DIRECT CARBONATE FUEL CELLS (DFC) FOR **GREEN POWER**

Remarks by

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2009 Fuel Cell Seminar & Exposition Award

Palm Springs, CA

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THANK YOU

FUEL CELL SEMINAR

FOR THE RECOGNITION!

A big thank you to Dr. Baker and all my colleagues at FCE and IGT

“Abhar” to my family and friends

40 YEAR JOURNEY…

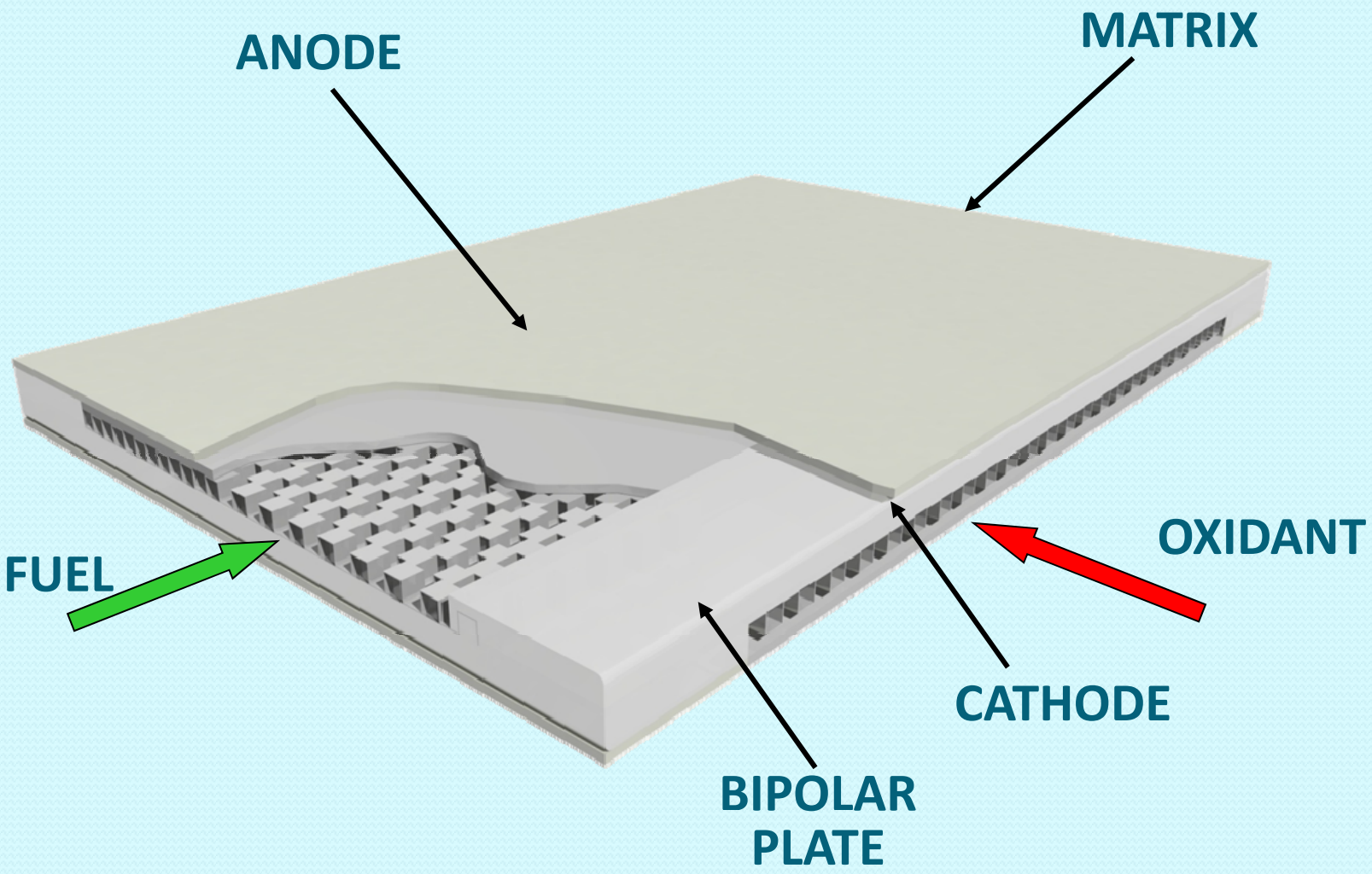
- Scale up laboratory cells (from 3 cm^2 to 10,000 cm^2)
- Cells/stack (from 1 to 350+)
- Life (from <1000 h to >40,000 h)
- Power from 100 milliwatts to 2.4 megawatts
- From hand-crafted cells to 70 megawatts/yr mfg factory

… 40 YEAR JOURNEY

- Cost reduced by a factor of 8 from 1995 levels
- FCE staff growth from 5 people to 500
- 95 megawatts installed /backlog
- ~350 million kilowatt-hour generated since 2003 (equal to a 1 megawatt plant operating for over 40 years)
- **Currently generating 30 megawatts in the field**

FIRST CARBONATE FUEL CELL

CARBONATE FUEL CELL CONFIGURATION



KEY TECHNOLOGY DECISIONS

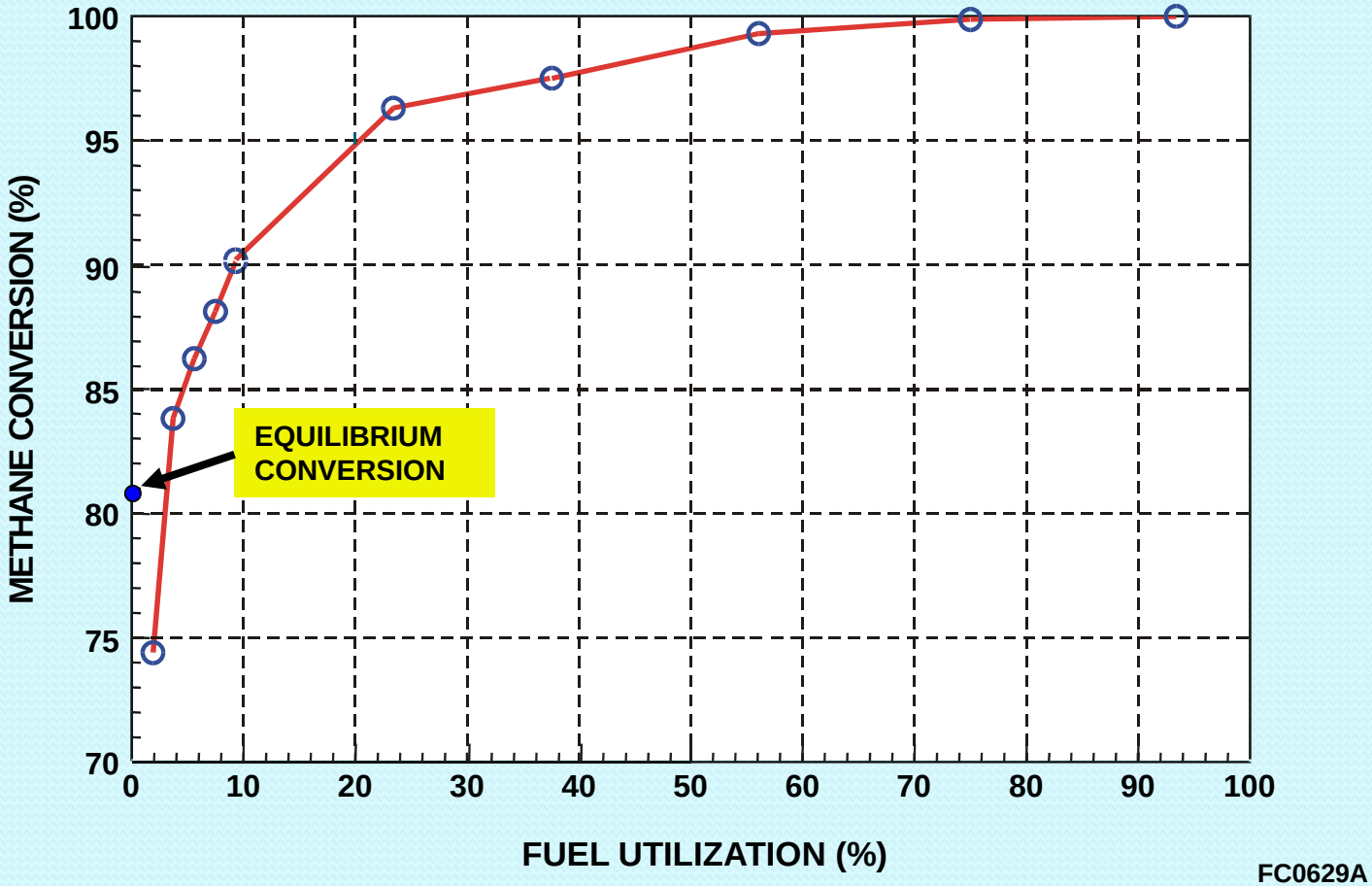
- Alloy nickel anode
- In-situ oxidized nickel cathode
- Alpha $LiAlO_2$ micro pore matrix
- Optimized pore structure
- Internal reforming, atmospheric pressure Direct Fuel Cell design
- Externally manifolded 300+ cell stack
- Insulated vessel, “hot” stack

DIRECT FUEL CELL FEATURES

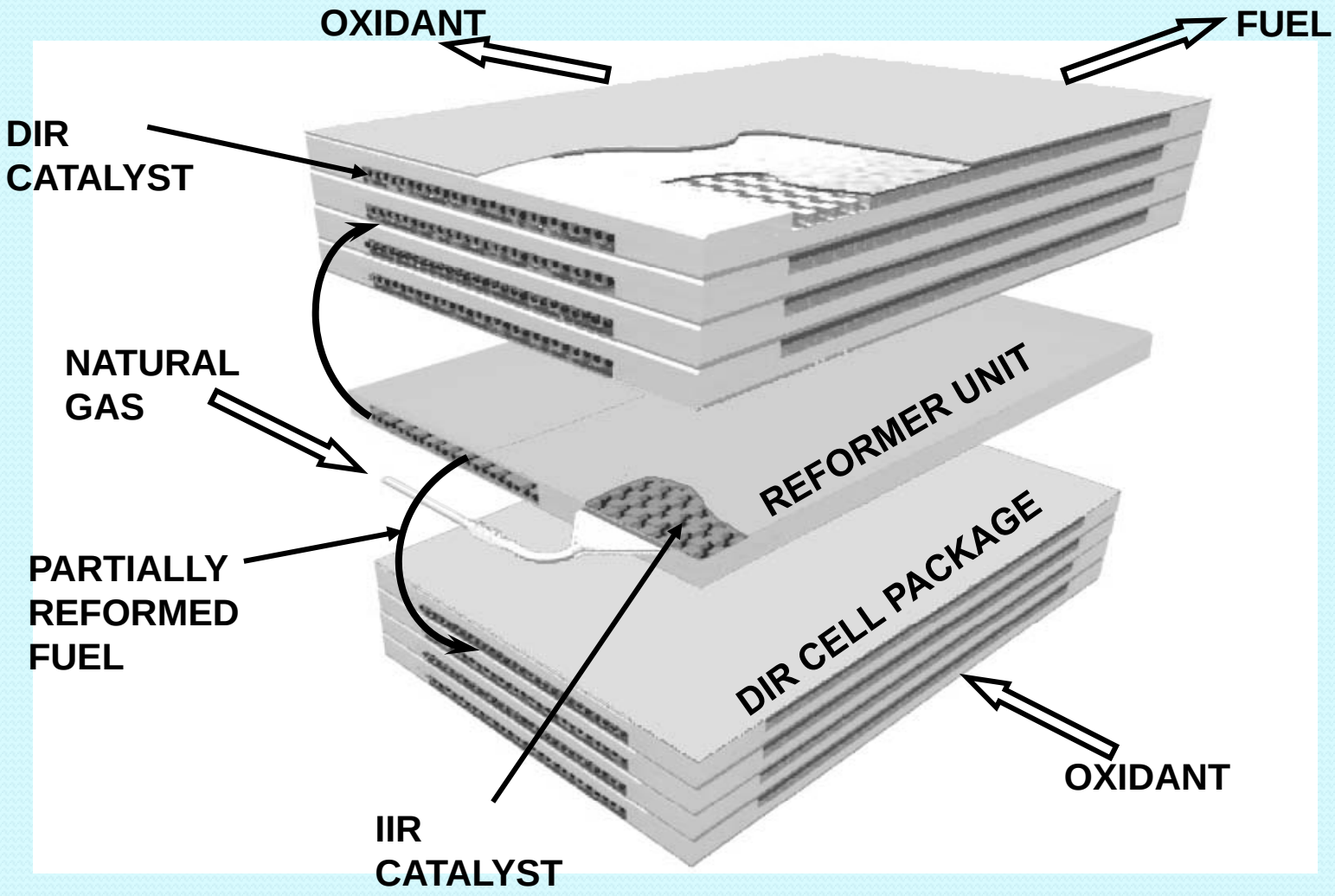
- **FACT**: fuel cell produces heat, reforming consumes heat
- **CONCEPT**: Carry out both functions in proximity of each other
- **BENEFITS**:
  - 10% less fuel required
  - Simpler system, less heat exchange equipment
  - Selective cooling of fuel cell, additional degree of freedom
  - Less cooling gas flow, long life
  - Near-zero NOx formation

DFC ACHIEVES FULL REFORMING AT LOW TEMPERATURE

(DFC @ 650°C, 1 atm, s/c = 2.0)



DFC CONFIGURATION



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CRITICAL EVENTS

- **1990** – The American Public Power Association, a consortium of utilities, selected ERC's 2MW DFC power plant design for deployment by utilities.

- **1993**-APPA support along with DOE instrumental in organizing the Santa Clara demonstration of utility scale dispersed generation.

Late 1990s-- deregulation resulted in a loss of utility support and a shift in focus to the commercial and industrial market.

SANTA CLARA 2MW PROOF-OF-CONCEPT DEMONSTRATION

STACKS FOR 2MW PROOF-OF-CONCEPT DEMONSTRATION

DIRECT FUEL CELL STACK

Features

- High Utilization of Geometric Area
- High Heat Capacity (Metallic Hardware)
- Robust to Thermal Variations During Load Cycles and Trips
- Most Suited for Base-load Operation

FOUR-STACK MODULE

DFC's ENVIRONMENT PROTECTIVE ATTRIBUTES

- **Conserves Resources**
  - Conserves Fuel
    - High Electrical and Thermal Efficiencies
    - Enables Distributed Generation (high overall fuel efficiency, Avoids T&D Losses
    - Bio-gas friendly
  - Conserves Water
- **Reduces Environmental Emissions**
  - Reduces GHG (CO2 and NOx)
  - Reduces Acid Rain Precursors Emissions (SOx and NOx)
- **Green Manufacturing**
- **Allows Recycling at the end of its life**

THE JOURNEY CONTINUES …

- DFC efficiency verified in the field
  - 45-49% LHV Electrical efficiency
  - 65-90% Overall Thermal efficiency
- Total 95 MW installed/backlog, additional 95 MW in targeted applications
- Need additional R&D to capture full potential
  - Double the power per stack (from 300 kW to 600 kW)
  - Double stack life (from 5 years to 10 years)
  - Reduce power plant cost

… THE JOURNEY CONTINUES

- Ultra high efficiencies and innovative products being developed
  - Hybrid DFC-Turbine (approximately 60% efficient)
  - DFC-H2 system for co-production of electricity and H_2
  - DFC attached to conventional power plant can help CO_2 separation while **increasing** net electricity output
- **Less than 7% of U.S. capacity replaced with current generation DFC can help U.S. meet Kyoto Protocol for power plant CO_2 reduction. DFC a strong candidate**
- **HAVE A NICE JOURNEY !**

- end

FIELD EXPERIENCE (FCE)

- Over 80 units installed worldwide since 2003
  - Longest operation: >3 years
- Environment contribution – Emissions avoided:
  - CO_2: 200,000 tons
  - SOx: 1,500 tons
  - NOx: 600 tons
  - PM10: 40 tons
- ~350 million kWh of **Green Electricity** generated

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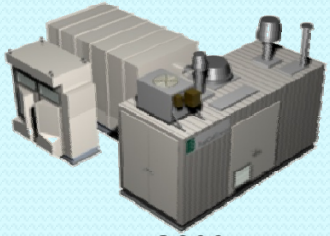
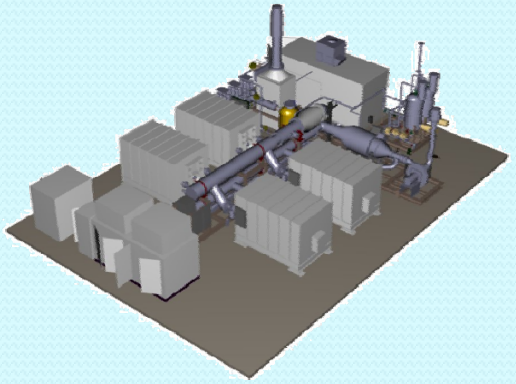
Slide 20

f1 Removed one 'Longest ..." sentence
farooque, 11/10/2009

APPROACH TO PRODUCT LINE

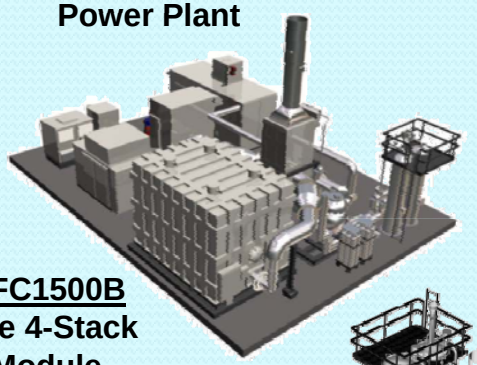


DFC300
Single Module Power Plant



DFC1500A
Four Module Power Plant

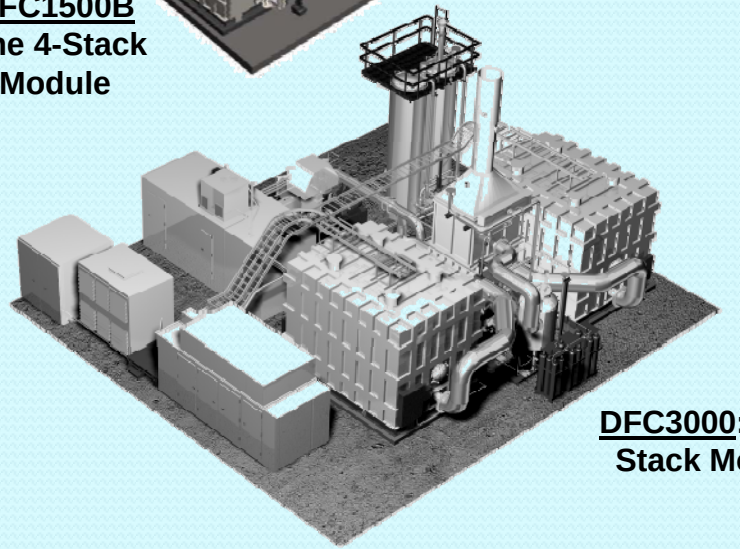
Single-Stack Module



DFC1500B
One 4-Stack Module

Cell Package and Stack

Four-Stack Module



DFC3000: Two 4-Stack Modules

FIRST BIPOLAR PLATE CARBONATE STACK (10” X 15”) TESTED