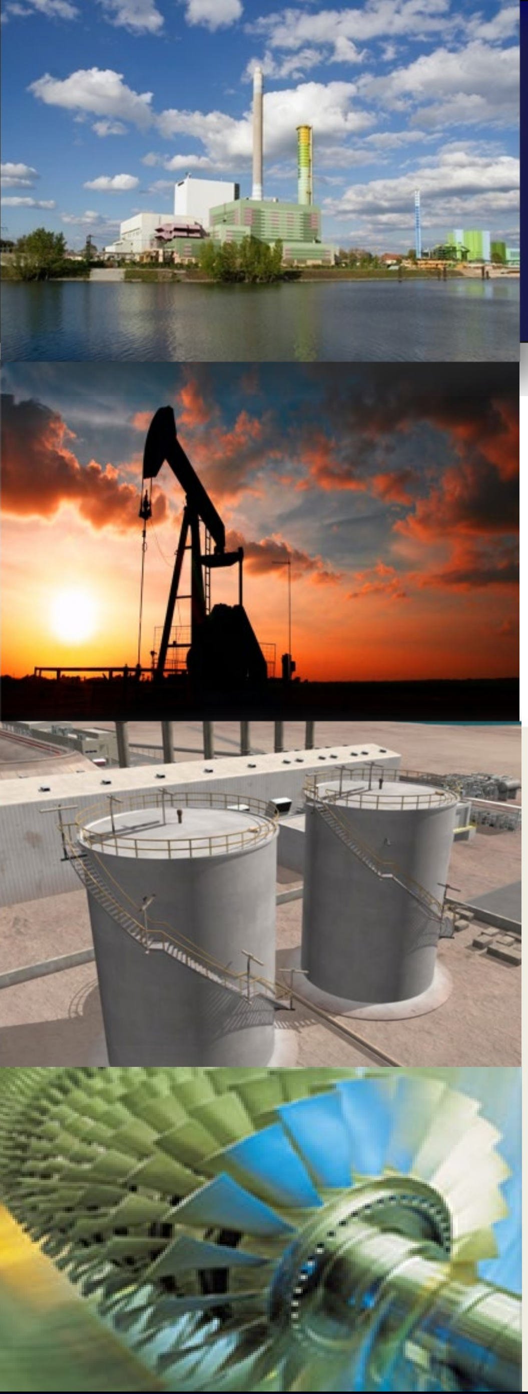


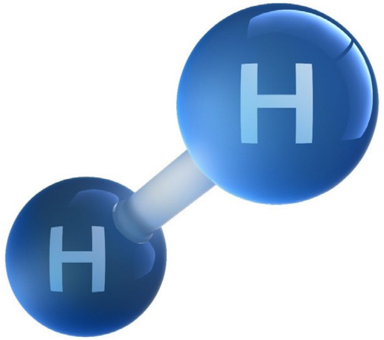
U.S. DEPARTMENT OF ENERGY | Office of Fossil Energy

Hydrogen Strategy
Office of Clean Coal and Carbon Management

John Litynski
Deputy Director
Advanced Fossil Technology Systems

Regis Conrad
Division Director
Advanced Energy Systems

July 23, 2020 | Hydrogen Workshop | USEA



Office of Clean Coal and Carbon Management

Mission:

Discover and develop advanced coal technologies that ensure America’s access to resilient, affordable, reliable, and carbon neutral emitting coal energy resources

R&D Priorities:

1. Advancing small-scale modular coal plants of the future, which are highly efficient and flexible, generate electricity and hydrogen, with carbon-neutral emissions
2. Creating new market opportunities for coal
3. Reducing the cost of carbon capture

HOLISTIC APPROACH TO ENERGY GENERATION FROM FOSSIL FUELS

21st Century Power Plants - Coal FIRST: Enabling a Carbon Free Hydrogen Economy

(Flexible, Innovative, Resilient, Small, Transformative)

- **Carbon neutral, including net negative CO_2 emissions with co-firing coal and biomass,** power plant **R&D effort in the world**
- **Capable of producing power and/or hydrogen** for polygeneration
- **Coal, biomass, and plastics with CCUS excellent and economical feedstocks for hydrogen**
- **Contributes to IEA minimum cost scenario** for deep CO_2 emissions -- **carbon capture**
- Provides **low cost power generation**; economically competitive
- Potential to **sustain U.S. coal communities**; provide a source of **high value exports**

Carbon neutral Emissions
Negative CO_2 emissions when co-firing biomass

Flexible **coal plant operations to meet the needs of the grid**

Transforms **how coal technologies are designed and manufactured**

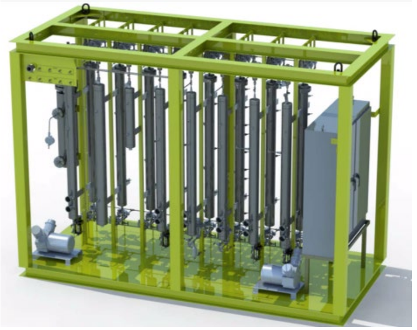
Innovative **and cutting-edge components; improved efficiency and carbon neutral emissions**

Smaller **than conventional utility-scale coal plants**

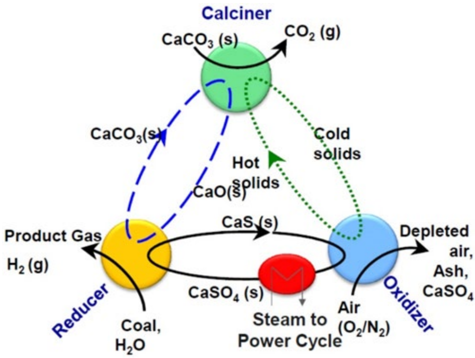
Resilient **power generation**

Existing Gasification R&D—H_2 Production

Recent DOE/NETL supported work—innovative WGS & process integration focus



- TDA developed integrated water-gas shift with pre-combustion CO_2 capture technology (alternative to conventional multi-stage WGS with inter-stage cooling followed by CO_2 removal)
- RTI developed Warm Syngas Cleanup (WGCU) integrated with novel water-gas shift technology (for high H_2 syngas production)
- Alstom's limestone chemical looping gasification (LCL-G™) process (for H_2 or high H_2 syngas generation) using limestones
- Ohio State's syngas chemical looping for H_2 production using iron oxide based oxygen carrier
- Praxair's advanced H_2 transport membranes for coal gasification
- Kentucky CAER chemical looping with spouting fluidized bed for H_2-rich syngas production from catalytic coal gasification
- Kentucky CAER chemical looping with spouting fluidized bed for H_2-rich syngas production from catalytic coal gasification
- GTI's Hybrid Molten Bed (HMB) gasifier for high H_2 syngas production
- Small modular gasifier design and Air separation



Pre-Combustion Capture Technologies – Reduce Cost of Capture in Gasification

DOE has been working on cleanup of syngas streams for many years. Numerous tests have been conducted at the NCCC, a recent shift in focus is toward polygen and H_2.

Recent example of R&D activities:

- **TDA** Sulfur & carbon capture process based on WGS with a physical adsorbent to eliminate CO_2 emissions from a coal-based polygen system.

Trig Gasifier at the NC3

- **MPT** Microporous ceramic membranes have been proven to be low cost, stable material for high temp. application.
- **Air Products –** Port Arthur PSA sorbent modules - Commercial Demonstration

Future of Gasification with MSW and Plastics

Alternative feedstock & blending possibilities

- Low-cost localized sources

Syngas can:

- Produce heat and/or power
- Provide higher value products

Environmental Benefits

- Reduce landfill burden
- Sustainable waste to energy

Innovating New Approaches in Gasification

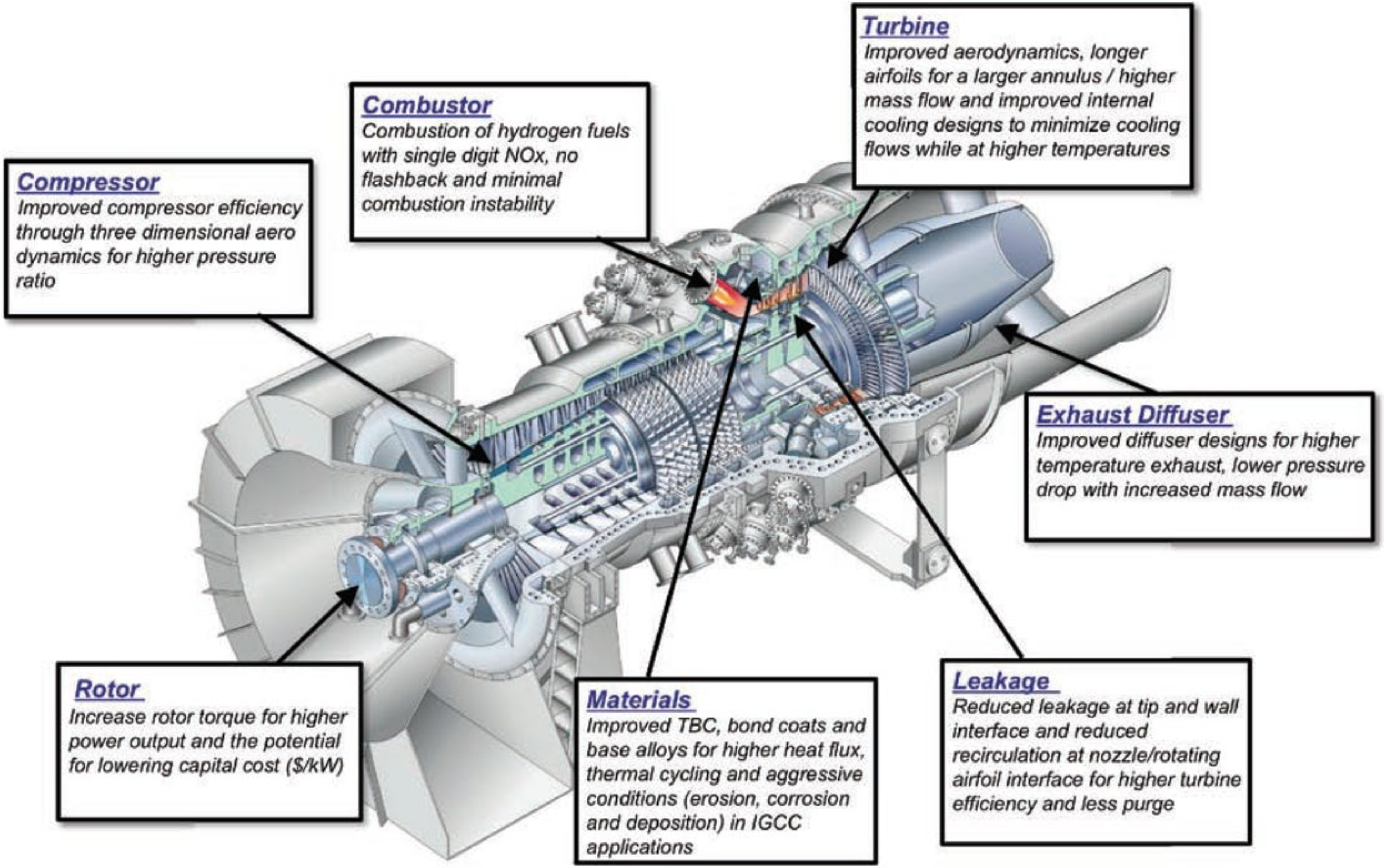
Low cost oxygen enables:

- Low cost pre-combustion carbon capture
- Low cost feedstock (e.g. MSW)

Future work – where are we heading?

- Waste Plastics as Gasifier Feedstock
- Pre-combustion carbon capture technologies
- Negative CO_2 w/ Biomass Blending
- Ultra High-Pressure Gasifier
- Microwave assisted gasification systems
- Materials development (extreme materials and catalysts)

Hydrogen Turbine Systems Affected



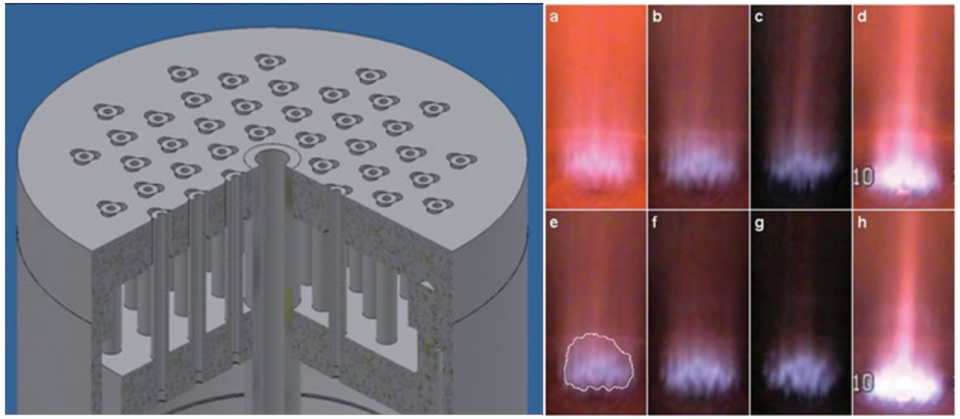
These combustion turbine systems are affected by firing with H_2 instead of natural gas.

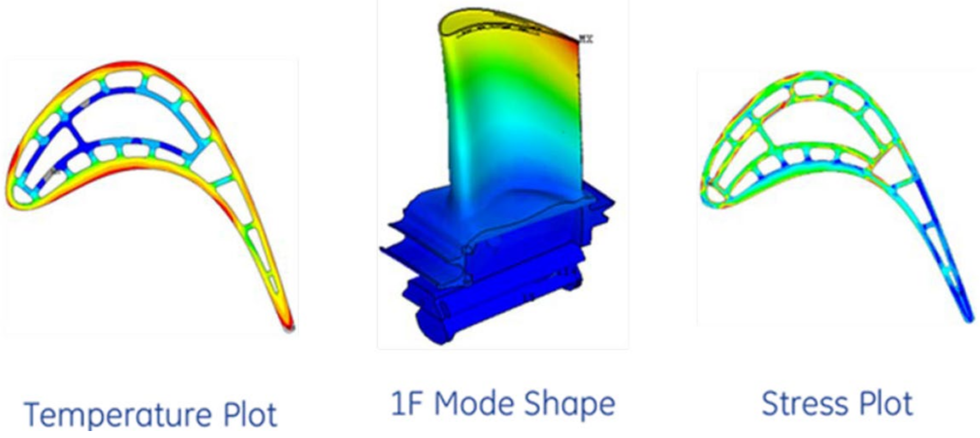
Technical challenges are due in part to H_2 characteristics:

- ❑ High flame speed
- ❑ Broad flammability limits
- ❑ Low density
- ❑ Low volumetric energy content (Btu/ft^3)
- ❑ High mass energy content (Btu/lb)
- ❑ Low ignition energy

Hydrogen Turbine R&D Planned by FE

- Science and engineering knowledge of stable high temperature, low NO_x hydrogen combustion.
- Combustion of carbon neutral fuels (i.e. NH_3, ethanol vapor).
- Apply H_2 combustion engineering to utility scale and aero derivative machines.
- Develop and test hydrogen combustion retrofit packages.
- Apply advanced manufacturing for hydrogen combustors.
- Apply and develop advanced CFD with reacting flows.
- Develop control strategies and instrumentation.
- Assess and mitigate moisture content effects on heat transfer and ceramic recession.
- Aim for 100% hydrogen machine.





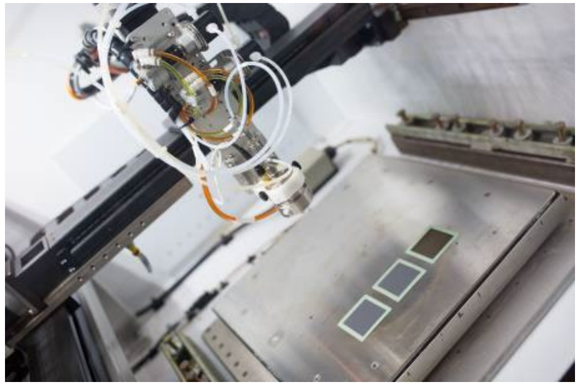
Reversible Solid Oxide Electrolysis Cell (SOEC)-RSOFC

- Attractive option to produce hydrogen at high efficiency – higher the operating temperature, higher the efficiency

- Reversing the operation of a solid oxide fuel cell (SOFC) system

- SOEC system is supplied with electricity and water (steam) to produce hydrogen, oxygen and heat

- Hydrogen in turn, can be used to produce power again - potential to provide a significant means for energy storage



Reversible Solid Oxide Electrolysis Cell (SOEC)-RSOFC

- **SOECs have similar materials set as SOFCs**
  - Dense, thin and chemically stable ionic conductor as electrolyte
  - Porous electrodes
  - Dense, thin and chemically stable electronic conductor as interconnect between cells
- **SOECs share the similar stack design as SOFCs**
- **Potential for hybrid systems to produce hydrogen in SOEC mode and electricity in SOFC mode**

Prior and on-going SOFC R&D supported by FE will provide the technology basis for SOEC development going forward

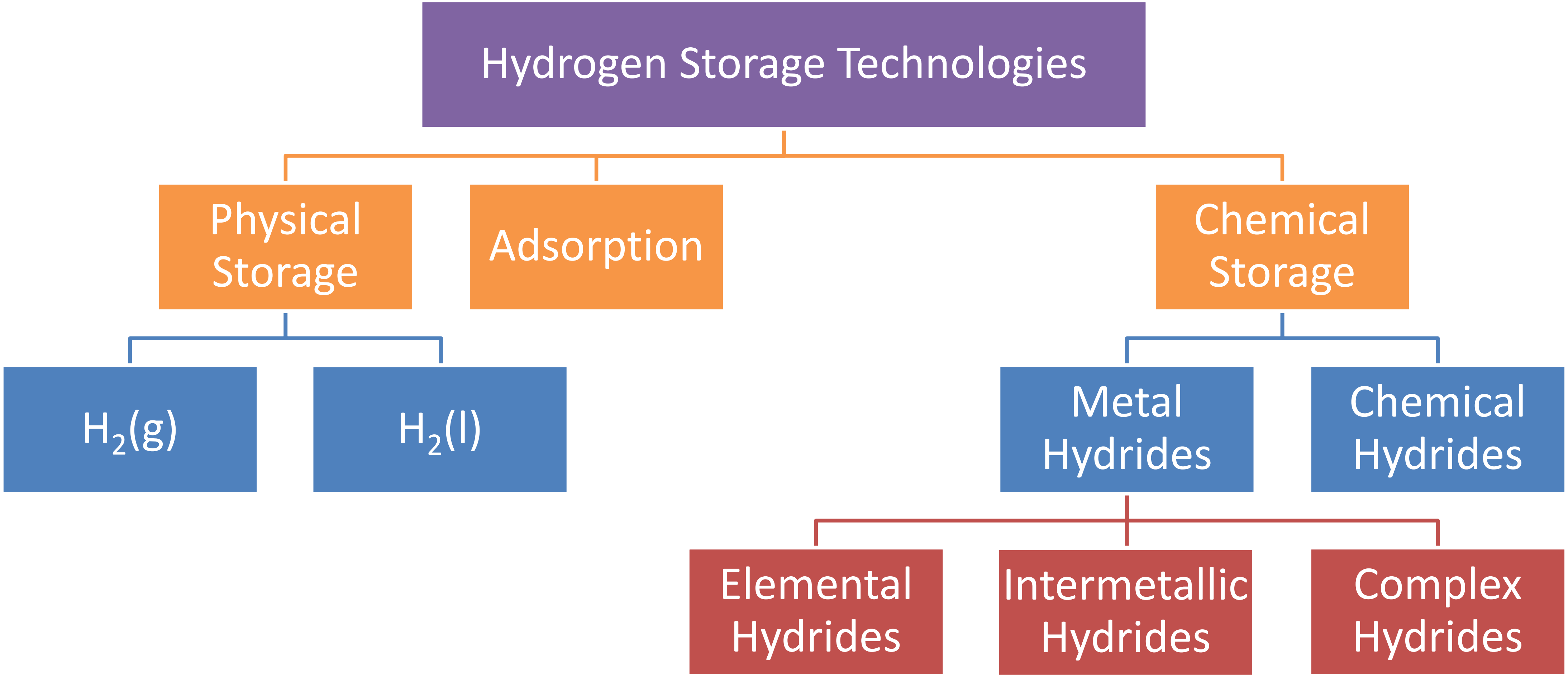
Benefits of Storage: Reliable, Affordable, Clean

- ☑ **Reliability** in a changing grid
- ☑ **Resiliency** in unplanned events
- ☑ **Secure** energy supply
- ☑ **Reduced** customer cost
- ☑ **Clean** infrastructure & end use
- ☑ **Optimal** asset utilization

Image Source: Adobe Stock

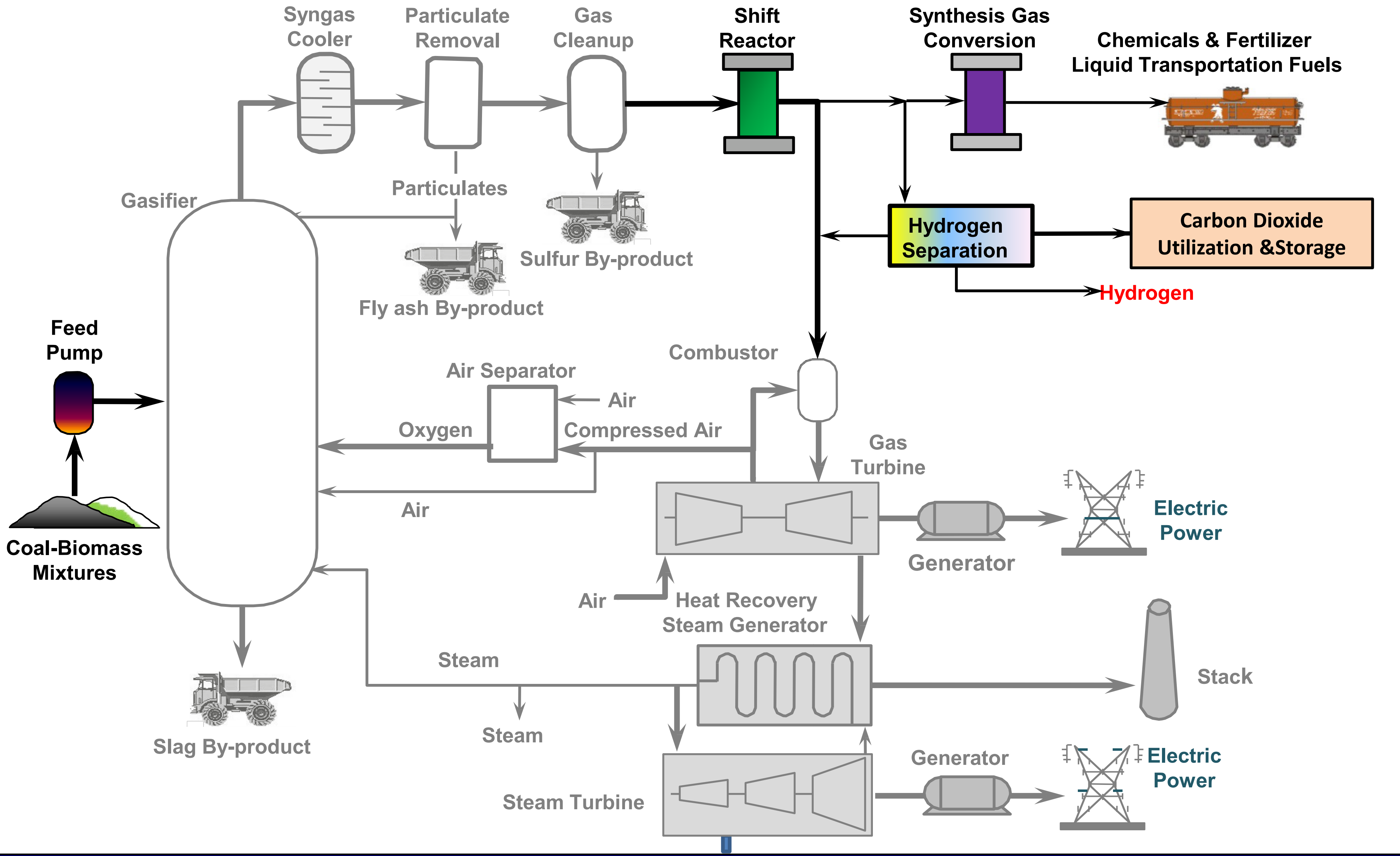
Hydrogen Storage Technologies

Generalized groups of hydrogen storage technologies



Ref: Andersson, J. and S. Gronkvist, 2019, "Large-scale storage of hydrogen." International Journal of Hydrogen Energy, Vol. 44.

Example: Gasification/Poly-generation



Request for Information—Hydrogen Technologies DE-FOA-0002369

Seeking input from stakeholders about hydrogen technology opportunities and research needs that could lead to technological advances

Topic Areas

1. Natural Gas Hydrogen Production, Transport, and Storage
2. Hydrogen Production from Coal, Biomass, and Waste Plastics Gasification
3. Hydrogen Turbines
4. Hydrogen Storage
5. Hybrid Energy Systems with reversible solid oxide fuel cells to produce hydrogen

Responses Due: August 24^{th}, 2020 to DOE FE National Energy Technology Laboratory

https://netl.doe.gov/business/solicitations

Questions?

John Litynski
Deputy Director
Office of Clean Coal and Carbon Management
Advanced Fossil Technology Systems

John.Litynski@hq.doe.gov

Regis Conrad
Division Director
Office of Clean Coal and Carbon Management
Advanced Energy Systems

Regis.Conrad@hq.doe.gov