One Step Hydrogen Generation Through Sorption Enhanced Reforming

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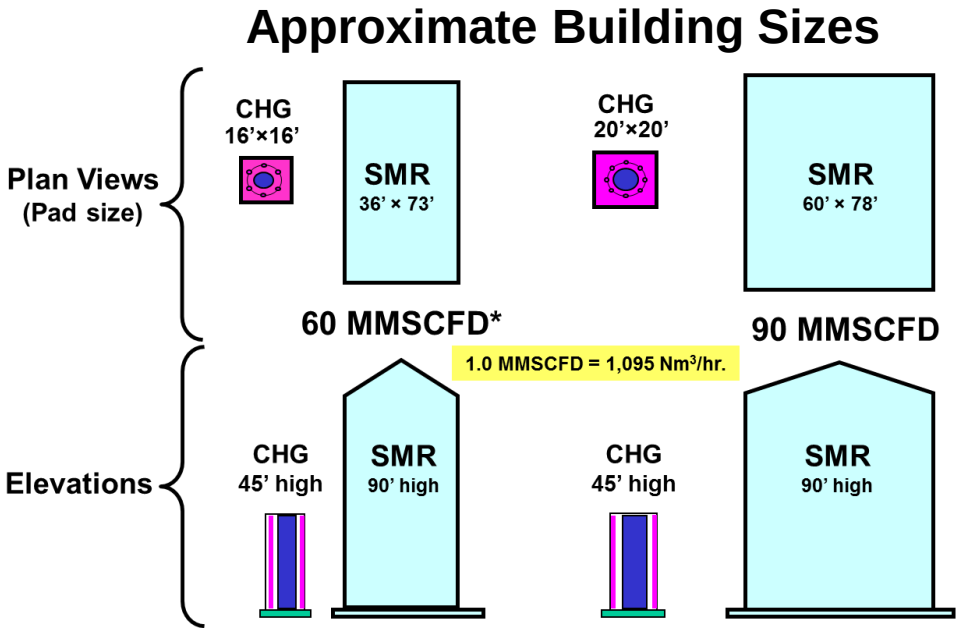
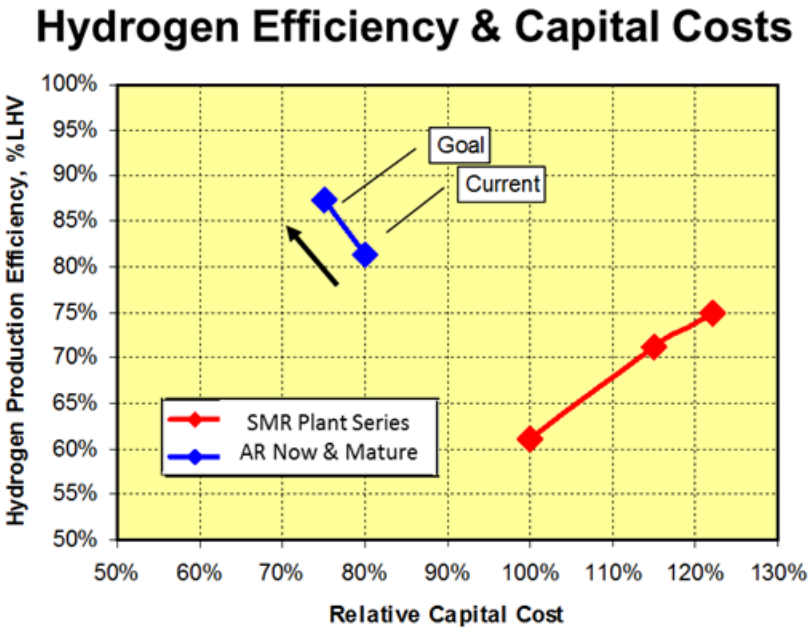
Project Objective

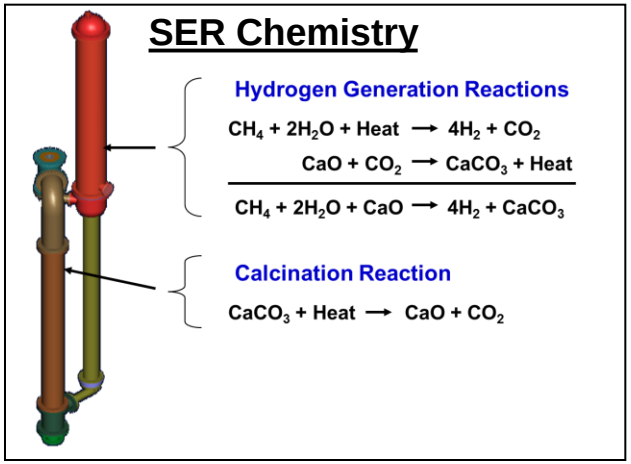
- Develop compact, hydrogen production technology for large-scale applications
  - Reduces cost of hydrogen by 15-20% vs. current technology
  - Reduces cost of carbon dioxide capture
- Mature Technology Readiness Level (TRL) of the Sorbent Enhanced Reforming (SER) process from 4 to 6

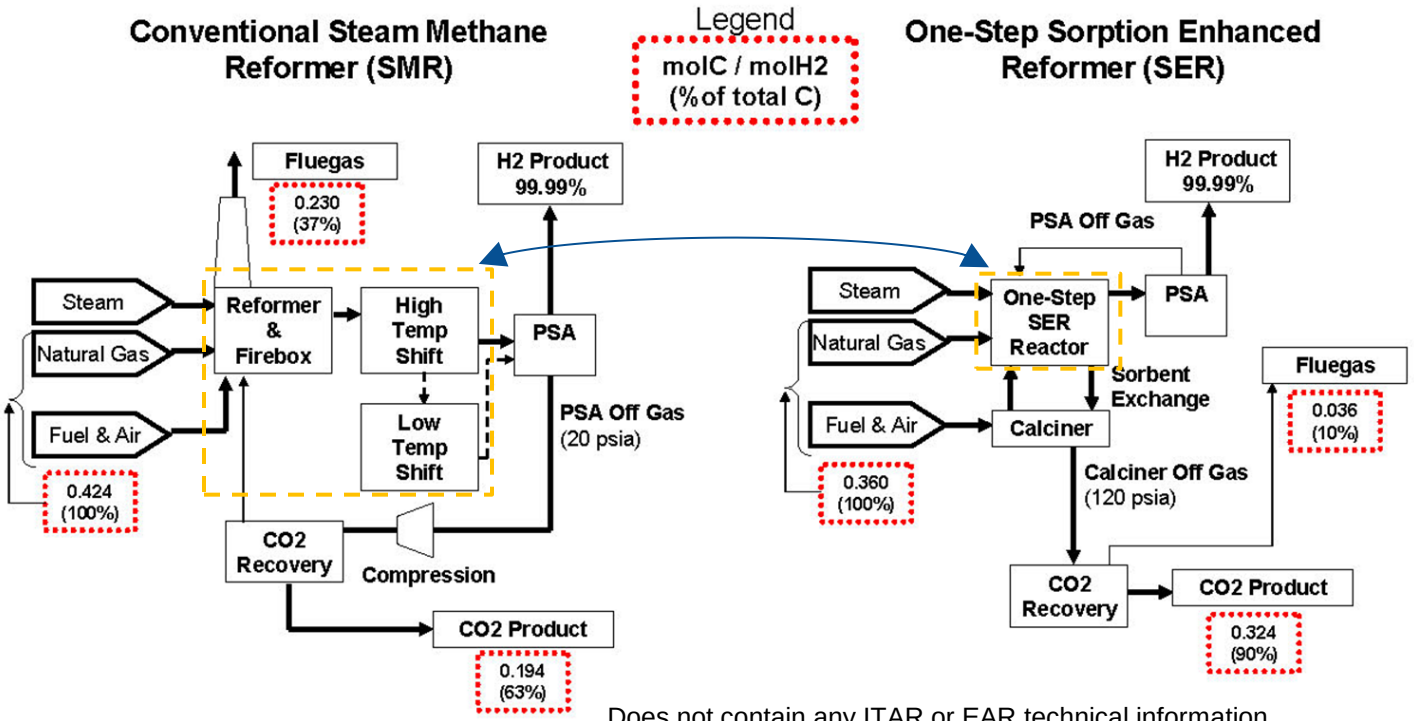




Technical Approach

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





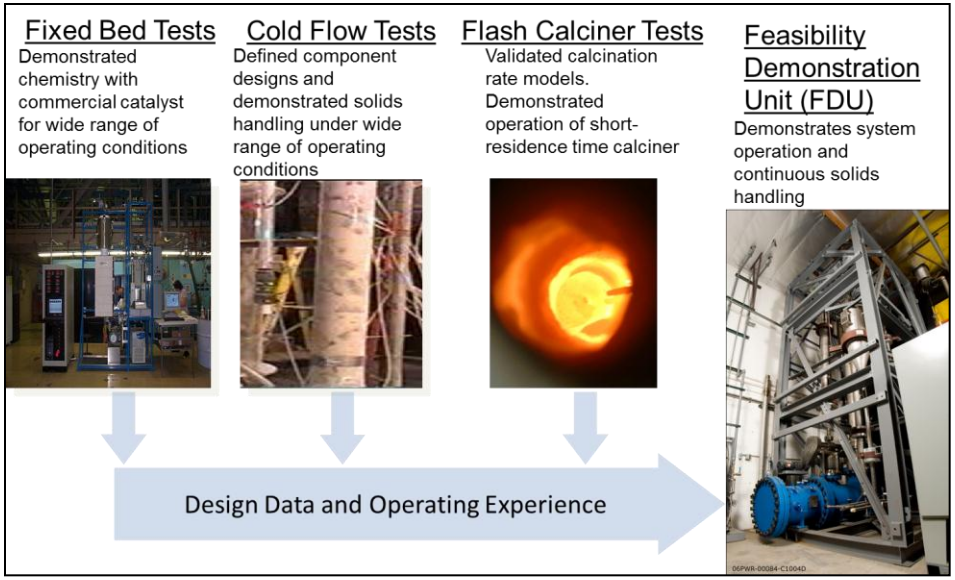
Benefits

- Lower capital cost and higher efficiency result in lower cost of hydrogen
- Separate CO2 stream arising from calcination reduces CO2 capture costs

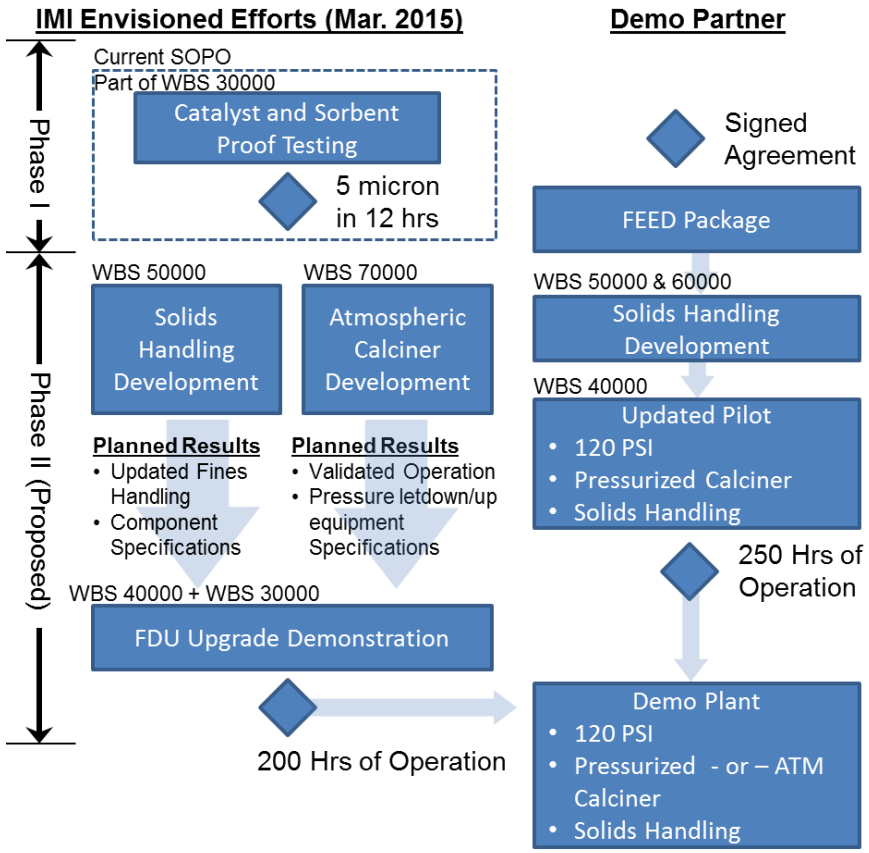
Technical Approach

- 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

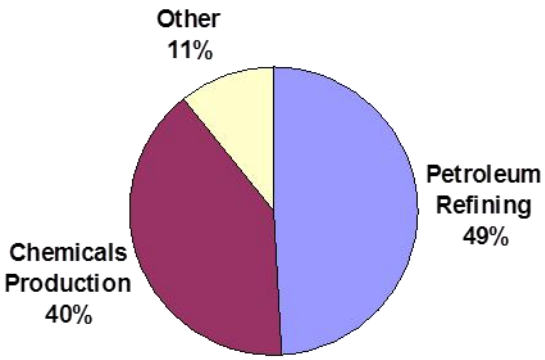


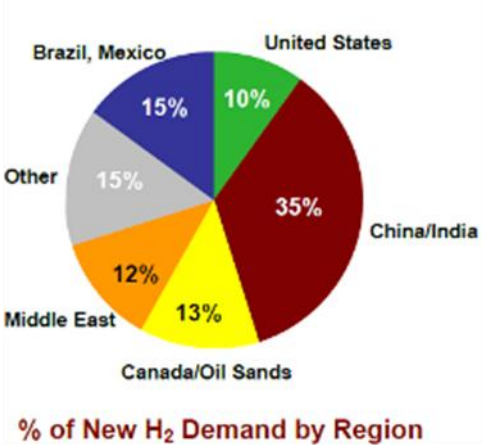
Go-Forward Approach



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
  - Improved efficiency
  - Smaller Footprint

Large market, growing at steady rate

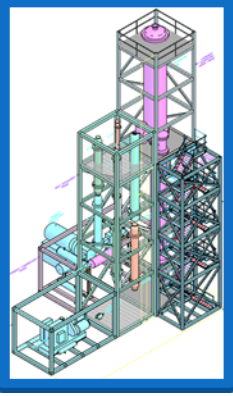
Transition and Deployment

AR and Partner Perform Technology Development → AR and Partner finalize commercial plant configuration. → End Customers Own & Operate Plants

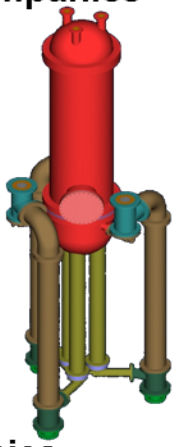
Existing Pilot → Modified Pilot w/ Atmospheric Calciner

Lessons Learned → Updated Pilot operating at commercial conditions

Modified Pilot w/ Atmospheric Calciner + Updated Pilot operating at commercial conditions → Demo Plant with commercial configuration



- Industrial Gas Companies
  - Praxair
  - Air Liquide
  - Air Products
  - Linde
- Oil Companies
  - ExxonMobil
  - ConocoPhillips
  - ChevronTexaco
  - Others
- Chemical Companies
  - PCS Nitrogen
  - Agrium



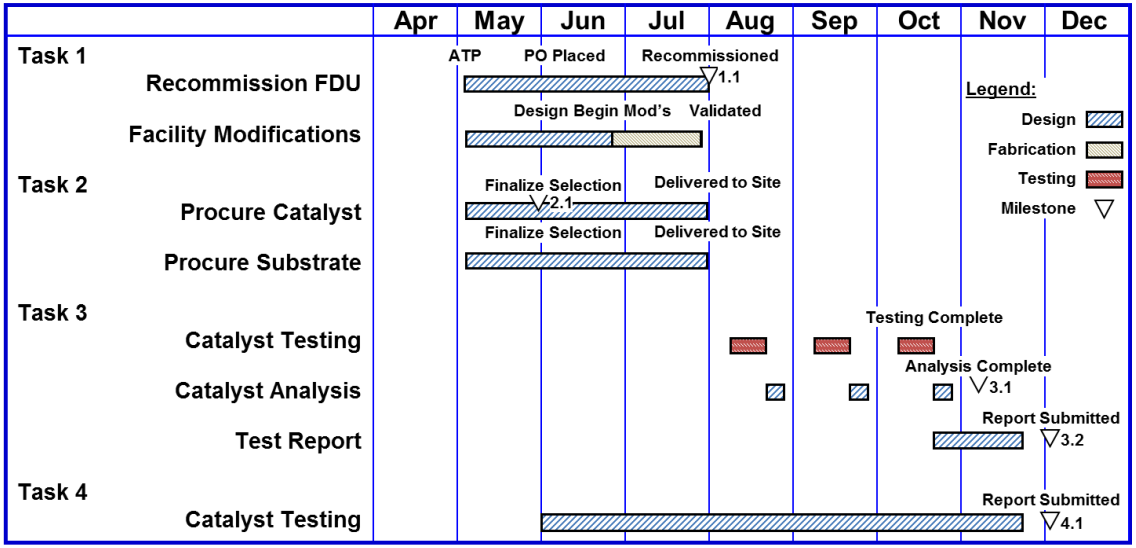
- Utilize continuous improvement process for technology sustainment
  - Separate technology improvement budget will be jointly funded with licensing revenues

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., 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 for manufacturing of special equipment and engineering

Project Management & Budget- Phase I

- Project Duration = Nine Months
- An earned value system will be used to assess progress and performance of the project



Phase I Project Budget	
DOE Investment	$750,000
Cost Share	$401,444
Total	$1,151,444

Does not contain any ITAR or EAR technical information

Results and Accomplishments

- At time of submittal, contract start is still pending
- Accomplishments, prior to contract:
  - Equipment and facilities have been commissioned
  - >50 hours of SER hydrogen (>80% purity)
    - With >24 hours continuous hydrogen production
  - >90 hours of solids circulation
- Expected Phase I results:
  - Demonstrate 3 different catalyst substrates and inspect for significant coating generation for a 12 hour period of SER-mode operation