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A consortium approach to commercialized Westinghouse solid oxide fuel cell technology

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Abstract

Westinghouse is developing its tubular solid oxide fuel cells (SOFCs) for a variety of applications in stationary power generation markets. By pressurizing a SOFC and integrating it with a gas turbine (GT), power systems with efficiencies as high as 70–75% can be obtained. The first such system will be tested in 1998. Because of their extraordinarily high efficiency (60–70%) even in small sizes the first SOFC products to be offered are expected to be integrated SOFC/GT power systems in the 1–7 MW range, for use in the emerging distributed generation (DG) market segment. Expansion into larger sizes will follow later. Because of their modularity, environmental friendliness and expected cost effectiveness, and because of a worldwide thrust towards utility deregulation, a ready market is forecasted for baseload distributed generation. Assuming Westinghouse can complete its technology development and reach its cost targets, the integrated SOFC/GT power system is seen as a product with tremendous potential in the emerging distributed generation market. While Westinghouse has been a leader in the development of power generation technology for over a century, it does not plan to manufacture small gas turbines. However, GTs small enough to integrate with SOFCs and address the 1–7 MW market are generally available from various manufacturers. Westinghouse will need access to a new set of customers as it brings baseload plants to the present small market mix of emergency and peaking power applications. Small cogeneration applications, already strong in some parts of the world, are also gaining ground everywhere. Small GT manufacturers already serve this market, and alliances and partnerships can enhance SOFC commercialization. Utilities also serve the DG market, especially those that have set up energy service companies and seek to grow beyond the legal and geographical confines of their current regulated business. Because fuel cells in general are a new product, because small baseload applications are a new segment, and because deregulation will continue to shake up the mature traditional power generation market, the commercial risks of launching a new product at this time are unique and considerable. Hence, a collaborative approach to commercialization is deemed desirable and appropriate, and collaboration with GT manufacturers and utilities will be addressed in this paper. © 1998 Elsevier Science S.A.

Keywords: Solid oxide fuel cells; Commercialization; Consortium; Distributed generation; Gas turbines; Modularity

1. Commercial considerations

Commercial considerations are shown in Fig. 1.

When you consider what has to occur to commercialize the solid oxide fuel cell (SOFC) technology, there are several key considerations.

- Product standardization. What products in 250 kW to 7 MW will we offer?
- We must continue to build on basic enabling technology – our tubular SOFC technology.
- We must build a competitive edge to be successful.
- There must be major emphasis placed on manufacturing technologies and processes.
- We must have access to reputable suppliers and materials and form strategic linkages.
- We must create awareness and gain experience in our target markets.
- We have to have access to these target markets and develop cost effective channels.
- Financial resources of Westinghouse and its partners must focus on the capitalization of the business short term, but we all must have the staying power for the long term as well.
- There must be an appetite for risk and the potholes along the way.
- SOFC must fulfill its niche and meet the demand in an emerging distributed generation market that will

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Fig. 1. Commercial considerations.

be enhanced by deregulation as well as remote power needs for off-grid power.
- Lastly, we must gain market acceptance in a highly competitive distributed generation environment.

The status of Westinghouse's tubular SOFC product development is encouraging.

2. SOFC status

The status of Westinghouse's tubular SOFC is shown in Fig. 2.

Our 25-kW power systems have exceeded expectations.

- They have operated for approximately 1.5 years; and have achieved <1% degradation on operating cells.
- We have achieved over 100 thermal cycles.
- We have experienced 8-year life demonstration on single cells.
- We have standardized on our 150-cm cells for commercialization and these cells are currently in production.
- We have made excellent technical progress to date as we move toward commercialization.

3. SOFC Commercialization needs

What we must focus on to commercialize our tubular SOFC product is summarized in Fig. 3.

First, we must:

- move to scale up our kW size units; i.e., 25, 50 and 100 kW to megawatt-size plants;
- develop modular designs that can be configured as a turnkey plant or in modules for power packagers and distributors;
- achieve rigorous cost reduction targets – orders of magnitude from where we are today;
- develop product reliability through field experience; this will come with time and through our demonstration plants that are planned over the next few years;
- scale up our manufacturing from our present 4 MW pilot manufacturing facility to a fully integrated automated facility capable of 100 MW capacity in 2001, our first year of commercial production;
- continue to implement our aggressive strategic plan by moving through a series of demonstrations and refining commercial product offerings through customer input and reactions to our planned product offerings.

4. Westinghouse steps to commercialization

Our commercialization steps are delineated in Fig. 4.

- A 100-kW cogen system in the Netherlands for the

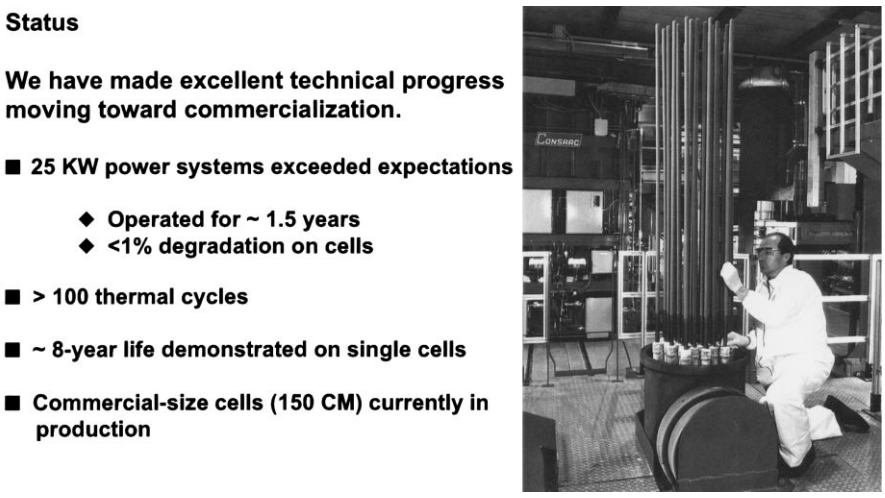

Fig. 2. Status.

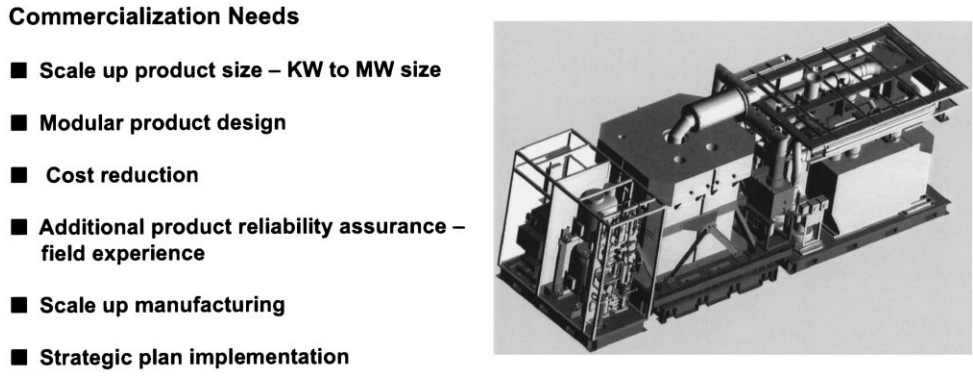

Fig. 3. Summary of commercialization needs.

Dutch/Danish Utility Consortium (EDB/ELSAM). This demonstration program utilizes our 150 CM cells which we will standardize for our commercial offering. This will ship from our plant in early November. We will have a venture with NUON International to market fuel cell systems in the Benelux countries.

- We continue to work with Ontario Hydro to pressurize our cells and SOFC modules to gain higher power outputs and efficiencies. Pressurization can add 10–15% in power output at 6–7 atmospheres.
- We are currently under contract to Southern California Edison (SCE) to deliver a 250-kW pressurized system integrating the SOFC with a gas turbine. A micro turbine rated at 50 kW will be used and the plant will have efficiencies of 60%.
- We plan a megawatt scale demonstration at Ft. Meade, MD. This project is sponsored by the EPA, DOE and Westinghouse Consortium Partners who will also be our joint venture partners in commercializing the technology.
- We are currently developing our manufacturing scale up plans that will be in concert with the current commercialization of our SOFC product.
- We will begin to place orders for process equipment required for the initial 100 MW of capacity in 1999 and also make the final decision on location of this facility which will be located in the United States.
- Building a factory in 1999 or taking over an existing shell is top priority. With this plan, we should begin to take commercial orders in the year 2000.
- In our commercialization plan we will continue our product development and improvements with inputs received from our customer base.
- We have recently formed SOCA (Solid Oxide Fuel Cell Commercialization Association), a non-profit entity aimed at gaining input from a market perspective to our commercialization plan and strategy.

5. SOFC Technology development

Technology development leading to commercialization is tabulated in Fig. 5.

- The key events will be continued refinements in costs and deliverables over this plan with major emphasis on reducing product cost and processes from the air electrode, the interconnection, the electrolyte, fuel electrode and the key process step – the electro vapor desposition (EVD) step in all processing.
- All of these steps and these product/process improvements will culminate in our high-efficiency commercial SOFC module offering configured in a combined cycle with a gas turbine. As we look at these key demonstrations all envisioning scale-up to MW class demos, we are confident that we will gain valuable input in evolving our commercial offering in the timetable we envision – delivering commercial product by the 4th quarter of 2001.

6. Product vision

Our product vision is summarized in Fig. 6.

- We will focus on 250 KW to 7 MW with the market

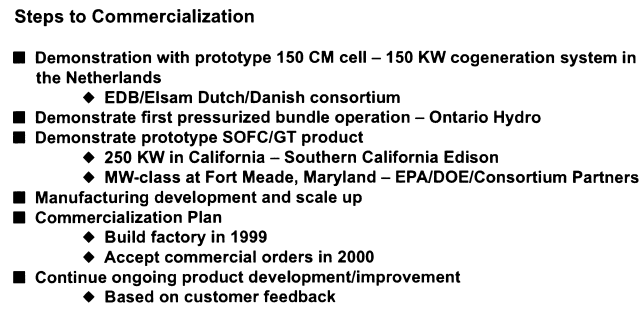

Fig. 4. Steps to commercialization.

Technology Development

	JGU & SCE 25 kWe Demo's Previous Process	EDB/ELSAM 100 kWe Demo Current Process	SCE 250 kWe PSOFC/MTG Demo	OHT 800 kWe PSOFC/GT Demo	1.3 MWe PSOFC/GT Demo	2.5 MWe PSOFC/GT Demo	Technology Upgrade	Commercial Process
Date of Activity	2 Qtr 1997	4 Qtr 1997	3 Qtr 1998	2 Qtr 1999	1 Qtr 2000	1 Qtr 2001	TBD	4 Qtr 2001
Activity	Site Tests Completed	Initial Site Acceptance Test	Initial Site Acceptance Test	Initiate Site Testing	Initiate Site Testing	Initiate Site Testing	Spare	Initiate Commercial Production
SOFC Rating Submodule Identification	25 kWe	100 kWe	200 kWe DOE-1	500 kWe DOE-2	1000 kWe DOE-2 & 3	2000 kWe DOE-2,3,4,& 5	500 kWe DOE-6	500 kWe
Cell Diameter	16 mm	22 mm	22 mm	22 mm	22 mm	22 mm	22 mm	22 mm
Cell Active Length	500 mm	1500 mm	1500 mm	1500 mm	1500 mm	1500 mm	1500 mm	1500 mm
Air Electrode (AE) Mfg Process	Extrude, sinter	Extrude, sinter	Extrude, sinter	Extrude, sinter	Extrude, sinter	Extrude*, co-sinter with IC	Extrude*, co-sinter with IC	Extrude*, co-sinter with IC
Geometry	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical	Cylindrical or cylindrical with rib	Cylindrical or cylindrical with rib	Cylindrical or cylindrical with rib
Interconnect (IC)	Plasma sprayed	Plasma sprayed	Plasma sprayed	Plasma sprayed	Plasma sprayed	Co-sinter with AE	Co-sinter with AE	Co-sinter or co-extrude with AE
Electrolyte (EL)	EVD	EVD	EVD	EVD	EVD	Some EVD, some sintered	Some EVD, some sintered	Sintered or EVD
Fuel Electrode (FE)	EVD	EVD	EVD	Some sintered, some EVD	Sintered in DOE-3	Sintered	Sintered	Sintered
No. of EVD Steps	Two	Two	Two	One, some two	One	One and zero	One and zero	Zero or one

*Perhaps co-extrude with IC

Fig. 5. Technology development.

Vision

- **Initial product focus: 250 KW to 7 MW**
  - **Market will determine progress beyond 7 MW**
- **Standard 500 KW SOFC modules**
  - **Larger and smaller modules as market dictates**
- **Atmospheric SOFC power systems for cogeneration**
- **SOFC/GT integrated power systems**
  - **Standard units (>62% efficiency)**
  - **High efficiency units (70% efficiency)**

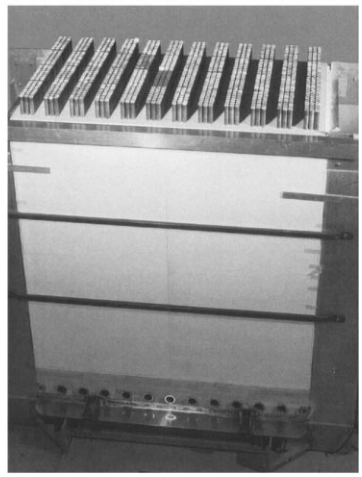

Fig. 6. Vision.

determining the size ranges beyond 7 MW. We feel there will be opportunities beyond 7 MW, and we believe they will occur as SOFC penetrates and gains acceptance in our target markets – industrial, commercial and electric utility segments. The gas utilities will also be customers.

Commercialization Challenges – Business/Market

- **Fuel cells are a new "disruptive product"**
  - **Customer awareness issue**
- **New market segment for Westinghouse – under 50 MW**
- **New/emerging customer segment worldwide – DG, baseload**
- **New market environment – deregulation**
  - **Customer identification issue**
- **Market forecasting – difficult**
- **Initial manufacturing capacity – large versus small**
- **Regional approaches needed**
- **Distribution channels**
- **Maintenance and service opportunities**

Fig. 7. Commercialization challenges: business/market.

- We will standardize on 500-kW SOFC modules, but we will remain flexible for smaller modules – say 250 or 100 kW and larger sizes should market demands dictate.
- The atmospheric SOFC power plant for cogeneration applications will be our focus.
- We are planning for our SOFC/GT integrated power system to have standard units with efficien-

Risks – Uncontrollable

- **Electricity prices decline because of deregulation**
- **Environmental laws become less stringent – SOFC environmentally friendly**
- **Competing technologies – all well positioned**
  - **Small gas turbines**
  - **Diesels**
  - **Other fuel cells**
  - **The local grid**
- **Natural gas prices decline or rise very high**

Fig. 8. Risks: uncontrollable.

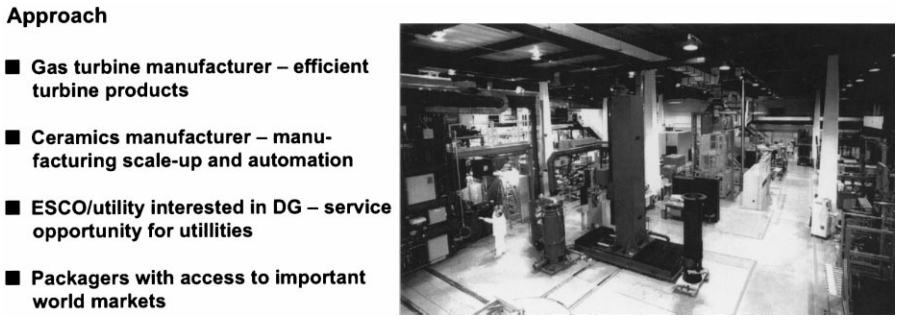

Fig. 9. Approach to mitigate risk.

cies of >62%; and high-efficiency units also combined with gas turbines with efficiencies exceeding 70%.

- We view our plan as aggressive, but achievable, but it does not come without its challenges.

7. Commercialization challenges

These challenges are addressed in Fig. 7.

8. Risks

For commercialization of our SOFC product, the risks are somewhat out of our control. These risks are summarized in Fig. 8.

All of these risks can be of deep concern when we consider them. However, we must move forward by continually monitoring our market environment and factoring in changes to this environment in our strategic planning process to assure successful commercialization.

9. Consortium approach

When we look at commercialization of our SOFC product, we will take a joint venture or consortium approach. Fig. 9 covers an approach to mitigate risk.

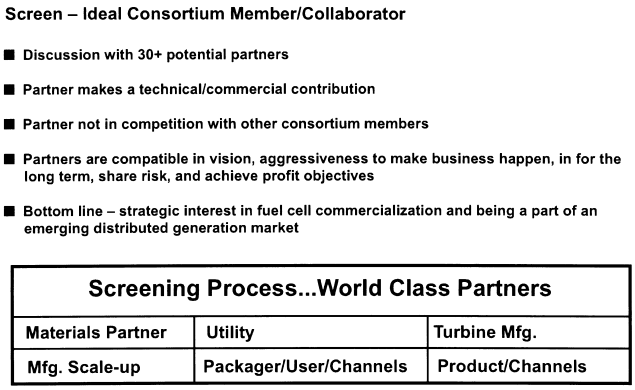

Fig. 10. Screen: ideal consortium member/collaborator.

A consortium of strategic partners to mitigate risk while choosing strategic partners that can enhance our chances to build a world-class successful, profitable business.

We have under consideration:

- gas turbine manufacturers that can bring efficient turbine products and distribution;
- ceramic manufacturers that can bring in scale-up manufacturing and automation capabilities;
- electric utility who through the establishment of an Engineering Service Company can address the distributed generation market for both sales and service; and
- packagers who can address important world markets through a successful in-country relationship.

10. Screening process

Fig. 10 elaborates our screening process to identify ideal partners.

Over the past year we have screened many ideal partners.

- We have held discussions with over 30 potential partners who have a strategic interest in the distributed generation market.
- We were looking for partners who could have a technical as well as a commercial impact.

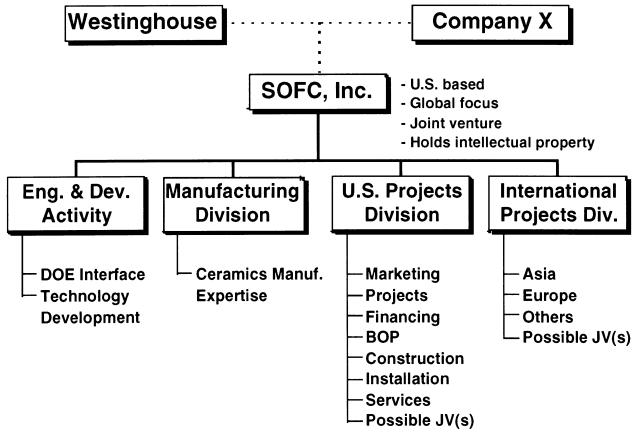

Fig. 11. Overall strategy.

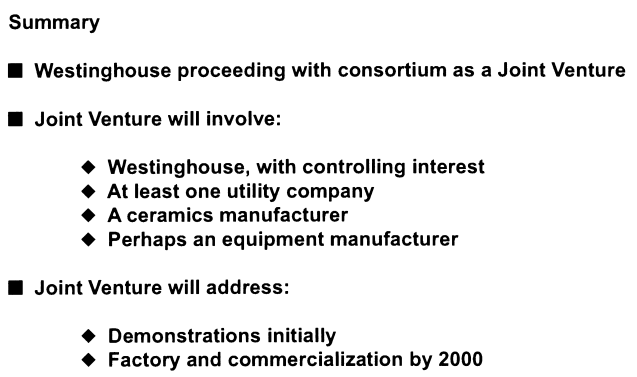

Fig. 12. Overall summary.

- We also wanted to make sure that partners were not going to be in competition with other consortium members. We didn't want partners with conflicting interests. We wanted partners with a compatible vision, business aggressiveness to make the business happen, and had the resources to be in this venture for the long term, share the risks in commercialization, and achieve the profit objective and return that the business can achieve.
- Our bottom line was to have strategic partners willing to form a joint venture company that has the same strategic view in fuel cell commercialization and being a part of a business serving what we consider to be an emerging distributed generation market.

11. SOFC Commercialization strategy

Our overall strategy for implementing a commercial entity is depicted in Fig. 11.

When we envision organizing our commercial entity, which we will call for the time being SOFC, Inc., or NextGen, Inc., we see a company majority owned by Westinghouse with one to three strategic partners.

- This company will have the ability to continue product development and deliver on our cooperative research program with the US Department of Energy, build SOFC modules by establishing fully integrated manufacturing facilities, and have the ability to design and deliver thermal management and balance of plant, providing turnkey packaged plants for a variety of end-use markets including electric and gas utilities who wish to deploy SOFC systems within their defined business base.
- Our plans call for cooperative agreements and partnerships on a global basis. Our US projects organization will have the ability to market, finance, design, build, deliver and install SOFC plants on a turnkey basis. We will work with utilities, power packagers and distributors to assure a broad marketing approach to reach our customer segments while leveraging several channels to market.

12. Summary

Our business objective is to be a world-class, affordable supplier of SOFC packaged power plants as summarized in Fig. 12.

- The joint venture will have Westinghouse as the majority shareholder with a utility partner, a ceramic materials partner who has the ability and resources to work with us on automation and plant processes; and perhaps an equipment manufacturer who is in the turbine business.
- The joint venture will address the planned demonstration programs, the DOE cooperative development program, and the final plans to commercialize and build a facility to commercialize the SOFC product.

Our business objective is straightforward.

- Establish an on-going world-class business that is an affordable supplier of SOFC packaged power plants.
- We are confident that Westinghouse and its planned joint venture partners, collaborators, and suppliers will be successful. The next three years will be extremely important to enable the business to accept orders in the year 2000 and be fully commercialized in 2001.