Systems Analysis Program Objectives & Goals

DOE Hydrogen and Fuel Cells

Sub-Programs

- Research and Development (R&D)
  - Hydrogen Fuel
    - Production
    - Delivery
    - Storage

- Safety Codes and Standards

Objectives

Through system-level approach and analysis-
- Evaluate technologies and pathways,
- Guide selection of RD&D technology approaches/options,
- Estimate potential value of RD&D efforts and targets, and
- Evaluate energy security and socio-economic benefits of the program targets.
Focus: Determine technology gaps, evaluate impacts of early stage R&D and estimate benefits of energy security and economic/job growth from key technology advances.

Number of Activities by Focus Area

- Studies & Analysis: 9
- Develop & Maintain Models: 5
- Support Functions: 6
- Systems Integration: 2

FY 2017 Appropriation = $3.0 M
**Strategy**

Support a strong foundation of data, build relevant analytical models and execute insightful integrated analyses

**Partnerships with labs, industry, academia**

### System Analysis Framework
- Consistent and transparent data
- Prioritized analysis tasks
- Organize data and results for decision making
- Effective analytical workshops to gather key input assumptions for analysis

### Models and Tools
- Life cycle analysis benefits of hydrogen and fuel cells for diverse applications
- Portfolio of validated models for near and long term analyses

### Studies and Analysis
- Initial phases of technology early market penetration
- Long-term potential and issues
- Energy security analysis
- Energy storage analysis
- Resource supply for hydrogen production
- Consumer choice and behavior impacts

### Deliverables/Results
- Support decision-making processes and milestones
- Direction, planning and resources
- Independent analysis to validate decisions
- Risk analysis of program area targets
- Sustainability metrics

**FCTO Program Collaboration and Input**

**Internal and External Peer Review**
DOE’s Fuel Cell Technologies Office model and tool portfolio is versatile, comprehensive and multi-functional.

Models and Tools:

- VISION+, SERA, ANL JOBS
- MA3T, ADOPT, VISION
- GREET
- Autonomie
- H2A, H2FAST, HDSAM

Integrated Analysis

Macro-econ. (Fin. and Employ.)

Market Penetration

Lifecycle Modeling

Vehicle Modeling and Simulation

Technology, Fuel, Infrastructure and Data

Model Description Fact Sheets: http://www.energy.gov/ere/fuelcells/systems-analysis
The FCTO analysis portfolio (left) covers the full analysis space and includes some redundancies. Some projects (e.g., GPRA, below) span all categories for a truly integrated analyses.

Example:

<table>
<thead>
<tr>
<th>Analysis Type:</th>
<th>Tech., $H_2$, Infras &amp; Data</th>
<th>VEHICLE</th>
<th>Lifecycle</th>
<th>MARKET</th>
<th>MACRO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Models:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H2A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDSAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ORNL and HyARC databases</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autonomie</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FASTSim</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GREET</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MA3T</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADOPT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SERA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JOBS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VISION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**GPRA* Integrated Analysis**

<table>
<thead>
<tr>
<th></th>
<th>DATA</th>
<th>VEHICLE</th>
<th>Life Cycle</th>
<th>MARKET</th>
<th>MACRO</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2A, HDSAM and expert input</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Autonomie</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GREET</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MA3T</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VISION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Government Performance Results Act
Hydrogen Infrastructure: Production Sites in the U.S.

U.S. annual hydrogen production

10 million metric tons

Largest Users in the U.S.

Petroleum Processing 68%
Fertilizer Production 21%
Fuel Cell Car Sales and H₂ Stations on the Rise

U.S. Fuel Cell Car Sales
Growing Exponentially

Fuel Cell Cars Sold/Leased in the U.S.

~1,800 fuel cell cars
by April 2017

Number of California Retail H₂ Stations Increasing

27 Retail H₂ stations
by April 2017

Sources: California Office of the Governor

Note: Cumulative number of vehicles sold/leased. Source: hybrid.com
Energy Security Benefits resulting from Hydrogen and Fuel Cell Technologies

Petroleum Displacement Increasing Exponentially

Energy Security: Cumulative Petroleum Displacement (thousands of gallons)

>1.7M gals. of oil reduced by 2016

Source: DOE record #16021
https://www.hydrogen.energy.gov/pdfs/16021_ghg_emissions_petroleum_reduction_from_fk.pdf

Preliminary
DOE Hydrogen and Fuel Cells Impact

Innovation

650 H₂ and fuel cells patents enabled by DOE funds

Job Potential from H₂ Refueling Infrastructure Buildout

A single H₂ fueling station creates ~52 jobs

Station development accounts for 73% of jobs; station operation for 27% of jobs

Source: ANL JOBS model and California report

Job Potential

Today

Approximately 16,000 jobs in the fuel cell car sector


Future

More than 200,000 jobs from future fuel cell car sales

Under an approximately 20% market penetration scenario.
Source: Preliminary results from employment study update (ANL)
Systems Analysis – FY16-17
Highlights Accomplishments
Techno-Economic Analysis Guides R&D Portfolio

**Fuel Cells**
- Catalyst
- Bipolar Plates
- Membranes
- BOP
- MEA
- Frames/Gaskets
- GDLs

**Focusing on**
- Low and Non PGM Catalysts,
- Alkaline Membranes

**H₂ Station**
- Storage
- Cooling
- Dispensing
- Other

**Compression**
- Advanced Compression
- Alternate Approaches

**H₂ Storage**
- BOP/Assembly
- Other processing
- Resin

**CF/Conversion**
- Low Cost Carbon Fiber (CF)
- Long term Materials Approaches
Cost Analysis and Performance Requirements Drive R&D Strategy

**FCEV Cost Reduction Pathways**

*at 100,000 units*

- **R&D Needs**
  - Catalysts, membranes, electrodes, BOP and increase in durability
  - H₂ Production, delivery and storage
  - Manufacturing R&D and processes, QC and high volume fabrication
  - Additional progress needed for ultimate targets

---

Total cost of ownership analysis identifies key R&D needs to be competitive with incumbent and other advanced technologies
Hydrogen Cost Targets and Status

Current cost of low volume dispensed H₂ (includes production and delivery) ranges from $10 – $16/gge in California.

**Objective:**
Assess the hydrogen cost for low volume production/delivery for current market applications for transportation fuel.

**Basis and Notes:**
- The cost of hydrogen is based on hydrogen produced at a central production site.
  - Delivery by gaseous or liquid truck within 200 miles at volumes of 500-1000 kg/month.
  - Production cost based on actual costs provided by industrial gas suppliers and end users.
- Hydrogen cost for compression, storage and dispensing is based on the results from H₂FIRST Station Design Report.
- Current selling price range of H₂ at public retail stations in California is $9.99-$16.00/gge (5/2017).

---

1 - Record 11007 Hydrogen Threshold Cost Calculation
2 - Record 15011 Low Volume Hydrogen Production and Delivery Cost Status
3 - Record 15012 Low-Volume Early-Market Hydrogen Cost Target
4 – Air Products and Chemicals press release 2017
Impact of FCTO Targets on Fuel Savings and Vehicle Cost Reduction

Achieving FCTO program R&D targets can reduce FCEV fuel and component manufacturing costs by $2,600 - $4,000

Baseline Assumptions
- Storage: $17/kWh @ 100k units/yr.
- Fuel cell efficiency: 59%
- Hydrogen Cost: $4/gge

Next steps to evaluate the fuel cell and storage targets versus their marginal benefits.
In a portfolio of conventional and alternative technology vehicles, FCEVs can achieve market penetration and reduce petroleum use by 300,000 – 800,000 bbls/d.

**Energy Security Analysis: Petroleum Reduction from FCTO R&D**

**Analysis basis**
- Based on combined analysis of VTO and FCTO
- FCEVs included in a portfolio of vehicles including ICEVs, HEVs, PHEVs and BEVs.

**FCEV Assumptions**

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>Program targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cells, $/kW</td>
<td>48</td>
<td>30</td>
</tr>
<tr>
<td>Storage, $/kWh</td>
<td>17</td>
<td>8</td>
</tr>
<tr>
<td>H₂ Cost, $/gge</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Infrastruct.</td>
<td>Follows Veh. penetration</td>
<td></td>
</tr>
</tbody>
</table>

Source: ANL GPRA Analysis
### Total Cost of Ownership (TCO) Difference between FCEVs and BEVs

<table>
<thead>
<tr>
<th></th>
<th>50 Miles</th>
<th>100 Miles</th>
<th>150 Miles</th>
<th>200 Miles</th>
<th>250 Miles</th>
<th>300 Miles</th>
<th>350 Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-Seaters</td>
<td>$0.05</td>
<td>$0.01</td>
<td>-$0.03</td>
<td>-$0.07</td>
<td>-$0.11</td>
<td>-$0.15</td>
<td>-$0.19</td>
</tr>
<tr>
<td>Minicompacts</td>
<td>$0.05</td>
<td>$0.02</td>
<td>-$0.01</td>
<td>-$0.04</td>
<td>-$0.07</td>
<td>-$0.10</td>
<td>-$0.13</td>
</tr>
<tr>
<td>Subcompacts</td>
<td>$0.05</td>
<td>$0.02</td>
<td>-$0.01</td>
<td>-$0.04</td>
<td>-$0.07</td>
<td>-$0.11</td>
<td>-$0.14</td>
</tr>
<tr>
<td>Compacts</td>
<td>$0.04</td>
<td>$0.01</td>
<td>-$0.02</td>
<td>-$0.06</td>
<td>-$0.09</td>
<td>-$0.12</td>
<td>-$0.15</td>
</tr>
<tr>
<td>Midsize Cars</td>
<td>$0.05</td>
<td>$0.01</td>
<td>-$0.03</td>
<td>-$0.07</td>
<td>-$0.11</td>
<td>-$0.15</td>
<td>-$0.19</td>
</tr>
<tr>
<td>Large Cars</td>
<td>$0.04</td>
<td>$0.01</td>
<td>-$0.02</td>
<td>-$0.06</td>
<td>-$0.09</td>
<td>-$0.12</td>
<td>-$0.16</td>
</tr>
<tr>
<td>Small Station Wagons</td>
<td>$0.05</td>
<td>$0.01</td>
<td>-$0.03</td>
<td>-$0.07</td>
<td>-$0.11</td>
<td>-$0.15</td>
<td>-$0.19</td>
</tr>
<tr>
<td>Pass Van</td>
<td>$0.03</td>
<td>-$0.01</td>
<td>-$0.06</td>
<td>-$0.11</td>
<td>-$0.15</td>
<td>-$0.20</td>
<td>-$0.24</td>
</tr>
<tr>
<td>SUV</td>
<td>$0.03</td>
<td>-$0.02</td>
<td>-$0.08</td>
<td>-$0.14</td>
<td>-$0.19</td>
<td>-$0.25</td>
<td>-$0.30</td>
</tr>
</tbody>
</table>

**FCEVs Favored**

**Assumptions**
- **Range:** 13,000 miles/yr.
- **BEV:**
  - Battery cost: $165/kWh
  - Electric price: $0.12/kWh
- **FCEV:**
  - Fuel cell cost: $30/kW
  - Storage: $8/kWh
  - Hydrogen cost: $2.50/gge
  - Discount rate: 7%
  - Vehicle ownership: 15 yrs.

**Source:** Market Segmentation of Light-Duty Battery Electric and Fuel Cell Electric Vehicles
U.S. has an abundance of regionally distributed domestic resources to produce fossil fuel-based and renewable hydrogen

- Hydrogen can be produced from a variety of domestic resources including natural gas, nuclear, solar, wind and biomass.
- Resources are regionally distributed to meet hydrogen demand of FCEVs.
- Ratio of projected 2040 consumption and additional resource needed to supply 60 MMT H₂/yr is shown as a factor in parenthesis below each resource label at left.
By 2050, ~260,000 Jobs Associated with FCEV Manufacturing, Distribution & Sale (MDS)

**Multi Market Scenario, Supply-Chain Employment (Direct + Indirect)**

- ~100,000 gross supply-chain jobs associated with FCEV manufacturing
- ~160,000 gross supply-chain jobs associated with FCEV distribution & sales, independent of where FCEV is assembled
H2@Scale Analysis

Phase I - Analysis
✓ Initial Step (Complete)
• Identify potential demand
• Examine supply resources
• Identify impact potential
• Identify infrastructure issues

In-depth Analysis (FY17)
• Vette initial results with stakeholders in Texas workshop
• Evaluate H₂ price requirements
• Identify supply options and costs
• Examine 3 scenarios
• Identify impact potential
• Perform stage-gate review

Additional analysis (FY18)
• Identify future scenarios
• Examine economic inertia and externalities
• Perform spatial analysis
Most counties have sufficient renewable resources. Those that do not have renewable or nuclear resources nearby.
Sustainability Analysis

Develop sustainability framework and metrics to gauge the impacts of hydrogen and fuel cell technologies

Potential H₂ and Fuel Cell Technologies

Sustainability Framework

<table>
<thead>
<tr>
<th>Energy Security</th>
<th>Employment Impacts</th>
<th>Land Use</th>
<th>Water Use and Resources</th>
</tr>
</thead>
</table>

- Lifecycle analysis of petroleum use
- Employ. demand, skillset gaps and education
- Land use for H₂ Production
- Water use for H₂ Production

Goal: Sustainability framework and metrics for H₂ and fuel cell technologies

Approach: Establish process and metrics to guide FCTO R&D goals and priorities

Sustainability Process

- Develop, evaluate, and disseminate best practices
- Identify relevant environmental/social indicators
- Identify and balance tradeoffs and synergies
- Establish baselines and set targets
- Assess progress by measuring environmental and social impacts

Source: DOE BioEnergy Technologies Office
Multiple alternative-fuel buses are projected to be cost competitive on a life-cycle basis—supporting a portfolio approach for advanced vehicle evolution.

Assumptions
- 14-year ownership
- 35,000 miles per year
- 5% discount for annual fuel costs

Vehicle Types
Ref. SI: Diesel Transit bus
Advanced battery: Transit Bus Battery
Advanced fuel cell: Transit Bus Fuel Cell
CNG: Transit Bus CN

Technology Analysis: Total Cost of Ownership for Buses

- Joint analysis project with feedback from the Vehicle Technologies
- Vehicle life cycle costs being updated based on peer reviewer input

2040 Costs

<table>
<thead>
<tr>
<th></th>
<th>FC Buses</th>
<th>BEV Buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Cost, $/kWh</td>
<td>$300</td>
<td>$250</td>
</tr>
<tr>
<td>Fuel Cell Cost, $/kW</td>
<td>$4.00</td>
<td>NA</td>
</tr>
<tr>
<td>Fuel Cost in ¢/kWh</td>
<td>18¢</td>
<td></td>
</tr>
</tbody>
</table>
Well-to-wheel analysis of GHG emissions: Medium- and heavy-duty freight trucks

Gaseous hydrogen fuel cell trucks can achieve ~40-90% GHG emissions reduction compared to diesel.

- On a tonne-mile basis, gaseous (G.H2), hydrogen fuel cell hybrid-electric trucks (Class 6 and 8) emit less WTW GHGs in comparison with baseline diesel.

- GREET model for truck analysis has been upgraded to include fuel cells for multiple classes.

Class 6 Medium-Duty Freight Truck
Well-to-Wheel GHG Emissions (kg/tonne-mile)
(Based on EPA/NHTSA Vocational - Urban)

- Fuel
- Feedstock
- Operation (PTW)

Preliminary

Source: ANL GREET model
Criteria Emissions

Criteria emissions attributed to FCEVs are significantly less than gasoline ICEVs and achieve zero emissions during idling.

In FY2017, ANL GREET model representation for criteria emissions for conventional fuel/vehicle and hydrogen/FCEVs was updated.

Assumptions

- FCEV fuel economy: 55 mpgge
- ICEV fuel economy: 26 mpgge

Source: ANL GREET model

**Significant FCEV attribute:** Criteria emissions from FCEVs during idling will be ZERO.
Emphasis in FY17

- Early market and infrastructure analysis
- Life-cycle analyses of cost, petroleum use, and water use.
- Assess programmatic impacts on market penetration, job creation, and return on investment.
- Evaluate sustainability framework and metrics for FCTO

<table>
<thead>
<tr>
<th>FY 2017</th>
<th>FY 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Gaps and drivers for early market infrastructure cost</td>
<td>• Gaps and drivers for program R&amp;D</td>
</tr>
<tr>
<td>• Employment study - national employment impacts</td>
<td>• Program R&amp;D target impact assessment and integrated analysis</td>
</tr>
<tr>
<td>• Sustainability metrics for FCTO</td>
<td>• Energy security impact of FCTO targets and programs</td>
</tr>
<tr>
<td>• GHGs for medium &amp; heavy duty trucks</td>
<td>• Sustainability metrics for FCTO</td>
</tr>
<tr>
<td>• Integrate consumer choice in vehicle market penetration</td>
<td>• Target and metric assessment for medium &amp; heavy duty trucks</td>
</tr>
<tr>
<td></td>
<td>• H2@Scale analysis</td>
</tr>
</tbody>
</table>
Collaborations

Analysis and peer review input coordinated among national and international organizations.

EXTERNAL INPUT
- H2USA
- CAFCP
- HTAC
- NRC
- AMR

Collaboration
- Canada
- China
- DOD/VA

DOE-EERE Systems Analysis Activities

NATIONAL LABS
- Analysis Support
- Model Development and Support

OTHER EERE OFFICES
- VTO
- BETO
- Renewables

FCTO Program Areas

Industry
- OEMs
  Domestic & International
- Industrial Gas Companies
- USDRIVE Tech Teams
# Contacts

*For more information contact:*

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Phone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fred Joseck</td>
<td>Team Lead</td>
<td>202-586-7932</td>
<td><a href="mailto:fred.joseck@ee.doe.gov">fred.joseck@ee.doe.gov</a></td>
</tr>
<tr>
<td>John Stevens</td>
<td>!NEW!</td>
<td>202-586-7925</td>
<td><a href="mailto:john.stevens@ee.doe.gov">john.stevens@ee.doe.gov</a></td>
</tr>
<tr>
<td>Shawna McQueen</td>
<td>!NEW!</td>
<td>202-586-0833</td>
<td><a href="mailto:shawna.mcqueen@ee.doe.gov">shawna.mcqueen@ee.doe.gov</a></td>
</tr>
<tr>
<td>Vanessa Trejos</td>
<td>Support Contractor</td>
<td>202-586-5153</td>
<td><a href="mailto:vanessa.trejos@ee.doe.gov">vanessa.trejos@ee.doe.gov</a></td>
</tr>
<tr>
<td>Tien Nguyen</td>
<td>!RETIRED!</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>