BREAKOUT GROUP 4: LOW TEMPERATURE FUEL CELL SYSTEM BOP & FUEL PROCESSORS FOR STATIONARY AND AUTOMOTIVE PARTICIPANTS

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BREAKOUT GROUP 4: LOW-TEMPERATURE FUEL CELL SYSTEM BOP & FUEL PROCESSORS FOR STATIONARY AND AUTOMOTIVE BARRIERS

PURIFICATION AND SEPARATION FUEL PROCESSING	FUEL PROCESSING CATALYSTS	FUEL FLEXIBILITY	BOP/FC ENGAGEMENT
• Combine hydrogen purification and compression • Cost effective H_2 separation membranes – palladium PEM fuel reformers are too costly, driven by (relatively) high-temperature designs • CO_2 membrane separation • Fuel conditioning/impurity removal and clean-up • Fuel impurities	• Fuel processing catalyst cost and durability • PEM fuel reformers have too many components, driving complexity and cost – need multi-function components • H_2S stable – High-Temperature Water Gas Shift catalyst, Steam Methane Reformer catalyst • Catalyst regeneration/recovery • Durable catalyst for reforming, i.e., AutoThermal Reforming • De-sulfurization catalysts • Non NH_3 producing Fuel Processor System	• Very limited fuel flexibility (Natural Gas and Anaerobic Digester Gas - in one) • Variability in fuel processor feedstocks makes standardization difficult	• Engagement of BOP suppliers on behalf of the fuel cell industry • Lack of design for manufacturing • Narrow stack operating window results in higher cost, less efficient BOP components

BREAKOUT GROUP 4: LOW-TEMPERATURE FUEL CELL SYSTEM BOP & FUEL PROCESSORS FOR STATIONARY AND AUTOMOTIVE BARRIERS (CONT'D)

BOP	HUMIDIFIER	STACK MATERIAL
• Thermal cycle stability of low cost BOP components (ex: HEX) for CHP applications medium temperature fuel cells • Combined Cooling Heat and Power (CCHP), Combined Hydrogen Heat and Power (CHHP), Combined Heat and Power (CHP). • Operating and Maintenance costs are high and not predictable • There needs to be major BOP cost targets (e.g., blowers, DC-DC, etc.) • BOP components are not CE/Underwriters Laboratory/Canadian Standards Association certified. This increases cost and adds delays • BOP is too complex • Air filters - ΔP, size, cost, broad spectrum, regenerate or easy replace • Blowers are not efficient, compact, durable, or reliable enough to meet stationary power needs • The need for a low cost and quiet blower • BOP for PEM systems are too costly, driven by low volume sales • Efficiency of BOP components needs improvement • Need for more reliable, accurate flow measurement of H_2O at high press and low flow (this need is in reformate systems) • Need low cost structural material that are H_2 compatible	• Low cost humidifier/water management system required • Need for lower cost pumps that can operate at high pressure - low flow (Reformate system) • Address a simple system (pure H_2/O_2)	• Stack/MEA development and optimization rarely based on realistic operating conditions • Conventional PEM MEAs require humidification, which adds to system complexity • Required system complexity with present materials/components is too high

BREAKOUT GROUP 4: LOW-TEMPERATURE FUEL CELL SYSTEM BOP & FUEL PROCESSORS FOR STATIONARY AND AUTOMOTIVE BARRIERS (CONT'D)

POWER CONVERSION	SENSORS	MODELS/ALGORITHMS, DIAGNOSTICS	OVER ARCHING (LOAD PROFILES, STANDARDS)
• Power conversion devices are not scalable, flexible, or cost effective for all applications • Power electronics too costly • Power electronics need modular, comp design to enable cost effective solution • Power conversion devices are expensive and not flexible • Standardization for power conversion devices and targets • BOP supply voltages are not standardized	• Sulfur detection: low cost, highly sensitive ppb levels • H_2 sensor reliability • H_2 sensors are too costly, cross-sensitive and single use • Need reliable, low cost, compact sensors - H_2, CO, S • Sensor/actuator installation costs • Cost and availability of sensors for process feedback control and for safety	• Need smart diagnostic tools • Too many sensors; need for adequate predictive models to use to replace sensors • Stack diagnostics are costly • Real-time, real-cycles, data analysis of demos • Start-stop operations, turn-down ratio, diagnostics	• Baseline load profiles and operating conditions, market segments, life cycle efficiency • Standards for air path, electric path and fuel path • Corporate goals and technical targets should be aligned with each market segment (not only cost ($/kW))

BREAKOUT GROUP 4: LOW-TEMPERATURE FUEL CELL SYSTEM BOP & FUEL PROCESSORS FOR STATIONARY AND AUTOMOTIVE CRITICAL R&D NEEDS

POWER CONVERSION	DEVELOP ADVANCED, BUT CHEAP SENSORS	ELIMINATE SENSORS THROUGH DEVELOPMENT OF MODELS AND PREDICTIVE CONTROLS/ DIAGNOSTICS	BLOWERS
• Modular, scalable and cheap DC/DC to DC/AC converters > 95% • Power conditioners for flexible - DC to AC + DC output, higher efficiency and low cost • Modular, low cost, reliable, DC-DC and DC-AC converters (linked to solar standards)	• Low cost, durable H_2 safety sensors • Develop low cost, compact, robust, reliable H_2 sensors that are UL/CSA/CE certified • Sensors - sulfur, O_2, pressure, CO • Robust inexpensive sensors • Low-cost, durable system feedback sensors • Inexpensive devices for detecting S, NH_3, CO • Reliable sensors for steam to carbon ratio. Control for multiple fuels: e.g., natural gas, propane, ADG, Landfill Gas • Analytical methods and tools for field use - 10-100 ppb total S, siloxane - 50-500 ppb	• Smart/comprehensive diagnostics • Predictive modeling that can help eliminate sensors • Modeling to assist controlling steam to carbon ratio via temperature sensor or other (simplify) • Model-based predictive automation using minimum strategic sensors/monitor	• Reliable Cheap Efficient blowers > 35% • Develop new blower technologies that are more efficient, reliable and durable and UL/CSA/CE certified

BREAKOUT GROUP 4: LOW-TEMPERATURE FUEL CELL SYSTEM BOP & FUEL PROCESSORS FOR STATIONARY AND AUTOMOTIVE CRITICAL R&D NEEDS (CONT'D)

AIR CLEAN-UP	H_2O	REFORMER CATALYST (INCLUDE WATER GAS SHIFT)	PURIFICATION AND SEPARATION
• Low ΔP air filter • Air clean-up/purification/ impurity removal materials • Broad spectrum air filters • Air and fuel blower development • Regenerable air clean-up	• Hi-Temperature moisture transport membrane benefit - small/no boiler • Cost effective hot vapor transfer from exhaust to reformer (fundamental development) • Zero-net water CHPs. Water-independent systems under CHP conditions • R&D on H_2O recovery	• CO reduction catalyst/material development • Longer life catalyst for reforming and WGS - Goal 5 year life • More durable SMR catalyst • Robust, selective reformer catalysts • Sulfur tolerant catalysts - ATR, HTS • H_2S tolerance catalyst - minimize NH_3 formation • Non-ammonia forming reformer catalyst • Catalyst development - durability (temperature), performance (H_2S, NH) • Low temperature - alternative fuel processing catalyst development • Non-PGM FP catalysts that are temperature, S tolerant for SR & ATR • Effect of acid gases on FP catalyst • Fundamental understanding of effect of sulfur on catalyst - and approaches for addressing it	• H_2 purification materials - membranes, sorbents, etc. • Hi-temperature CO_2 membranes for use in reformer. Benefits - smaller, lower temperature Fuel Processor, reduced coking • Materials development for CO_2 separation • Lower pressure, stable H_2 separation membranes • CO-tolerant, higher efficiency H_2 separation membranes

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SULFUR REMOVAL	SIMPLIFIED FUEL PROCESSOR DESIGN	FUEL FLEXIBILITY AND CLEAN-UP	BOP COMPONENT - COST, DURABILITY, EFFICIENCY
• High capacity sulfur sorbents - >20 wt% for all types - H_2S, CS_2, COS, more organic sulfur compounds. Tolerant to H_2O and higher hydrocarbon • Low cost sulfur removal system • Desulfurization – Regenerable, robust with many S species – Compact	• Develop thermally and physically integrated reactors – Reformer, WGS, etc., catalyst coated • Simplified/combined WGS reactors • Reactors for integrated heat exchanger/reactor (reformer, WGS) • Rapid start catalysts (reformer), heated monoliths, catalyst coated • Develop single block PEM fuel reformer based on "tight" thermal and physical integration	• Fuel flexibility - better understanding of long-term effect of feedstock impurities on fuel processor performance • Development of a variable-fuel resistant processor • Robust/Flexible operation for fuel variability	• Heat exchanger - cycle temperature • Development of low cost, H_2 compatible structural materials • Humidifiers may have limited long term market. Consider this when determining funding priorities • Flow meters: high pressure - low flow (liquid) - low pressure drop (air) • High pressure, low flow pump with manufacturers engagement

BREAKOUT GROUP 4: LOW-TEMPERATURE FUEL CELL SYSTEM BOP & FUEL PROCESSORS FOR STATIONARY AND AUTOMOTIVE SESSION SUMMARY

POWER CONVERSION	FUEL PROCESSING	BALANCE OF PLANT	SYSTEM SIMPLIFICATION	OVERARCHING
• Commonality across sections (supplier to provide common part) • DC-DC, AC-DC (modular, low cost, reliable, efficient, and scalable)	• Sulfur removal/fuel clean-up • Reformer catalyst • Purification separation	• Develop advanced, inexpensive sensors • Standardize load profiles and targets • Air clean-up/blowers • BOP components (cost, durability, efficiency)	• Simplified fuel processor design (thermo integration, single block plug & play multi-functionality component • Eliminate sensors through predictive models, controls, diagnostics • Fuel Flexibility – Robust flexible operation for fuel variability – Better understanding of long-term impact of feedstock impurities – Fundamental understanding of fuel chemistry for reforming – Durability	• System simplification • Standard load profiles • Standard air path, fuel path, electric path • Wider operating window • BOP/FC teaming for compatibility in system • Stack/cell materials