ECN

Energy research Centre of the Netherlands

H_2 Technology Learning

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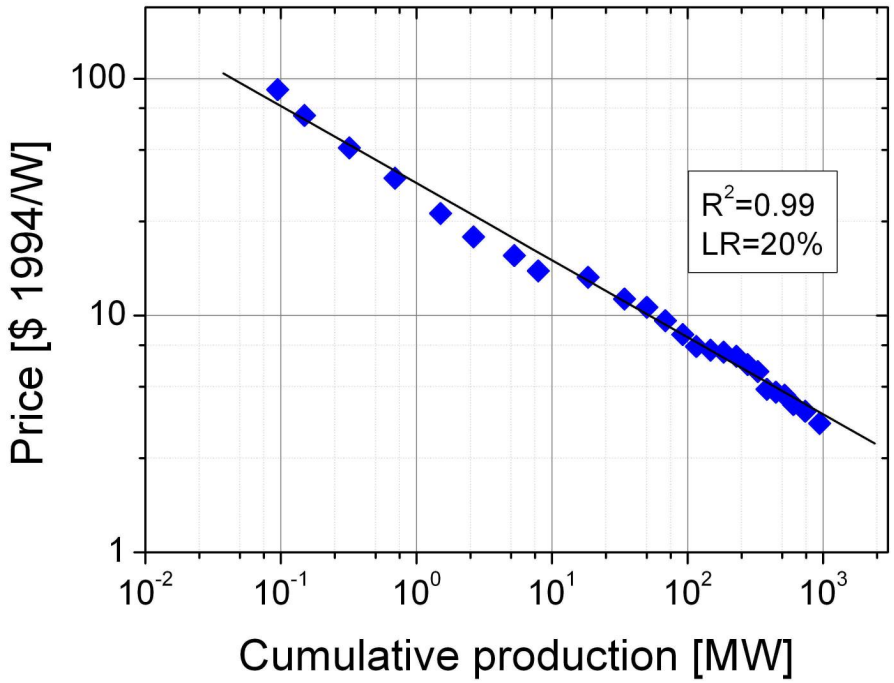
31 March 2009

Learning curve and progress ratio



Price data for PV modules with learning curve fit (Harmon, 2000).

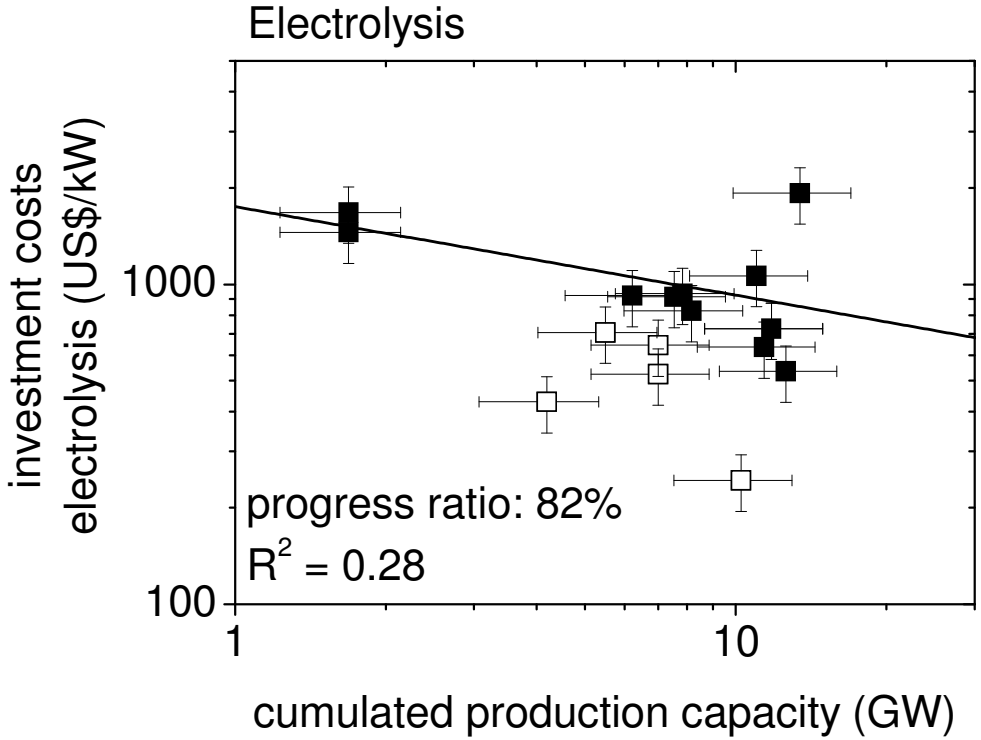
Learning curve analysis at ECN

- Development of learning curves for energy technology, e.g. related to hydrogen (several papers).
- Use of learning curves for strategic energy policy making (van der Zwaan and Rabl, 2003).
- Understanding the nature and opening the 'black box' of learning curves (Ferioli *et al*., 2009).
- The implementation of learning curves in integrated assessment models (van der Zwaan *et al*., 2002).

Learning for hydrogen technology

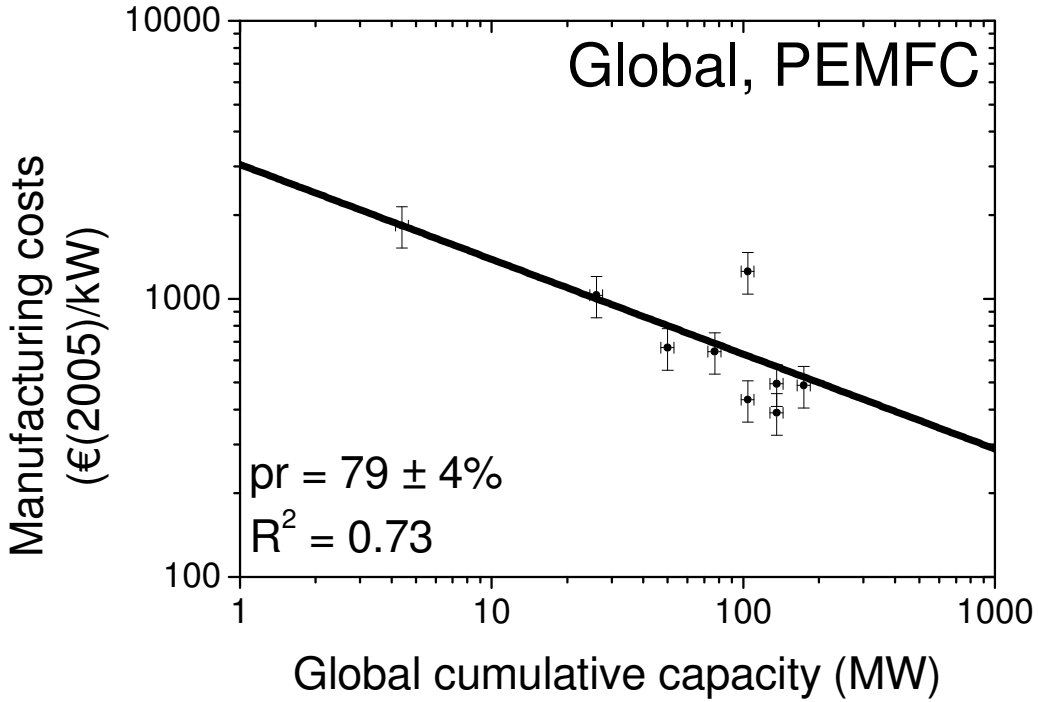
- So far we have investigated two essential parts of a possible hydrogen economy: H_2 production and use (in fuel cells).
- H_2 production: 3 types (steam-methane reforming, coal gasification, electrolysis) and 2 levels (investment costs and production costs).
- H_2 fuel cell manufacturing: 3 types (PEMFC, AFC, PAFC) and 2 levels (globally and three different manufacturers: NASA, UTC, Ballard).

Learning for hydrogen production



Investment cost data for electrolysis H_2 production capacity with learning curve fitting attempt (Schoots et al., 2008).

Global learning for hydrogen fuel cells



Learning curve for PEMFCs in transportation between 1995 and 2006 (Schoots et al., 2009).

Learning for hydrogen fuel cells

Fuel cell type	Progress ratio	R^2
Global		
PEMFC	79 ± 4 %	0.73
Manufacturer		
AFC	82 ± 9 %	0.84
PAFC	75 ± 3%	0.75
PEMFC	70 ± 9%	0.83

Progress ratios and error margins for different fuel cell types and production scales (Schoots et al., 2009).

Learning for hydrogen technology – caveats

- Some components do not learn: price of coal, gas, electricity, platinum.
- These resources display large price volatilities that may obscure learning effects.
- Resource price increases may outweigh learning effects in other components.
- Economies-of-scale and R&D prove very relevant, especially for fuel cells.
- Specific PEMFC costs vary: 860-4100/kW depending on size (250-5 kW), with 500/yr production scale.

Learning for hydrogen technology – to do

- We have started investigating the third essential part of a possible hydrogen economy: H_2 transport and storage – *suggestions most welcome*.
- Other FC types, among which solid oxide fuel cells.
- Other H_2 production types, such as HT electrolysis.
- We plan to continue opening the 'black box' of learning-by-doing: component learning curves, economies-of-scale, material costs.

Publications

- Schoots, K., G.J. Kramer and B.C.C. van der Zwaan, “Learning Curves for Fuel Cells: an Assessment of Past and Potential Cost Reductions”, *Working paper*.
- Ferioli, F., K. Schoots and B.C.C. van der Zwaan, “Use and Limitations of Learning Curves for Energy Technology Policy: a Component-Learning Hypothesis”, *Energy Policy*, forthcoming, 2009.
- Ferioli, F., K. Schoots and B.C.C. van der Zwaan, “Component-Learning for Energy Technologies: the case of hydrogen production”, *International Journal of Innovation and Learning*, forthcoming, 2009.
- Schoots, K., F. Ferioli, G.J. Kramer and B.C.C. van der Zwaan, “Learning Curves for Hydrogen Production Technology: an Assessment of Observed Cost Reductions”, *International Journal of Hydrogen Energy*, 33, 11, 2008, pp.2630-2645.