R&D for New Automotive Technologies
Insights from Fuel Cells

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Contents

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Introduction

- Fuel cells for automotive propulsion
  - Fuel cells represent a fundamentally new powertrain technology
  - Fuel cells compete technically with the internal combustion engine, traditionally a core competence of automakers
  - Rapid progress was made in the last five years with industry investments totaling $2bn

Research question:

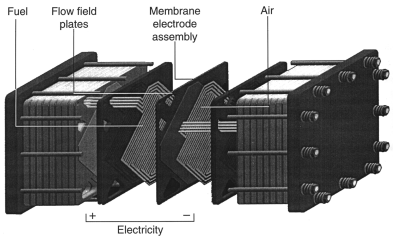
- How do automakers accomplish R&D for developing fuel cell vehicles?
- What are the strategic questions that automakers are faced with?
  - How is new technology identified?
  - How does automaker appropriate and develop technology that is not a traditional core competence?
  - How can automaker derive value and keep control over technology?

Research Agenda

- Project duration from fall 1997 to spring 1999
- Primary source of information
  - 25 interviews with managers at Daimler-Benz, Ford, and Ballard Power Systems
- Additional data for quantitative analysis
  - Citations in technical literature
  - US patent statistics from 1970 to date
- Final report available as IMVP Working Paper

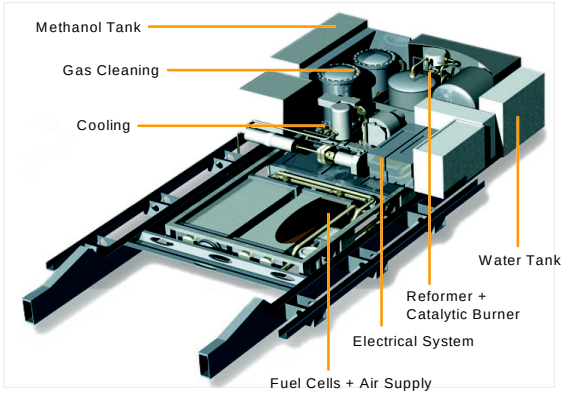
Fuel Cells for Automotive Propulsion

- Operating principle
  - Converts fuel (methanol, hydrogen) into electric power and water vapor
  - Low temperature electromechanical process
- Potential advantages
  - Reduced air pollutants (NO_x, HC)
  - Increased fuel efficiency (may not apply to total energy system)
  - Potential use of less CO_2-intensive fuels
- Current disadvantages, uncertainties
  - Requires methanol or hydrogen fuel
  - Costs
  - Lack of manufacturing and practical operating experience
- Regulatory drivers
  - ZEV regulation in California
  - CAFE standard in the US
  - Climate change debate



Source: Ballard Power Systems Inc.

Fuel Cell Powertrain



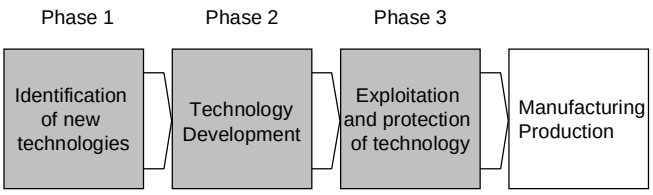
Source: DaimlerChrysler AG, Communications

R&D for New Automotive Technologies

- Automaker is faced with problem of budget constraints and uncertainty in R&D
  - R&D phases with decision points for further investments
  - Portfolio approach to identifying and exploring new technologies
  - Fuel cells are competing with a range of technologies: advanced internal combustion engines (spark-ignition and compression ignition), alternative fuels, electric vehicles, hybrid vehicles
- Challenge of new technology: Automakers had no internal competence in fuel cells, fuel cells were not part of the traditional technology portfolio of automakers
  - Why? Fuel cells have been developed for aerospace applications, and were initially too heavy, too expensive for automotive application
  - How can automakers develop mechanisms for early identification of non-traditional technologies, such as fuel cells?
  - How can automakers gain competence in fuel cell technology, and decide which parts to integrate vs. outsource?
  - How can automakers retain control over fuel cell technology and develop a position that allows automaker to exploit the future value chain of the technology?

Framework for Analysis

- Three phases describing the R&D process:
  - Identification of new technologies
  - Technology development
  - Exploitation and protection of technology
- Framework useful for discussion of
  - Threat of new technologies through competition with core competence
  - Technology integration / cooperation with suppliers



Phase 1: Identification of New Technologies

- Fuel cells have been developed for aerospace and electric power applications before becoming feasible for automotive application
  - Decade-long lead times before technology becomes feasible for automobiles
  - Role of government support for fuel cells in space, defense and energy (NASA, DOD, DOE, Canadian DND, EC, Japanese MITI)
- Technological breakthrough around 1987 made fuel cells feasible for automotive propulsion
  - Key role of a small R&D company (Ballard) with seed money from the Canadian DND
- Leadership roles in automotive fuel cell technology have since then been taken by
  - R&D company specialized in fuel cell technology (Ballard)
  - Automakers with strong ties to aerospace industry and past activity in fuel cells were among the first to recognize the potential of the technology (Daimler-Benz, General Motors)

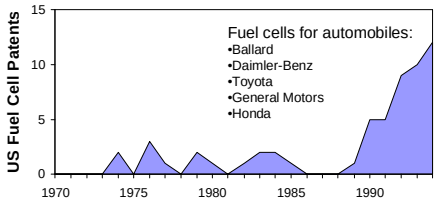
History of Fuel Cell Research

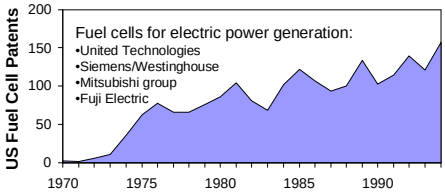
- Development of fuel cells for aerospace since 1950s/60s, for electric power generation since 1970s/80s, and for automotive propulsion since 1987

1950/60s
Fuel cells for aerospace:

United States
•NASA
•United Technologies
•General Electric
•Dow Chemical
•DuPont

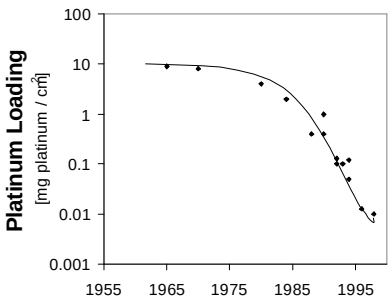
Europe
•ESA
•Siemens
•Dornier
•Varta
•Elenco

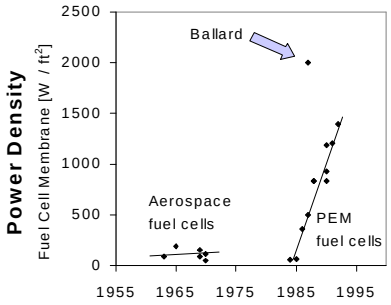




Critical Technological Breakthrough

- Breakthrough in fuel cell technology opened up possibility for application in automobiles
  - Reduction of platinum loading requirements of fuel cell membrane (Texas A&M, LANL)
  - Increase in power density of fuel cell stack (Ballard with support from Canadian DND)



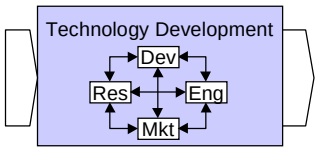


Leadership in Automotive Fuel Cell Technology

- Early identification of the breakthrough technology gave companies a lead in R&D investment and patenting
  - Daimler-Benz recognized fuel cell breakthrough through Daimler Aerospace and subsidiary Dornier, starts cooperation with Ballard
  - General Motors revives contacts with LANL through Delphi/Delco
- Conclusions from R&D Phase 1
  - Technologies that are not part of the traditional technology portfolio appear to be a threat to automakers
  - Uncertainty in R&D favors a portfolio approach to identifying and exploring new technologies
  - Leadership in automotive fuel cell technology has been taken by a small R&D company and automakers with strong ties to aerospace industry
    - Importance of early identification of breakthrough technology
    - Importance of technology development intelligence
    - Importance of bridges with related industries

Phase 2: Technology Development

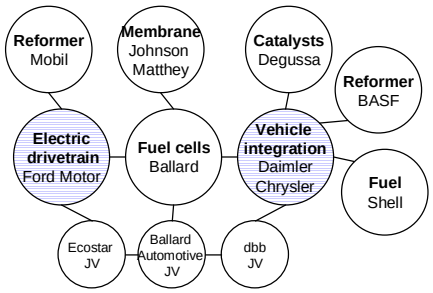
- Systems perspective in the technology development phase
  - Technology needs to be viewed from 'systems' perspective: Choice of fuel, fuel cell technology, integration into automobile
  - Iterations and overlap of research, development, engineering, testing, market research



- Automakers take different organizational approaches to gaining competence in fuel cells:
  - Internal development: Toyota, Honda
  - Collaborative research: DaimlerChrysler, Ford, General Motors
  - License technology (wait-and-see): VW, small OEMs

Insights from 'Daimler-Benz / Ford / Ballard' Alliance

- Research alliance covers all technical components of a fuel cell system
  - Ballard responsible for fuel cell stack
  - DaimlerChrysler responsible for systems integration and proprietary fuel cell stack
  - Ford responsible for systems integration and electric drivetrain
  - Alliance mirrors product architecture, builds on technical complementarity

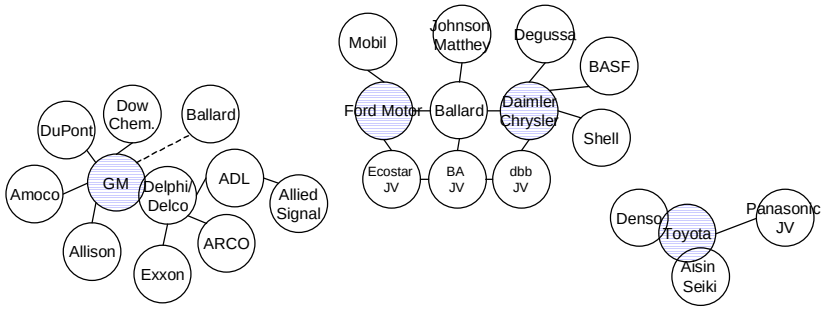


Fuel cell related patents, 1985-99	
Daimler-Benz / DaimlerChrysler	22
BASF	4
Degussa	2
Shell	2
Chrysler Corp. (pre-merger)	0
Ford Motor Co.	3
Mobil Corp.	0
Ballard Power Systems Inc.	35
Johnson Matthey	12
Total patents	**80**

- Alliance provides an effective way of broadening patent portfolio

Gaining Competence in Fuel Cells: Develop-or-Buy

- Develop-or-Buy approach to gaining competence in fuel cells:



- Conclusions from R&D Phase 2
  - Technology needs to be developed with a systems perspective
  - Different approaches to gaining competence in fuel cells: Internal development, collaborative research, licensing

Phase 3: Exploitation and Protection of Technology

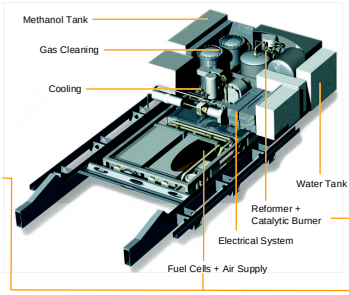
- Ability to control the technology is crucial for exploiting the future value chain of a fuel cell system
  - Automakers who gained competence in fuel cells become 'system integrators' with control over core technology
  - Automakers with little competence in fuel cells remain excluded from value chain
- Role of suppliers in the future value chain of fuel cells
  - Key role of a single R&D company: Ballard
  - Importance of suppliers with access to key components: Johnson Matthey, AlliedSignal, DuPont, Hoechst, Siemens

System Integration vs. Components

- Emergence of a future value chain of fuel cell powertrain
  - Suppliers participate in value chain according to their role as developers of components
  - Automakers take role as 'system integrators,' acquire competence in fuel cells to varying degree

System Integration
DaimlerChrysler
Ford
General Motors
Honda
UTC/International Fuel Cells
Mitsubishi
Nissan
Toyota

Membrane and Catalyst
3M
Asahi Chemical
DuPont
Hoechst
Johnson Matthey



Fuel Processor
A.D. Little
DaimlerChrysler
General Motors
UTC/International Fuel Cells
Johnson Matthey
Mitsubishi
Toyota

Fuel Cell Stack
AlliedSignal
Ballard Power Systems
General Motors
Honda
UTC/International Fuel Cells
Mitsubishi Electric
Siemens
Toyota

Conclusions

- Identification of fuel cells as a new automotive propulsion technology
  - Challenge of new technologies that are not part of the traditional technology portfolio
  - Portfolio approach to identifying and exploring new technologies
  - Early identification of breakthrough technology
    - Technology development intelligence, ties with related industries
- Technology development
  - Technology systems perspective
  - Develop-or-buy decision: Gaining competence in fuel cells through internal development or collaborative research
- Exploitation and Technology Protection
  - Future value chain of fuel cell system
  - Automakers can participate through systems integration
  - New suppliers as participants in the value chain
- Applicability to other cases: Electric vehicles, hybrid vehicles, airbags, ...