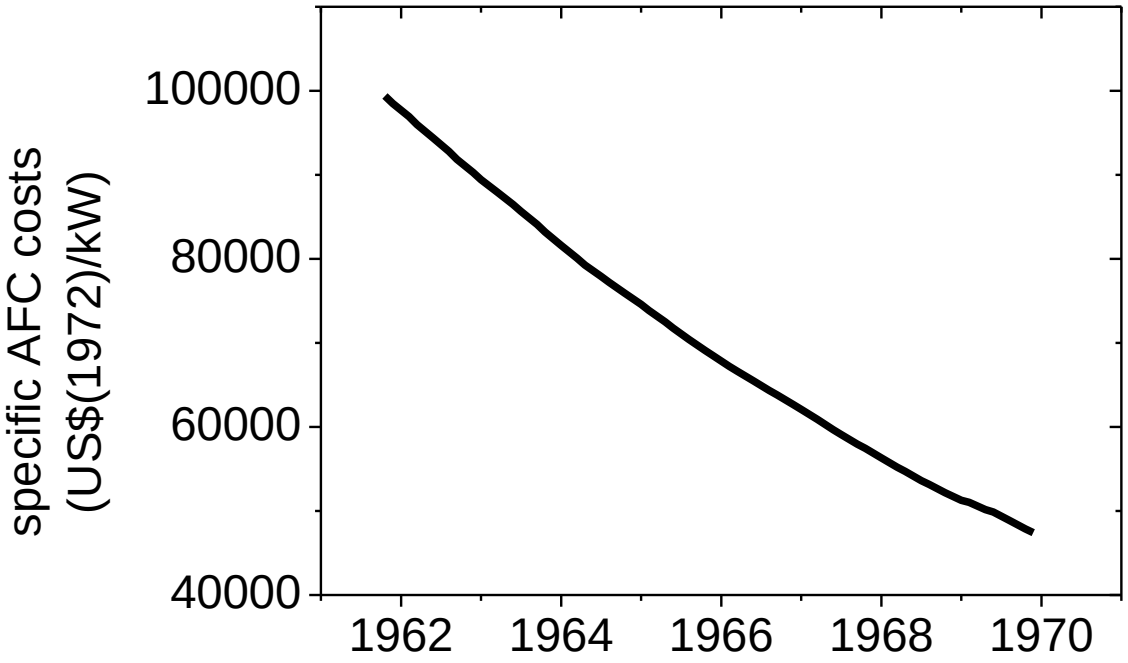
Apollo AFCs by Pratt & Whitney Aircraft

Cumulative production



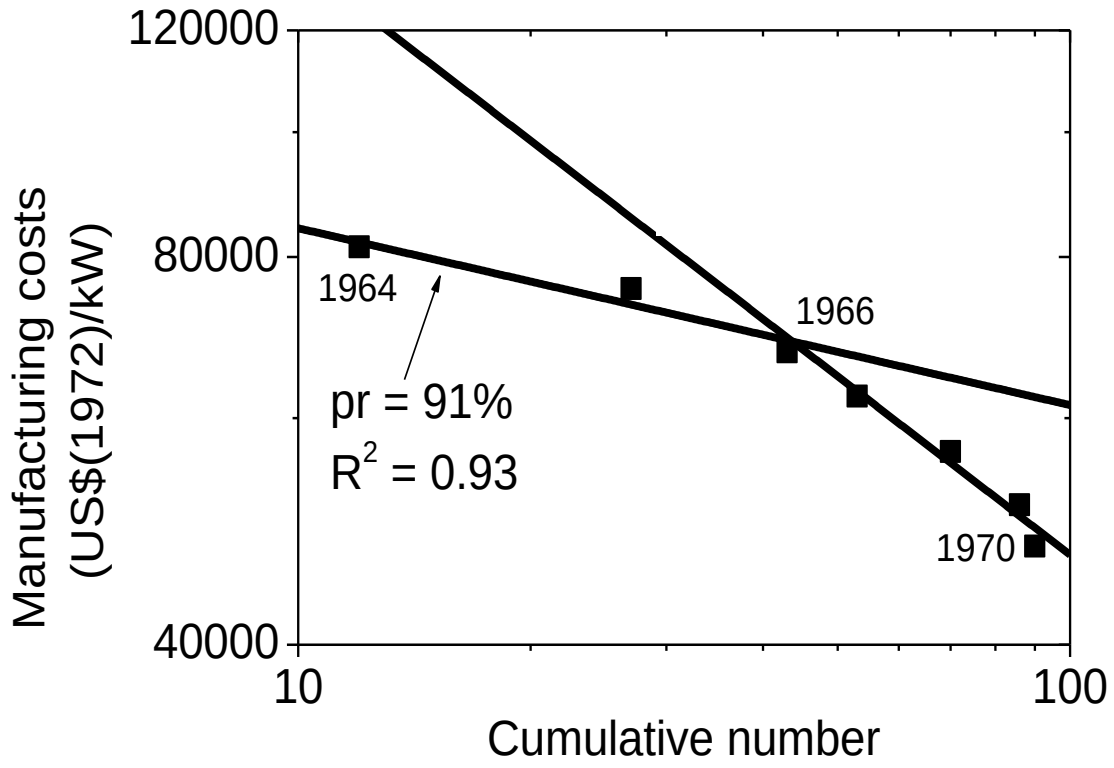
Apollo AFCs by Pratt & Whitney Aircraft

Time dependence of alkaline fuel cell costs



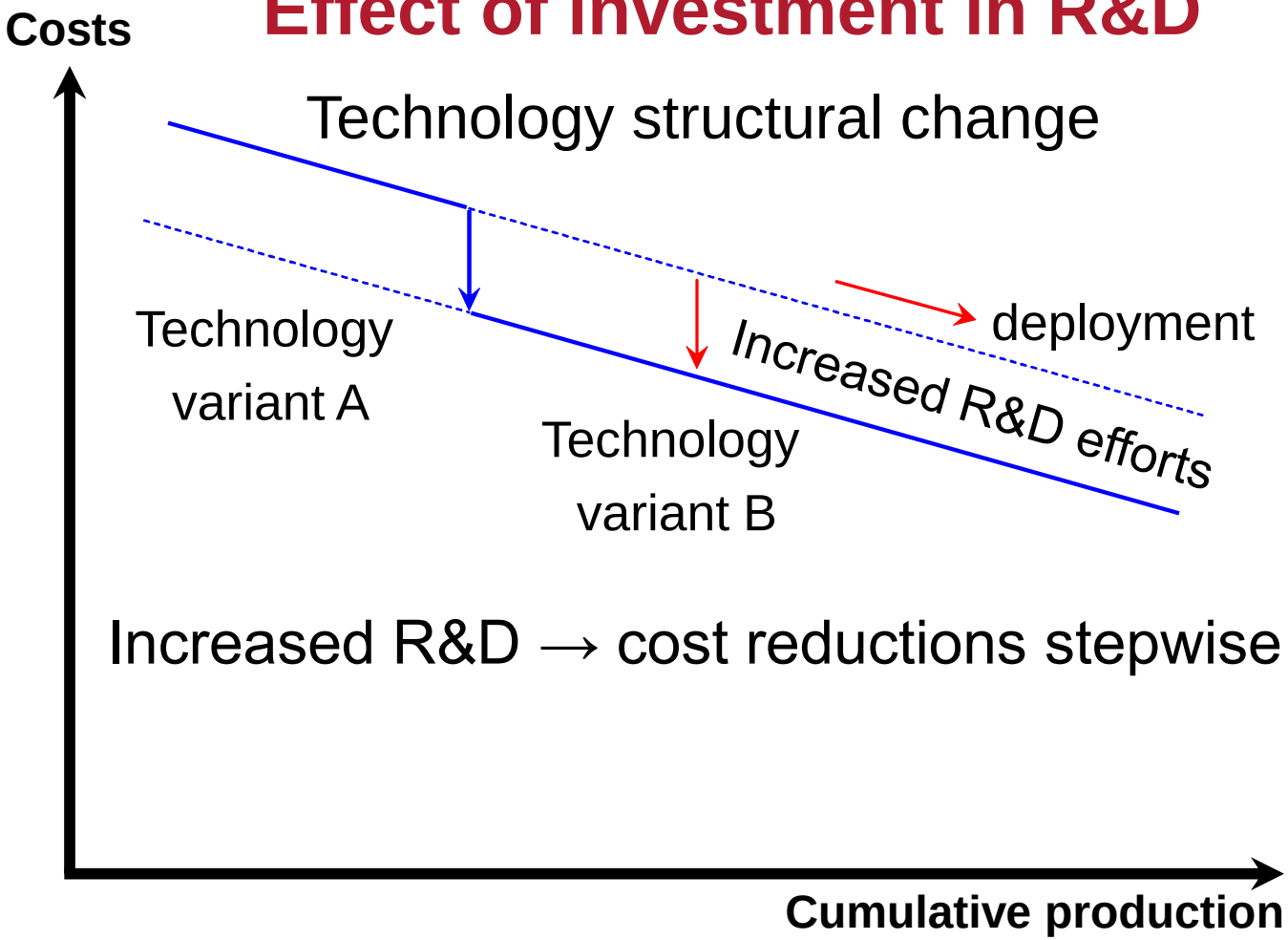
Apollo AFCs by Pratt & Whitney Aircraft

Learning curve

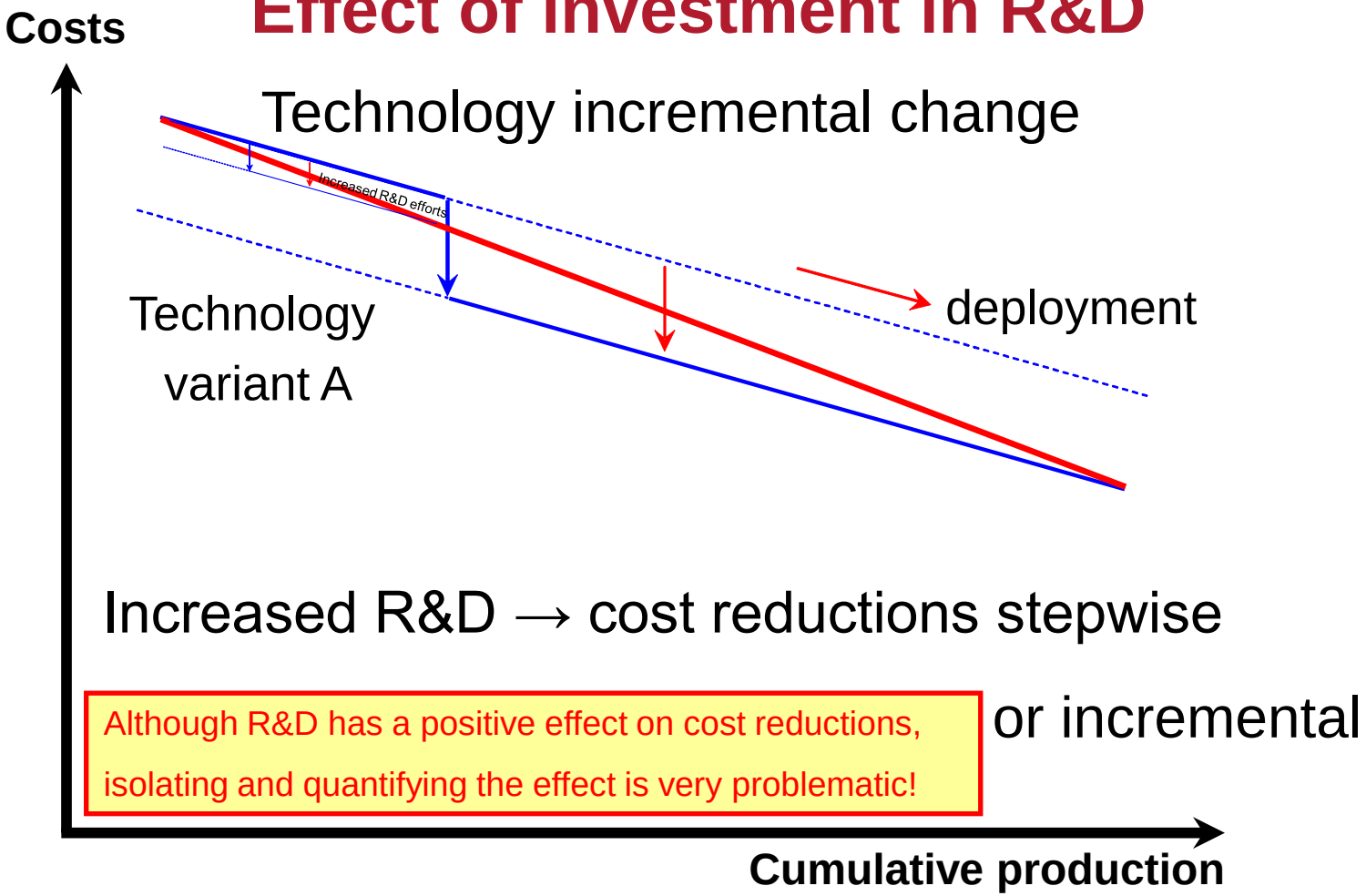


Jan 1967,
Apollo 1 accident
Design overhaul

Effect of investment in R&D



Effect of investment in R&D

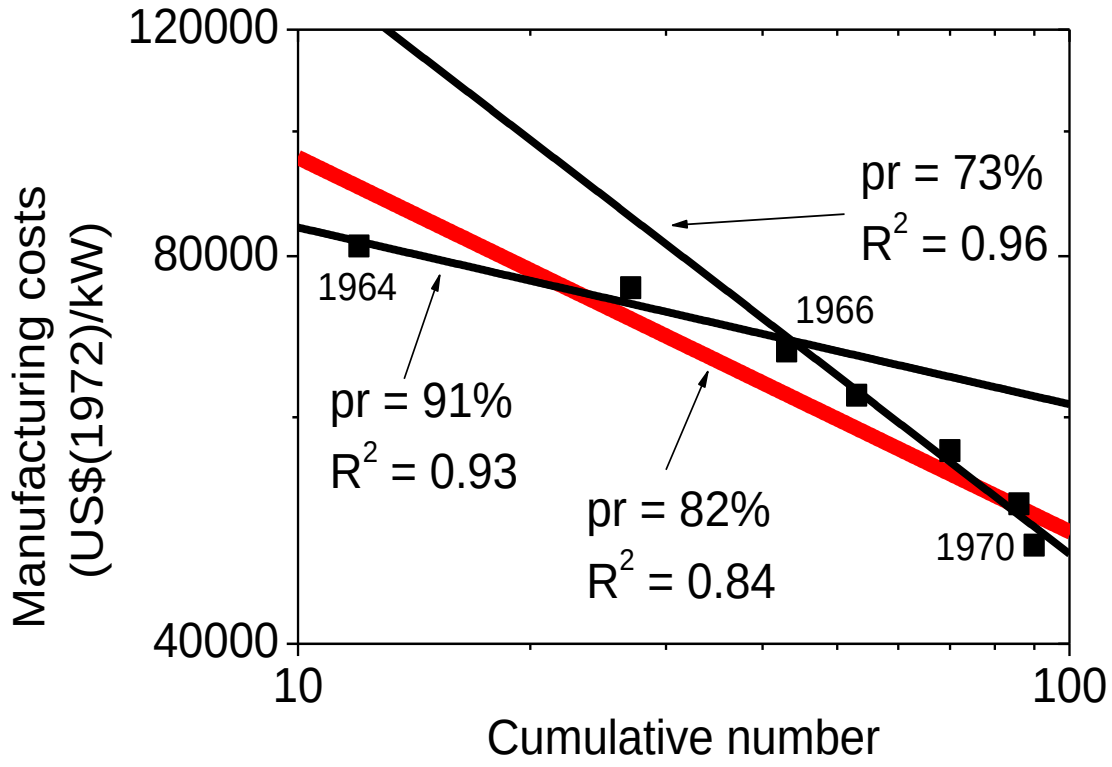


Increased R&D → cost reductions stepwise or incremental

Although R&D has a positive effect on cost reductions, isolating and quantifying the effect is very problematic!

Apollo AFCs by Pratt & Whitney Aircraft

Learning curve

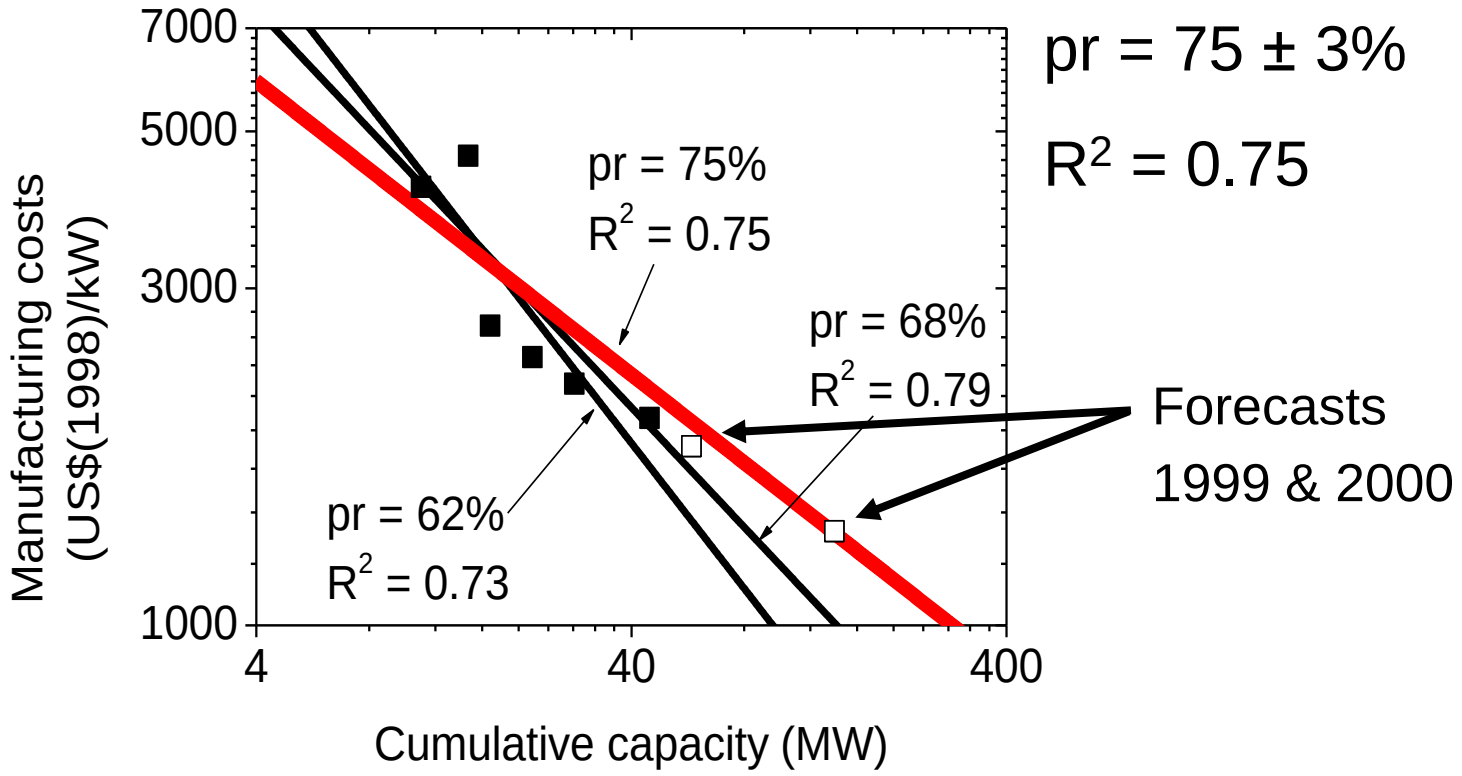


pr = 82 ± 9%

R^2 = 0.84

PAFC by UTC Power

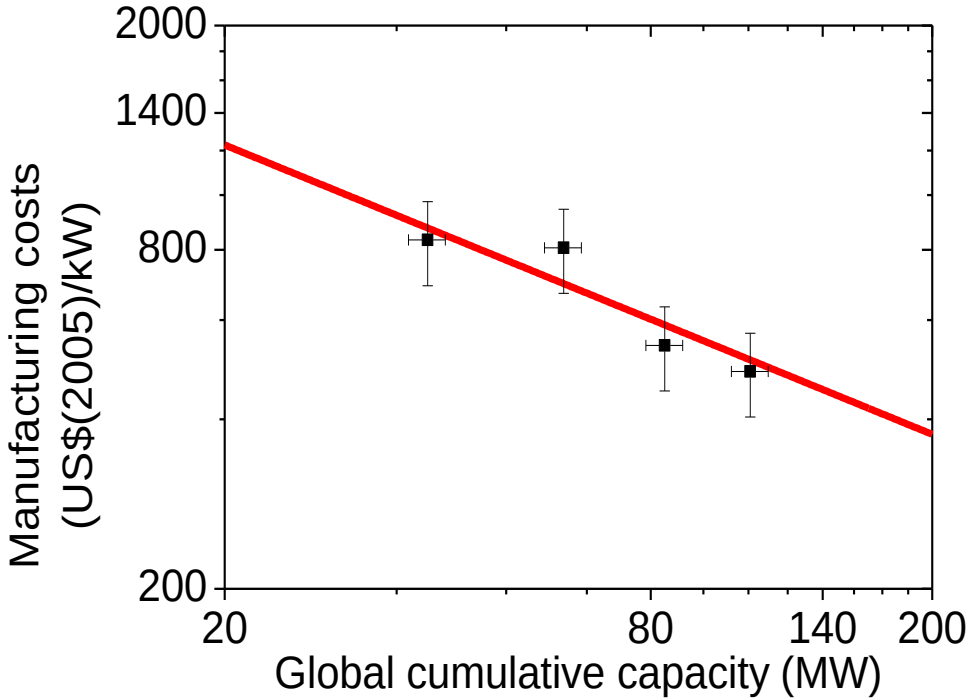
Learning curve 1993-2000



Source: R. Whitaker, Journal of Power Sources **71**, (1998) 71.

PEMFC by Ballard

Learning curve 2002-2005



pr = 70 ± 9%

R^2 = 0.83

Source: http://www.ballard.com/be_informed/fuel_cell_technology/roadmap Last checked May 1, 2007

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 Fuel Cell Economics

- How do hydrogen fuel cell costs develop?
  - Costs of PEMFC reduce by a global progress ratio of 79 ± 4%
  - Current costs at 1 k€(2005)/kW for 80 kW PEMFC
- What other factors play a role?
  - Economies-of-scale
  - R&D dominates current fuel cell developments and will remain important. Short-medium term: learning-by-searching complements learning-by-doing
  - Long term: Market price of components and labor may dominate fuel cell cost development
- Limitations to PEM fuel cell cost reductions?
  - Learning potential exhausted at 95 €(2005)/kW (assuming current state-of-the-art)