Institute of
Vehicle Concepts

Fuel Cells for Automotive Powertrains – A Techno-Economic Assessment

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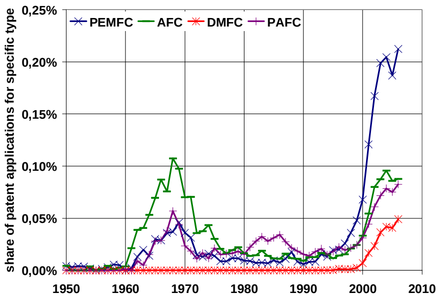
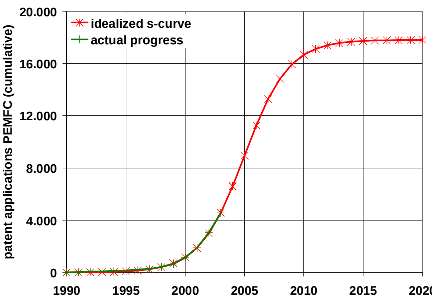
1. Patent Analysis

- Patent applications: *early indicator* for upcoming technological developments.

- **First boom** in 1960s/70s:
  - *Alkaline fuel cell (AFC)* most important type; used mainly for *aerospace activities* (e.g. NASA Apollo mission).
- **Second boom** from mid 1990s on:
  - *Proton exchange membrane fuel cell (PEMFC);* often used for *road transportation* applications.
- *No end of increasing trend* can be observed from patent applications.



- Cumulated number of patent applications for AFC during first boom follows perfectly an idealized *s-curve* shape.
- Applying **s-curve methodology** to second boom leads to inflection point in 2004 and saturation level in *2015*.

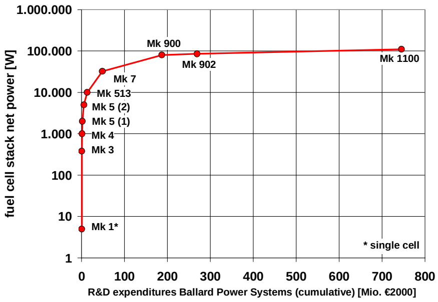


- New technology will most likely start *new s-curve* (e.g. HT-PEM).

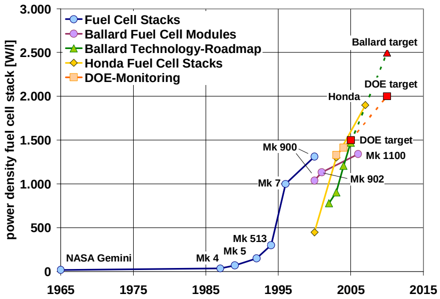
2. Technical Analysis

- Significant progress achieved; in some areas need for further improvement.

- **Stack Power:**
  - Has increased dramatically over time; however, *progress rate is decreasing* as product is getting more mature. Today's Stack Power is *sufficient for every-day usage* in most passenger cars.



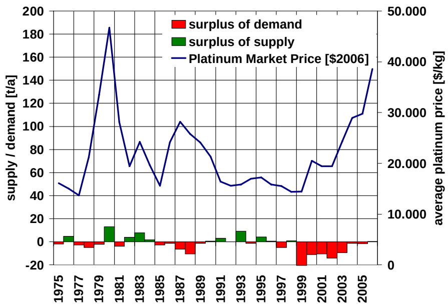
- **Stack Power Density:**
  - Impressive improvement over time; however, comparison is difficult due to varying definitions. *Target values* of U.S. Department of Energy (DOE) are *not yet achieved*; new materials will enable further advancement.



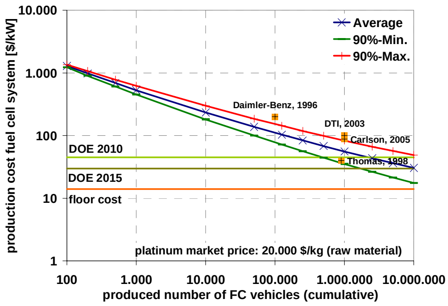
- **Further areas of interest** include:
  - Cell power density, platinum loading of electrodes, vehicle performance (e.g. top speed), hydrogen storage.

3. Economic Analysis

- **Bottom-up cost-model** for production at high volume: *90%* of cost *is for material*.
- *Most important factors:* power-density, platinum load, market price for platinum.
- *Assumptions* for cost calculations:
  - *Power density of the stack:* 1.000 mW/cm².
  - *Platinum loading of electrodes:* 0.1 mg/cm² (each).
  - *Market price for platinum:* 20,000 $/kg.



- **Learning curve rates** are derived using cost data for low production volumes and *Monte-Carlo analysis*; rates found are *74%-90%* (74% stack, 79% system).



- **Production cost** (stack | system):
  - *12-40 $/kW* | *35-83 $/kW* (1 Mio.)
  - *6-20 $/kW* | *18-49 $/kW* (10 Mio.)

- **Outlook**: using similar approach to evaluate *Lithium-Ion batteries* and to compare potentials for both technologies.

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