2005 SECA Core Technology Review

Review of Fuel Processing in the SECA Core Program

April 21, 2005

by

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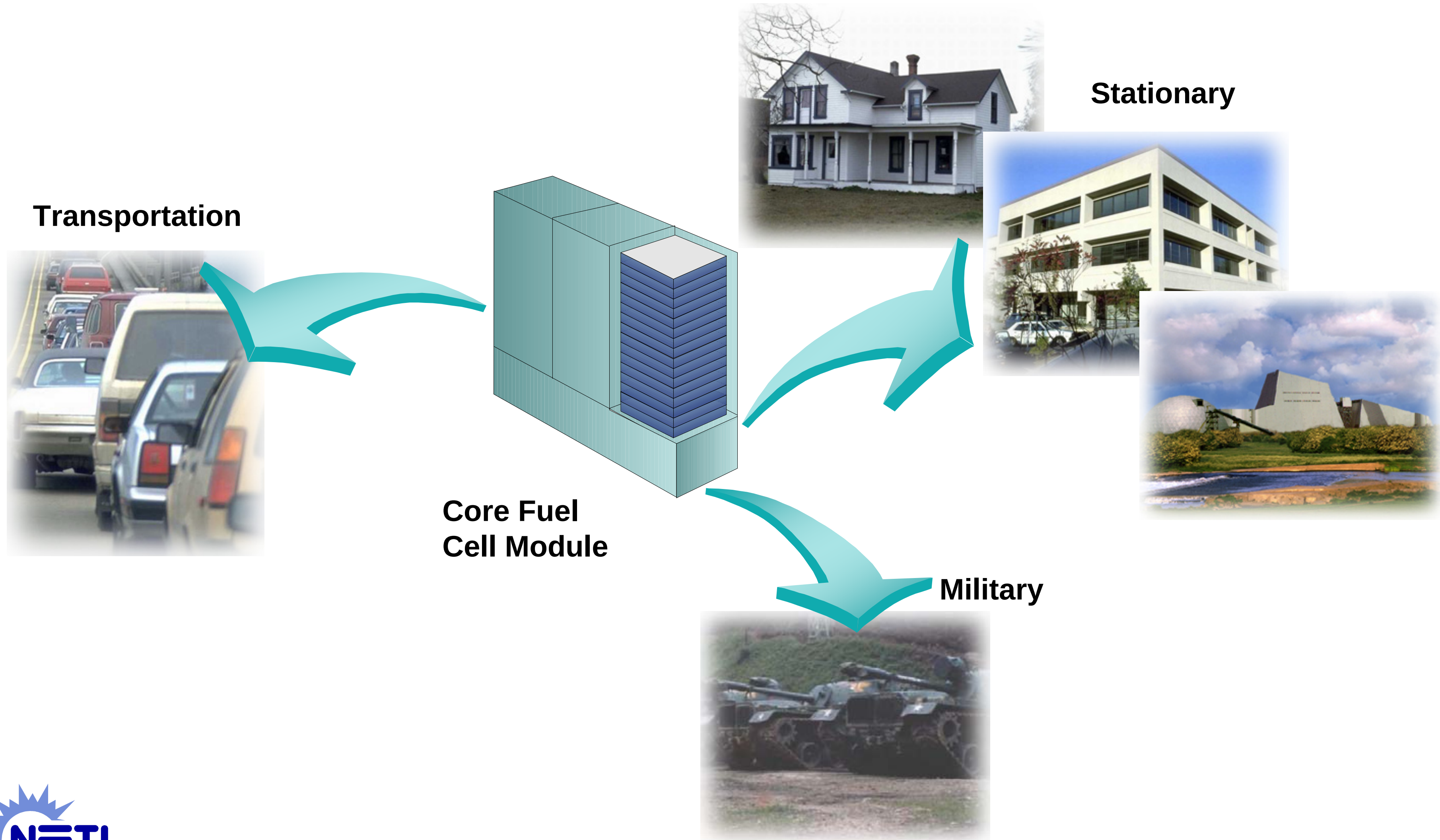
SECA Program Vision:
A Single Mass-Manufactured Core Module



SECA: A Path to Making Fuels Cells a Reality

2005

- **1st Generation Prototypes**
  - Testing & Evaluation

2010

- **$400/kW Modules**
- **Commercial products**
  - Residential, Commercial, Industrial CHP
  - Transportation APUs

2012 - 2015

- **Hybrid Testing at FutureGen**

2020

- **MW-Scale Hybrids for Advanced Coal Power Plants**

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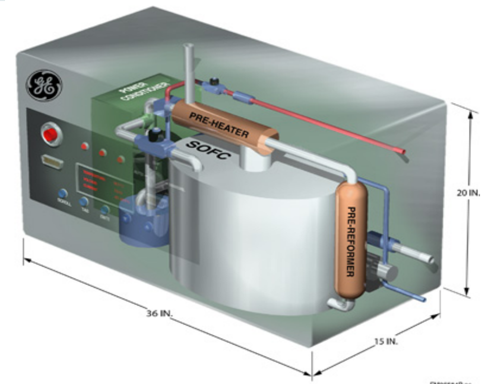
SECA Industrial Teams

FuelCell Energy

DELPHI
Driving Tomorrow's Technology

Battelle

General Electric Company



SIEMENS
Westinghouse

Acumentrics
Advanced Power & Energy Technologies

Cummins Power Generation

SOFCo EFS Holdings, LLC
Solid Oxide Fuel Cells and Fuel Processors

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Fuel Processing for SECA

Commercial fuels - A variety of development issues

Sulfur poisoning

Coke formation

High efficiency & thermal integration

Quick startup and transient response

Fuel Processing Focus Area
Technical Issues / Challenges

- **Hydrocarbon reforming is fundamentally difficult :**
  - Deactivation of fuel reforming catalysts and fuel cell anodes via carbon deposition and sulfur poisoning are a concern.
  - Improper reactant mixing can lead to hot spots and carbon deposition.
  - More complex fuels like diesel are even more difficult (relative to methane) for their propensity to form carbon.
  - Catalyst sintering (pore closure), metal vaporization, and metal agglomeration (for catalytic processes) are issues at high temperatures.

- **System complexity and cost can be a challenge:**
  - Depending on application and technology, reformer integration with fuel cell system requires potential desulfurization, water management, and thermal considerations (high efficiency).
  - Many catalytic processes are based on potentially expensive PGM / Nobel metal catalysts.

Fuel Processing Focus Area

Planning Assumptions – Core Program

- **Commercial infrastructure fuels:**
  - For the foreseeable future, fuel cells will need to utilize current infrastructure fuels (natural gas, gasoline, diesel, …) as a source of hydrogen and carbon monoxide – current focus is diesel fuel.
- **Sulfur tolerant reforming and anode catalysts :**
  - On-board or insitu sulfur removal adds a considerable cost and complexity to the fuel cell system. Most current infrastructure fuels will have very low levels of sulfur within the planning horizon of the SECA program, which should allow for a reasonable expectation of success with regard to sulfur tolerance.
- **Minimal water usage for hydrocarbon reforming:**
  - Excess water used as strategy for suppression of carbon formation. However, this increases system complexity and cost and decreases system efficiency.
  - Simplest and least cost systems utilize CPOx.
  - Use of CPOx, ATR, or steam reforming application dependent.

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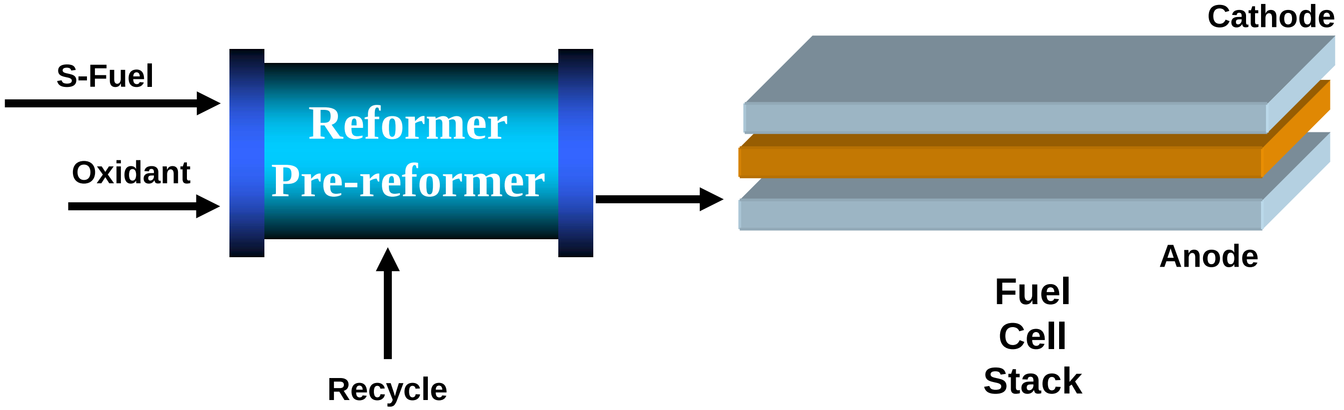
Fuel Processing for SECA
General Approach for Sulfur Containing Fuels

S-Tolerant Reformer & FC Anode:

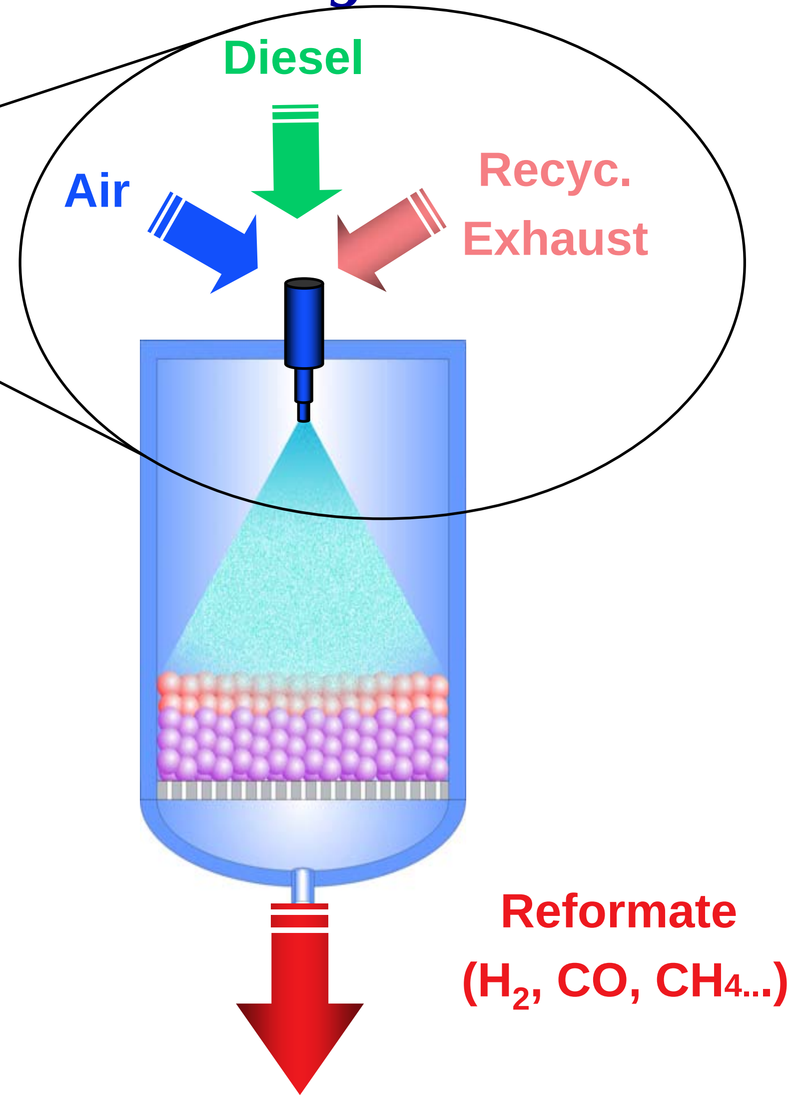


Fuel Processing for SECA
Reformer Nozzles – Reactant Mixing

Issues/Requirements:

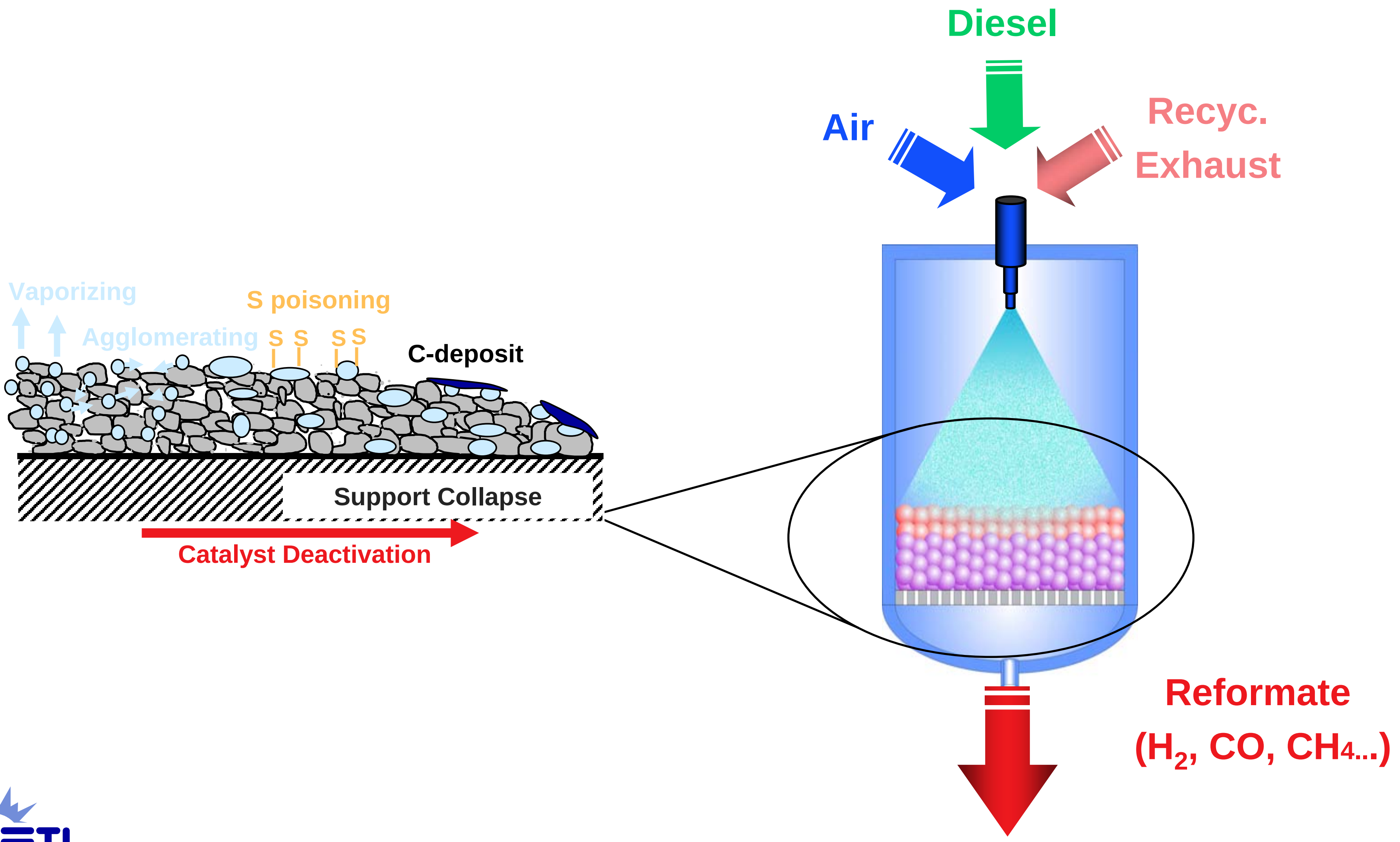
- Mixing Quality & Performance
  - Requires intimate mixing to avoid unwanted carbon / carbon precursor reactions or hot spots on reaction surface.
  - Turndown requirements may limit technology choices.
  - Fraction distillation of multi-bp component fuels like diesel difficult (Need to avoid tar & carbon formation). Temperature control critical.

Recycle & Preheat
  - Incorporation of high temperature anode recycle or preheated reactants non-trivial.

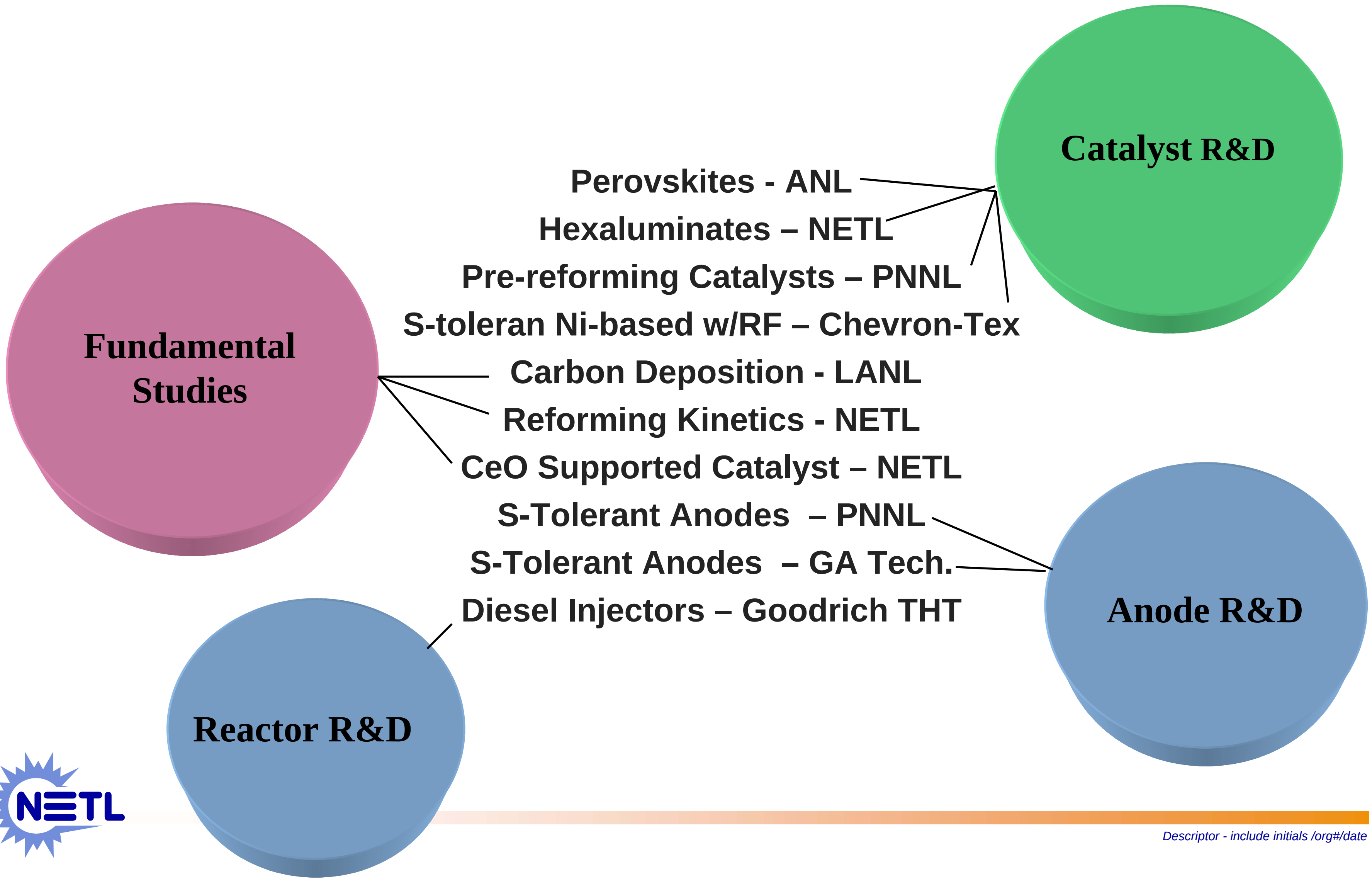


Fuel Processing for SECA

Reaction Media – Catalysts



Fuel Processing Focus Area
Current R&D Efforts in Core Program



Current Active Projects
Fuel Processing – Diesel Reforming

Chevron-Texaco
"Development of Ni-based Sulfur Resistant Catalyst for Diesel Reforming"

OBJECTIVE:

- Evaluate the use of Chevron-Texaco's proprietary Ni-based reforming catalyst for diesel fuel reforming.
- Ascertain the effectiveness or utility of radio frequency coke suppression by study of the effect of both field strength and frequency on catalyst performance and deactivation.

Current Active Projects
Fuel Processing – Diesel Reforming

Argonne National Laboratory
"Perovskite Catalyst R&D for Diesel Reforming"

OBJECTIVE:

- Evaluate the use of perovskite-based oxide materials as carbon & sulfur tolerant catalysts for the reforming of diesels .
- Evaluate the applicability of "cool-flame" technology for fuel pre-reforming.

Current Active Projects
Fuel Processing – Diesel Reforming

Los Alamos National Laboratory
"Diesel Fuel Reforming For SOFC Aux. Power Units"

OBJECTIVE:

- Evaluate the effects of sulfur-containing hydrocarbons (thiophene and dibenzothiophene) on carbon formation rate.
- Develop a catalyst sintering rate expression for a selected reforming catalyst as a function of temperature.
- Define aromatic diesel fuel component contributions to carbon formation rates

Current Active Projects

Fuel Processing – Diesel Reforming

National Energy Technology Laboratory

"Diesel Fuel Reforming R&D"

OBJECTIVE:

- Evaluate the use of hexaaluminate-based oxide materials as carbon & sulfur tolerant catalysts for the reforming of diesels .
- Investigate the behavior of oxygen-conducting materials (IE. CeO) for metal-supported catalysts.
- Develop fuel reforming kinetics / methodology for diesel CPox, SR and ATR. Characterize effects of sulfur & carbon.

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Current Active Projects
Fuel Processing - Anodes

Pacific Northwest National Laboratory
"Sulfur-tolerant SOFC Anodes"

OBJECTIVE:

- Evaluate the use of modified Ni cermet anodes for tolerance to carbon deposition & sulfur poisoning for on-cell anode methane reforming.
- Evaluate and characterize catalysts for fuel pre-reforming in supply of methane rich gas for SOFC feed.

Current Active Projects
Fuel Processing – Reformer Injectors

Goodrich TFT
"Integrated Diesel Fuel Injection & Mixing"

OBJECTIVE:

- Evaluate a variety of injector technology (piezoelectric, siphon, impinging-jet, …) for diesel fuel and reactant introduction / mixing into fuel reformers.

Current Active Projects
Fuel Processing - Anodes

Georgia Institute of Technology
"Novel Sulfur Tolerant Anode for SOFC"

OBJECTIVE:

- To evaluate a novel sulfur tolerant anode system and anode architecture.
- Conduct broad study to provide a theoretical basis for sulfur degradation processes and strategies for sulfur tolerance.
- Conduct wide range of measurements and model / predict the electrochemical reactions and transport processes within the anode.

Current Active Projects
Fuel Processing – Desulfurization (SBIR)

TDA Research Inc.

"Natural Gas Desulfurization Sorbent"

OBJECTIVE:

- Develop and demonstrate a novel high capacity sorbent for the desulfurization of natural gas.

Fuel Processing Focus Area

Current R&D Efforts in Core Program

Future Projects

Fuel Processing Focus Area
Current R&D Efforts in Core Program

FY 05 SECA Core Program Solicitation

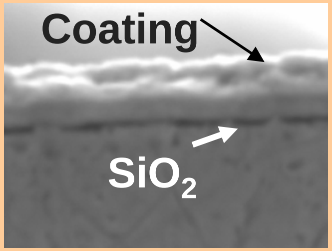
Focused on Materials & Fuel Processing:

- Seals
  - Rigid, High-Strength Sealing Concepts
  - Innovative Sealing Concepts
- Interconnect
  - Material for SOFC Cathode/Interconnect Interface
  - Identify/develop Interconnect Materials
- Electrodes
  - Infiltration of Active Elements into SOFC Electrode Structures
  - Quantification and Understanding of Cr Poisoning of Cathode Activity
- Fuel Processing
  - Sulfur and Carbon Tolerant Diesel Fuel Reformation Catalysts
  - Alternative Reforming Concepts
  - Technology for Logistic Fuel Applications

Fuel Processing Focus Area

QUESTIONS?

NETL On-site Fuel Cell Research

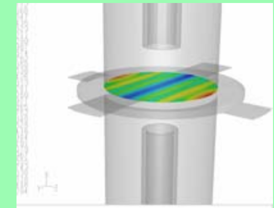


Investigation of interconnect coating/substrate degradation mechanisms

Insulating silicon layer formed below protective coating may Limit allowable metal silicon content.

Button cell testing

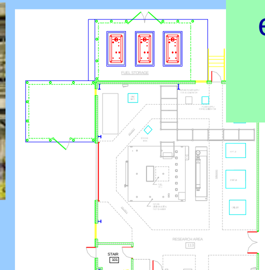
Simulation of current density concentration near collector



Investigation of current collector geometry effects on cell performance/degradation.

NETL hybrid turbine fuel cell facility to evaluate control options for hybrid generation

Investigation of hybrid turbine Fuel cell dynamics and control

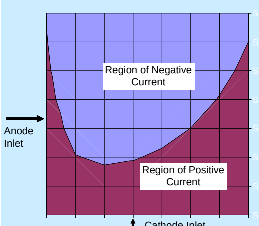


Location in NETL B-4 used for SECA prototype testing

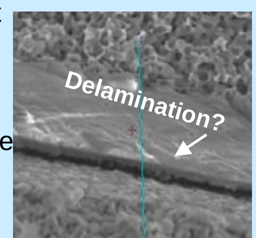
Fuel Cell Test Facility

Analytic equipment for catalyst and support evaluation

Evaluation of CeO supports and Hexaluminate supports for reforming.



Prediction of transient current reversal on SOFC (left, blue) and button cell cathode from long-term reverse current tests (right).



Analysis of load shed events on SOFC durability

Novel approach to measure In-situ strain in operating SOFC stacks (w/ Univ. Rhode Island).

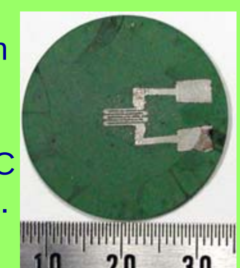


Photo of Indium Tin Oxide strain gage on NETL fuel cell button.