

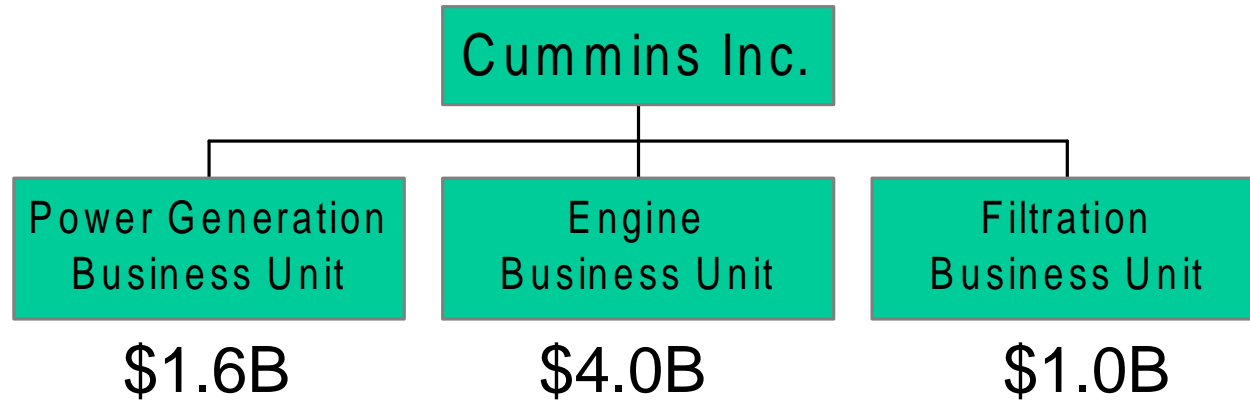
SECA

Third Annual Workshop

*Cummins Power Generation
10kWe SOFC Power System
Commercialization Program
March 22, 2002
Washington, DC*

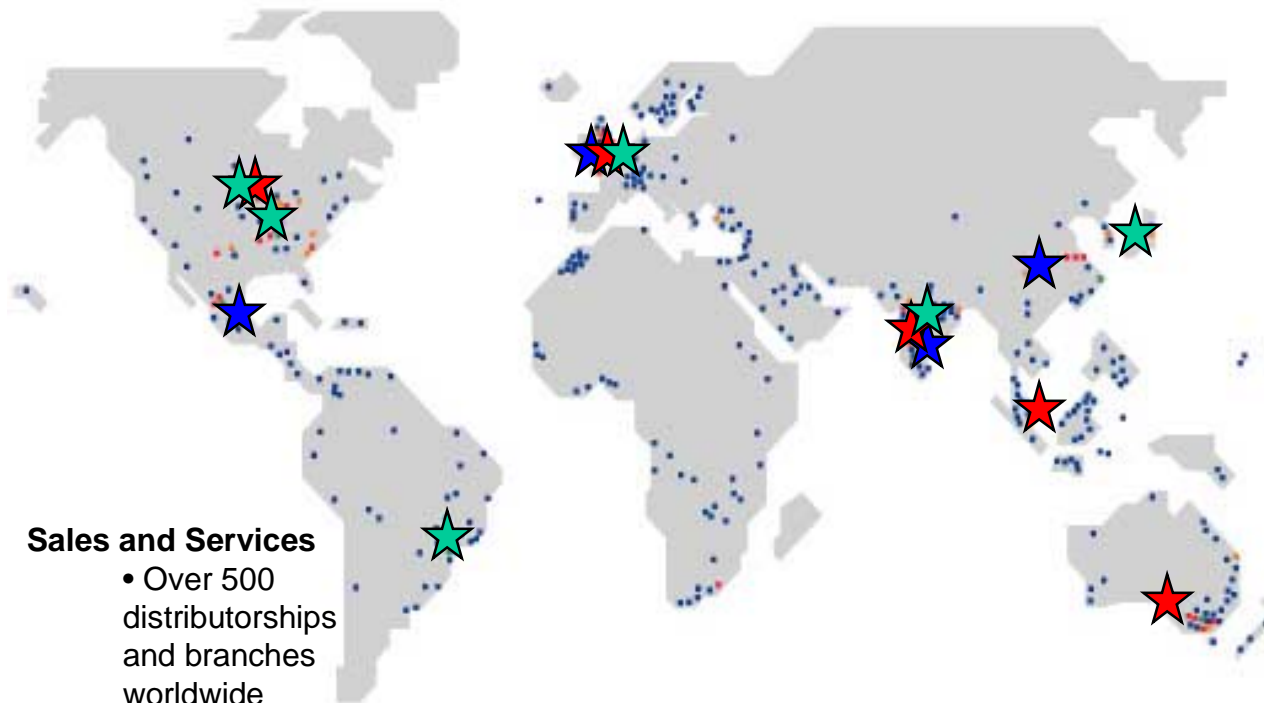
- Cummins
- Cummins Power Generation Markets
- Cummins - McDermott Technology / SOFCo Team
- SECA
- Product Vision
- Project Status

Cummins Overview



- CPG Sales
 - \$1.6 billion in 3kWe to 2 MWe range
 - \$200 million in 3kWe to 12 kWe range
- System meeting SECA cost and performance targets will displace current reciprocating engine technology in 3-12 kWe target markets
- Driving factors are
 - low noise,
 - low vibration,
 - high reliability
 - low emissions

Worldwide Presence



Sales and Services

- Over 500 distributorships and branches worldwide

Component Manufacturing

- Ahmednagar, India
- San Luis Potosi, Mexico
- Stamford, England
- Wuxi China

Genset Manufacturing

- Minneapolis, Minnesota
- Ramsgate, England
- Singapore
- Adelaide, Australia
- Daman, India

Technical Centers

- Columbus, Indiana
- Darlington, England
- European Engine Alliance, High Wycombe, England
- Minneapolis, Minnesota
- Industrial Power Alliance, Oyama, Japan
- Pune, India
- Sao Paulo, Brazil

Parts Distribution Centers

- Beijing, China
- Mechelen, Belgium
- Memphis, Tennessee
- Pune, India
- San Luis Potosi, Mexico
- Sao Paulo, Brazil
- Scoresby, Australia
- Shanghai, People's Republic of China
- Singapore



Cummins Power Generation Americas Minneapolis Headquarters and Manufacturing

1,000,000 ft²
1500 employees

Stationary Power Markets



★ *Current SECA Target*



Telecommunications



Standby

★ *Future SECA Targets*



Residential



Distributed Generation

Mobile Power Markets



Recreational Vehicle

Current SECA Targets



Commercial
Mobile



Portables



Marine

Future SECA Targets



Rental



Power Generation Technology Evolution



Engine Driven Gensets



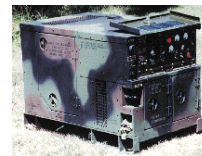
Switches & Switchgear



Variable Speed Gensets



Micro-Turbine Gensets



Commercial & Military Variable Speed Engine-Driven Gensets



Fuel Cell Power Systems



Truck APU



Military Portable



Hybrid Electric Vehicle

Mature

Emerging

Future



CPG – SOFCo Team



- Electronic controls
- Power electronics
- Fuel systems
- Air handling systems
- Noise and vibration
- System integration
- Manufacturing
- Marketing, sales, distribution

Clean energy for the world



- Planar SOFC technology
- Reformer technology
- Material science
- Heat transfer
- Computational fluid dynamics
- Numerical modeling
- Multilayer ceramic manufacturing

CPG Technical Competencies



- Controls
- Power Electronics
- Fuel Systems
- Packaging/System Integration
- Noise and vibration control
- Switchgear
- Engines
- Generators

- Planar SOFC technology
- Multilayer ceramic manufacturing
- Reformer technology
- Material science
- Heat transfer
- Numerical modeling and computational fluid dynamics

SECA

10 kWe SOFC Power System Commercialization

Objective: develop a SOFC system including:

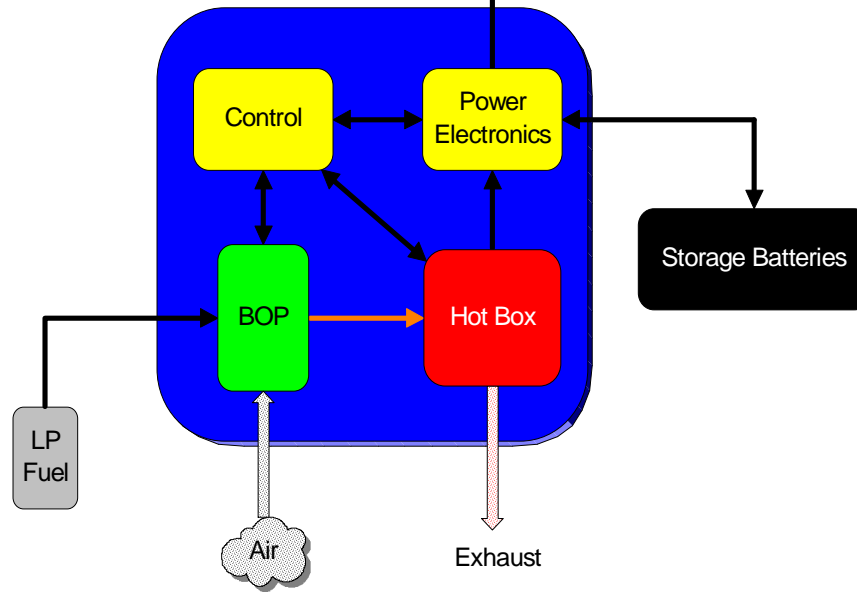
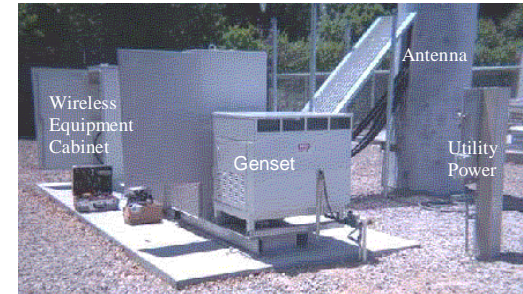
- SOFC stack, reformer, heat exchanger
- Balance of Plant
- Controls and Power Electronics
- Packaging and integration
- Factory cost of \$400/ kWe net by end of Phase III
- Commercialized at earliest possible date



**Power
Generation**

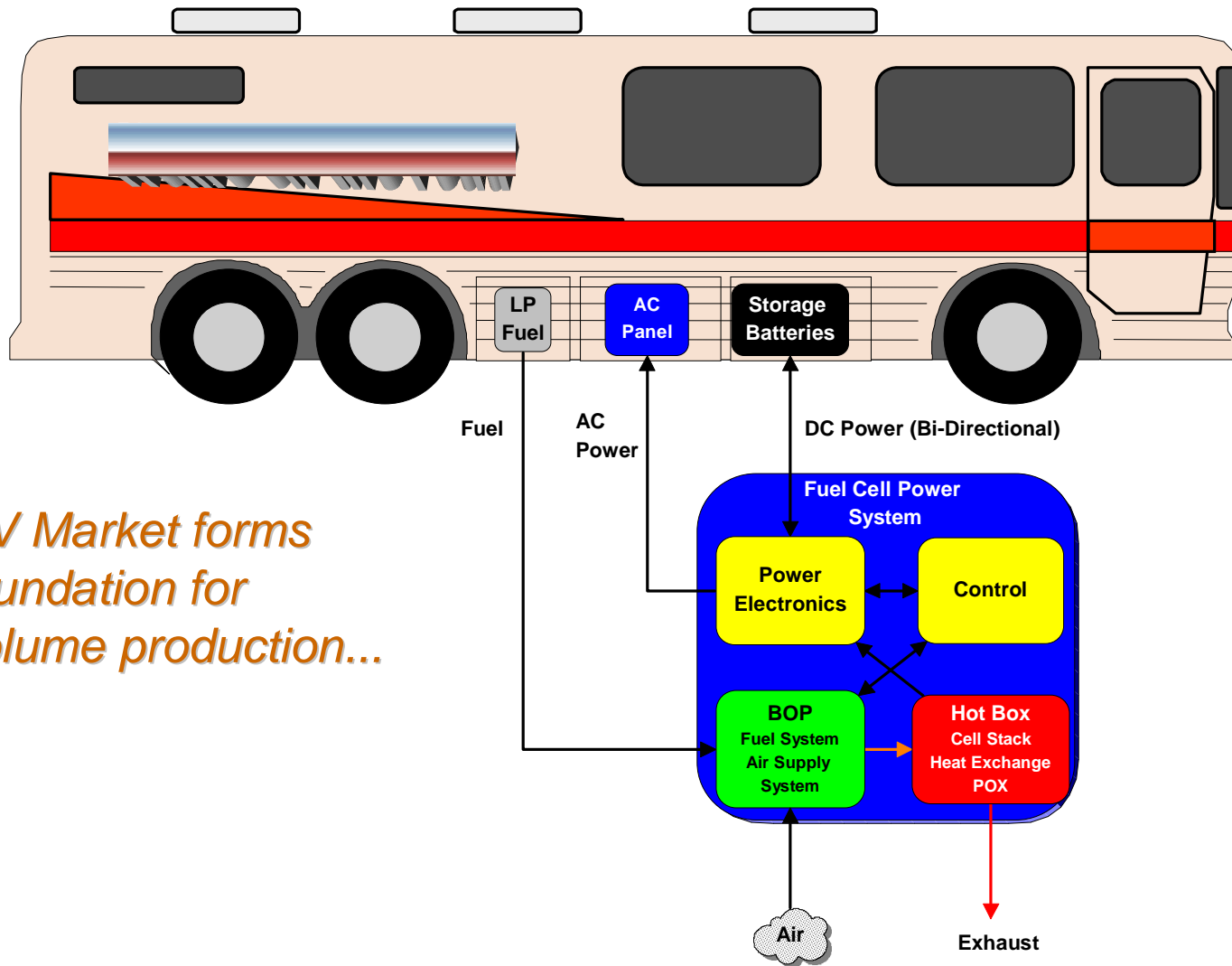
CPG Fuel Cell Product Vision

Power System Architecture



Commercial Mobile and Telecom add incremental volume...

RV Application



RV Market forms foundation for volume production...

- Voice of the customer
- Technical product description
 - performance
 - characteristics
 - specifications



Program **Benefits** for identified Markets...

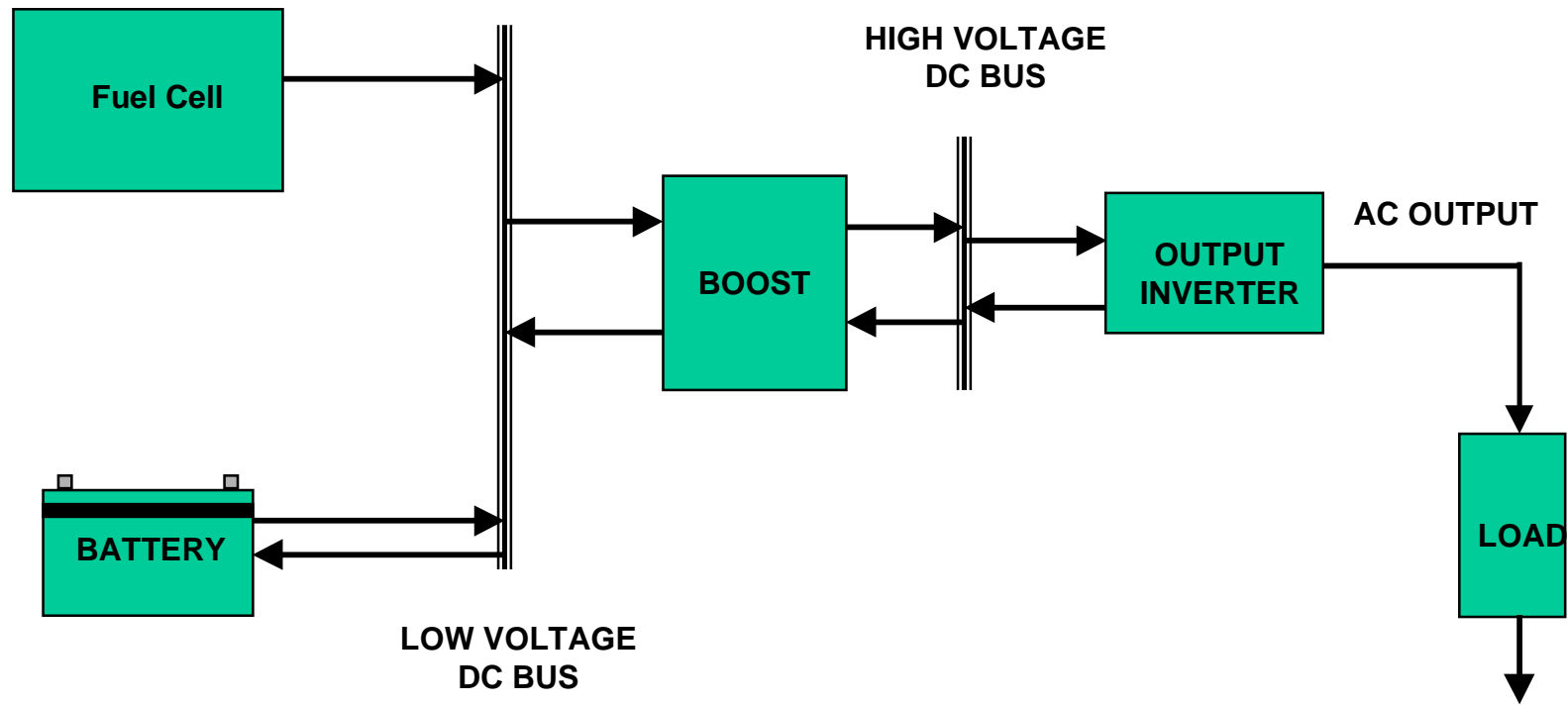
- Low noise
- Low vibration
- High reliability
- Clean power

Challenges identified in System Profile Development...

- Start up time
- Idle fuel consumption
- Power density
- Operating temperature range
- Salt environment
- Abnormal transients (emergency shut down, hot re-start)
- Cost

- System Rating
 - 8 kWe Continuous
 - 10 kW Intermittent
 - 15 kW Peak
- Battery boost system
- Controlled load sharing between battery and SOFC

System Configuration



- Phase I Base rating
120/240 VAC 1.0 PF
- Availability / Power during start sequence (Inverter Only)
- Voltage and frequency regulation same as electronically controlled variable speed Diesel product

Electrical Specifications



- Voltage and Regulation

Regulation - % Rated	2% NL-FL
Overshoot - % Rated	20% Max
Undershoot - % Rated	20% Max
Short term band width	2%
Long term band width	2%
Recovery time	5 sec Max

- System Performance

Efficiency at 60 Hz rating	AC/LHV \geq 25%
Max Set Air Inlet Temp	40C (104F)

- Battery Charging

Battery Charging --	42V 20 Amp
Starting Voltage -- Nominal	36 VDC
Starting Voltage -- Min during cold start.	32 VDC

- LP Gas (Propane)
- Simple and cost effective
- Already in use on RV's for Gensets, cooking, heating, refrigeration
- Market research indicates customers will accept LP on vehicles to gain benefits
- Some conversion to LP as propulsion fuel may occur over development period

- ASTM D1835
- Contains Mercaptan as odorant
- 185 ppm limit for H₂S and total sulfur for commercial propane.
- Oil content depending on propane source
- Boiling point
 - Propane -42 C (-44F)
 - Butane 0 C (+32F)
- Typical tank pressures:
 - Maximum 2.15 Mpa (312 psig)
 - Filled to 1.38 Mpa (200 psig)
 - Run down to 0.20 Mpa (30 psig)

Operating Environment



- Temperature Range -30 C to +50 C
- Altitude Sea Level to 3350 m
- Humidity Up to 100% RH
- Dust TBD
- Salt TBD
- Road Conditions RV Profile

- Start/Stop
- Aborted start sequence
- Emergency Shutdown
- Safeties
 - Fuel exhaustion
 - Overload
 - Plugged exhaust
 - Plugged air filter
 - Temperatures out of range
 - Oil in fuel
 - Short Circuit

- Start-up sequence initiated from cold when power need is anticipated
 - Development program will minimize start-up time
 - Battery + inverter power loads during warm-up
- Idle mode during low electrical demand
- Shut down when no power need is anticipated for extended time

Installation



- Phase III target: same size envelope as Diesel Genset -- 0.5 m³ (17.4 ft³)



Mobile Applications				
		Phase I 4 Years	Phase II 3 Years	Phase III 3 Years
SECA Based Requirements				
Cost	\$/kW	\$800	\$600	\$400
Net Power				
Continuous	kW	8	TBD	TBD
Intermittent	kW	15	TBD	TBD
Peak	kW	15	TBD	TBD
Efficiency	AC/LHV	25%	30%	30%
Steady State				
Availability	%	80%	85%	95%
Power Degradation	%/500 Hr	< 2%	< 1%	< 0.1%
Transient				
Cycles	n	10	50	100
Power Degradation	/n cycles	< 1%	< 0.5%	< 0.1%
Fuel		LP	LP	LP

Product Profile Development

- Aligns design to market requirements
- Provides common understanding
- Develops technical description
- Identifies technical challenges
- Provides input to performance model

Develop Steady State Model

- Vehicle for system optimization
- Provides data for sub-system design and component sizing

Develop Transient Model

- Predicts response of critical system parameters
- Inputs to control system model

PCU (Power Cell Unit) Ready for Testing

- Full scale unit for characterization
- Evaluation of seals and manifolding
- Qualification for system integration
- Ships to CPG for assembly

Summary



- Strong technical and commercial team
- Strong established presence in existing markets
- Access to new markets
- Moving forward with development program for commercialization



SECA Core Technology Program

Cummins Power Generation

10kWe SOFC Power System

Commercialization Program

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