One Step Hydrogen Generation Through Sorption Enhanced Reforming

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Gas Technology Institute

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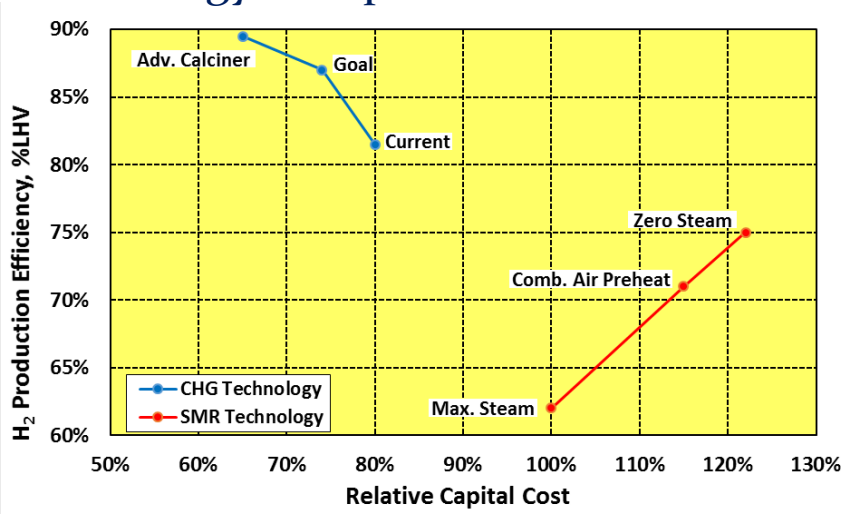
Project Objective

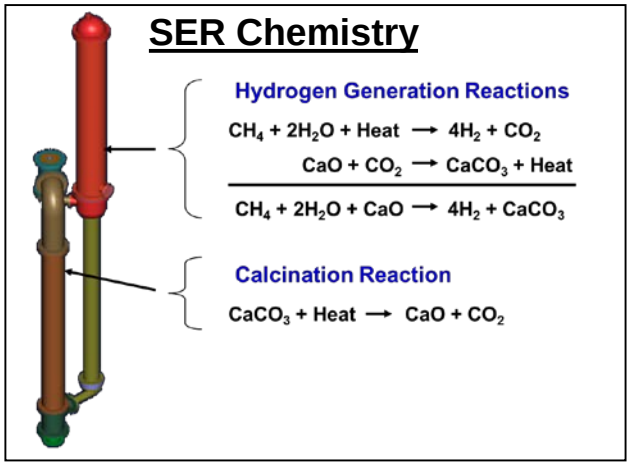
- Develop low-cost hydrogen production technology, utilizing Sorption Enhanced Reforming (SER), for large-scale commercial applications
  - Reducing cost of hydrogen by 15-20% vs. current technology
  - Reducing cost of carbon capture from natural gas feedstock
- Improve the Technology Readiness Level (TRL) from 4 to 6
- Develop a robust SER process and associated solids handling for fine, reacting sorbent particles

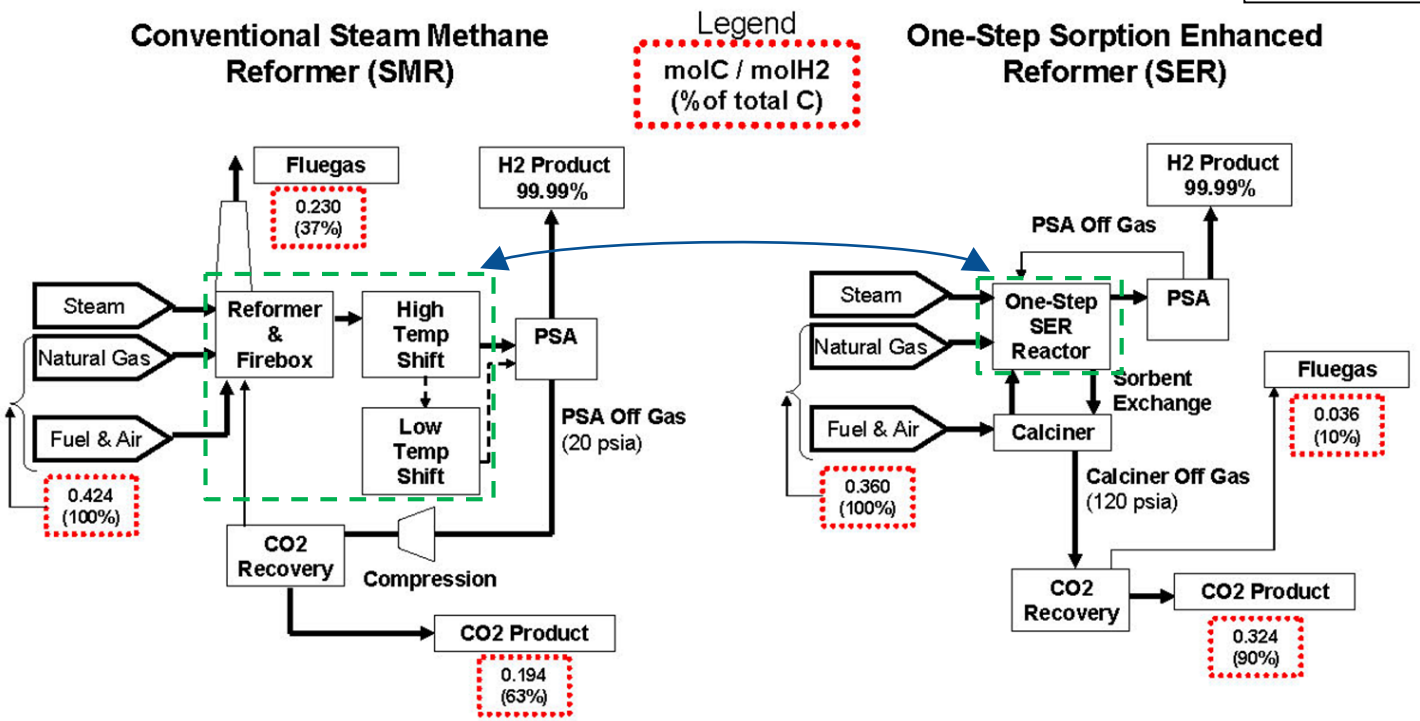
Technology Comparison: CHG vs. SMR



Technical Innovation

- Conventional hydrogen production uses Steam Methane Reforming (SMR)
- SER combines the reforming and water-gas shift processes into one-step (i.e., in the same vessel)
  - Sorbent balances heat necessary for reforming-eliminating costly SMR firebox and convective heat exchanger





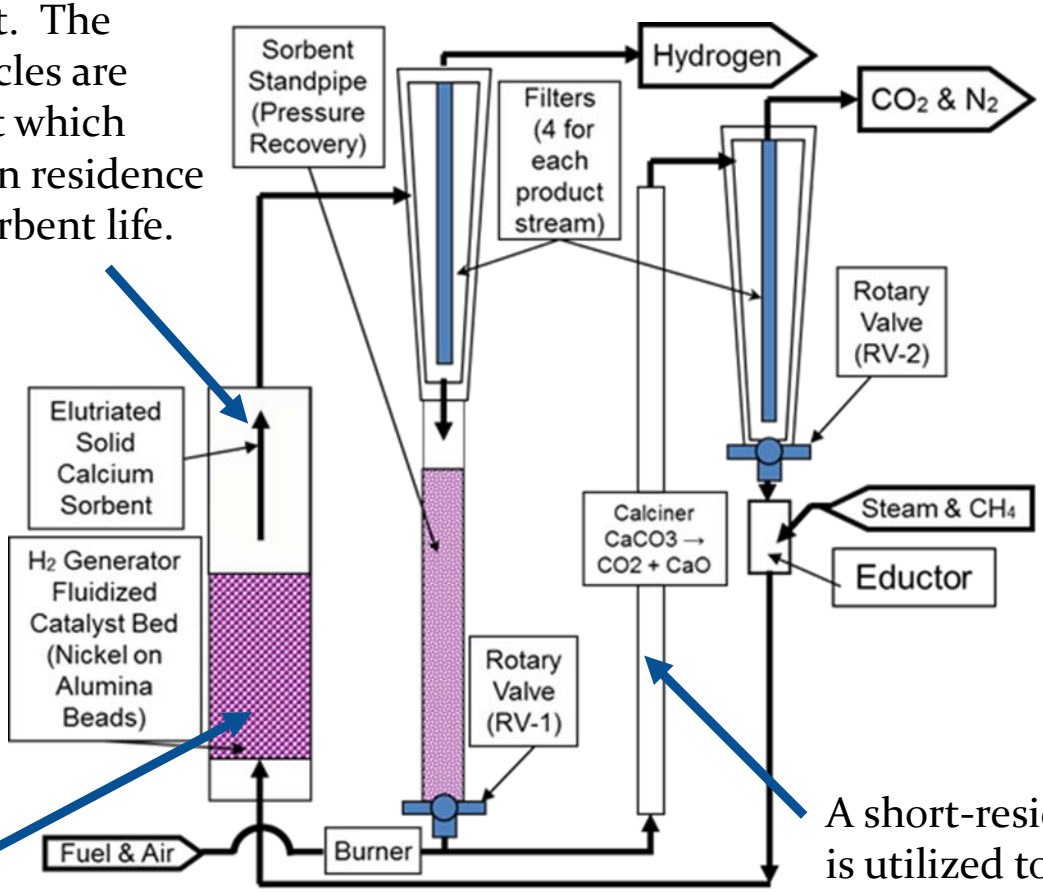
Benefits

Lower capital cost and higher efficiency result in lower cost of hydrogen

Separate CO_2 stream arising from calcination reduces CO_2 capture costs

Technical Innovation

A process which enables the sorbent to flow through a bubbling fluidized bed of catalyst. The elutriated sorbent particles are hindered by the catalyst which provides ~10x increase in residence time, thus extending sorbent life.



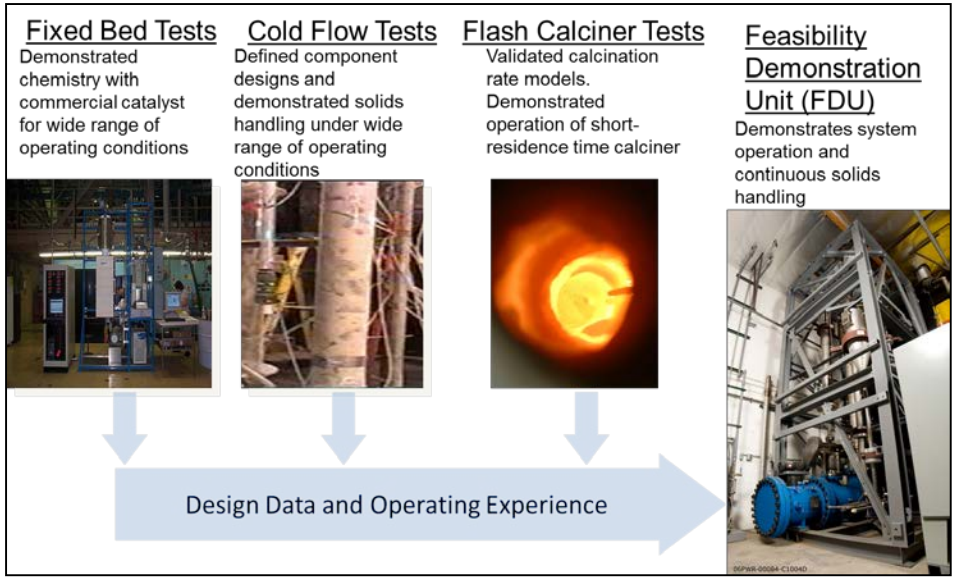
A high aspect ratio bubbling-bed, which increases the overall reactivity of the reactor

A short-residence time calciner is utilized to minimize "time at temperature" of the sorbent, and extends its reactivity (seconds vs. minutes)

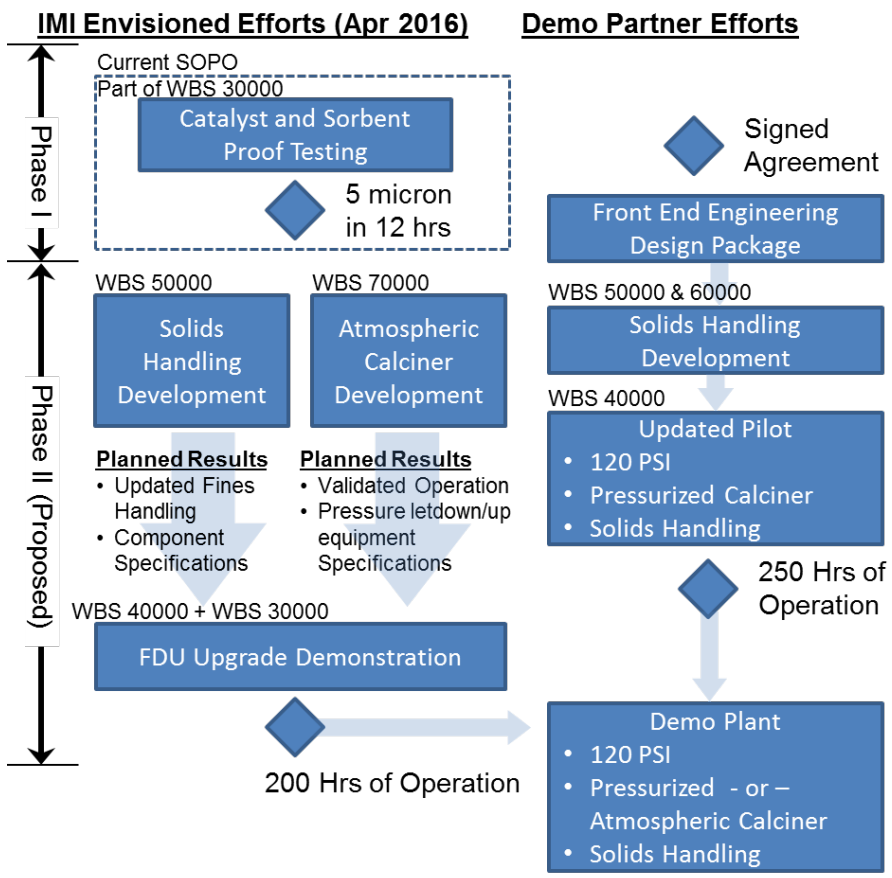
Technical Approach

- Actively pursue input from industrial gas suppliers and EPC's to validate the technology
- Leverage existing development assets and partners to develop and commercialize product

Technology Development History

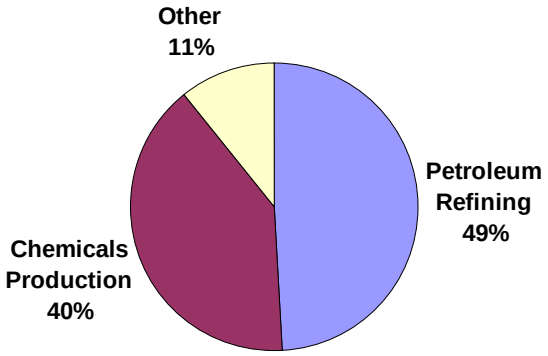


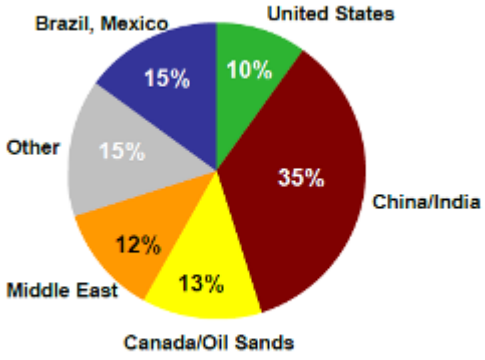
Go-Forward Approach



Transition and Deployment

Hydrogen Demand[3]





% of New H_2 Demand by Region

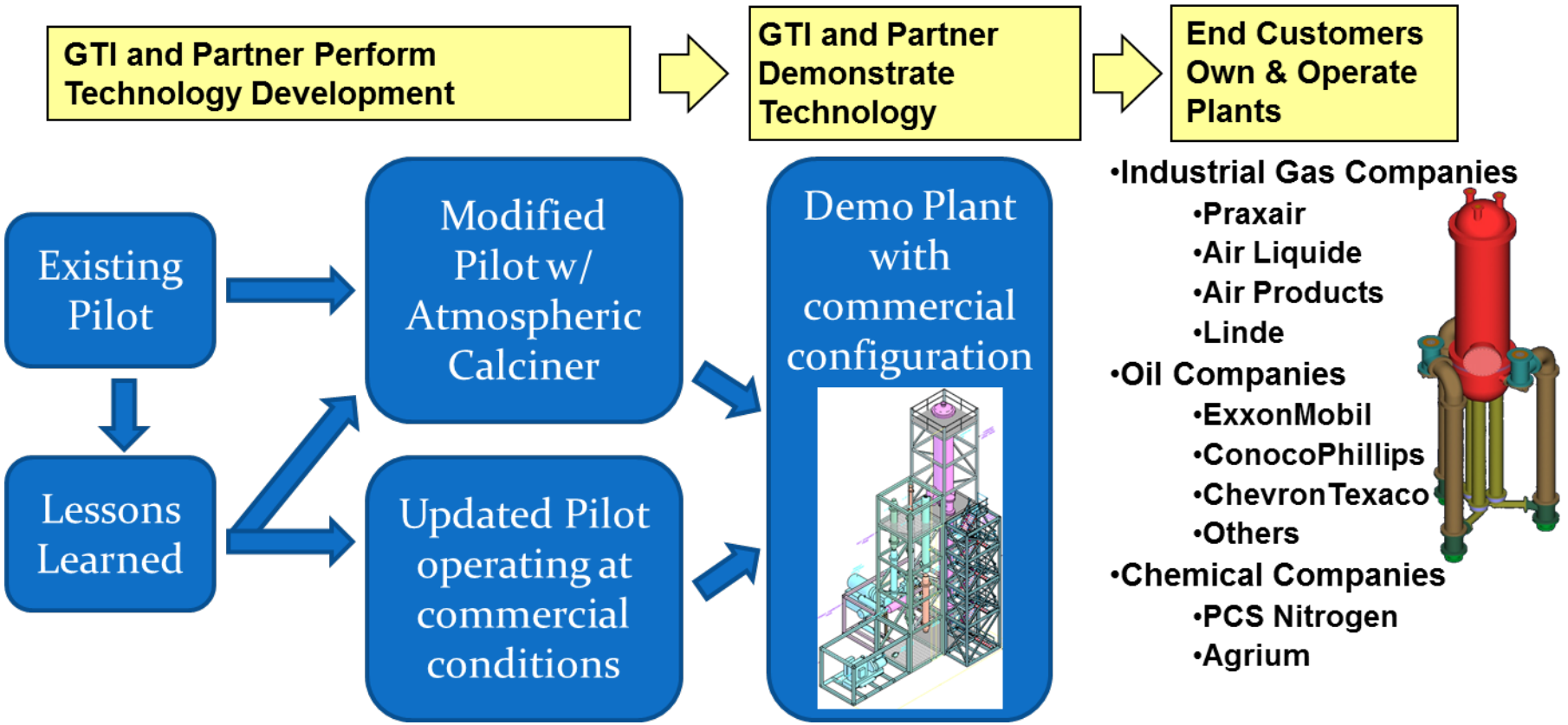
- Overall hydrogen market size is between $60B - $90B[1]
- Hydrogen equipment market size is between $3B-$4.5B
- Annual market growth ranges from 7%-15%[2]

[1] *Based on a average value of $2.00 - $3.00 Mscfd, where M represents thousands*
[2] *March 2010 Praxair CFO Presentation*
[3] *Hydrogen and Synthesis Gas, SFA Pacific, Inc., 1998 and March 2010 Praxair CFO Presentation*

- Hydrogen end-users benefit from process intensification
  - Reduced hydrogen cost through:
    - Lower capital cost
    - Improved efficiency
    - Smaller Footprint

Large market, growing at steady rate

Transition and Deployment



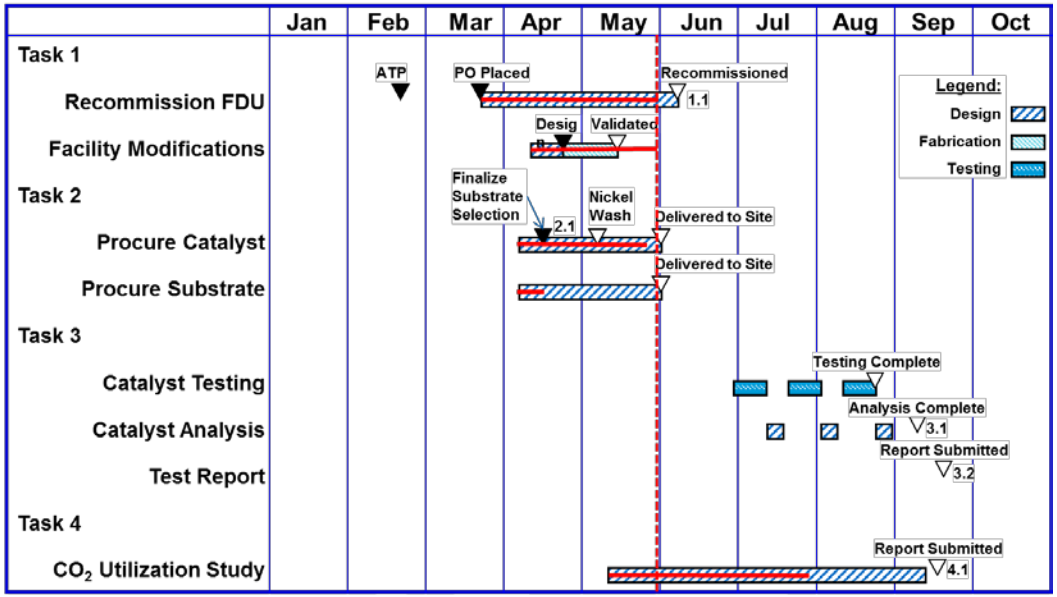
- Utilize continuous improvement process for technology sustainment
  - Separate technology improvement budget will be jointly funded with licensing revenues

Measure of Success

- Successful deployment of CHG technology will reduce cost of hydrogen, provide lower cost CO2 capture, and lead to additional market penetration due to compactness (e.g., debottlenecking, oil sands in-field upgrading)
- Success will be measured through an increase in market share against SMR's (projected to be 26% share in 10 years)
  - Equates to energy savings of 43.6 Trillion BTU/year
- Increased global marketshare results in more U.S. jobs in engineering and manufacturing of special equipment

Project Management & Budget

- Project Duration = 9 Months
- Project Performance: Schedule = 96% (behind), Cost = 105% (under budget)



Total Project Budget	
DOE Investment	$630,868
Cost Share	$651,377
Project Total	$1,282,245

Results and Accomplishments

- Only 3 months into the project, major progress:
  - Pilot Plant recommissioning 95% complete
  - 2 of 3 catalyst candidates procured
  - CO_2 co-production discussed with Oil Sands companies
- Work to be completed:
  - Complete recommissioning effort
  - Demonstrate catalyst performance
  - Evaluate Urea production applicability for CO_2 co-production study