



*Catalysis and Alternative Feedstocks in the Biofuels Industry Workshop*

# ***Industrial Perspectives on Hydrogen Production: Needs and Opportunities***

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# Agenda



- Industrial gases in the biofuels production chain
- Hydrogen market
- Hydrogen production
  - ✓ Production
  - ✓ Off-gas
  - ✓ Biosource
- Distribution modes



## Industry



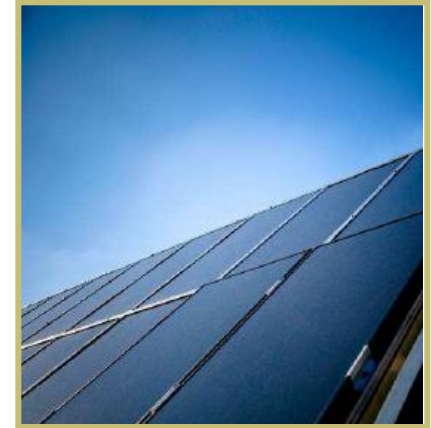
- For a wide range of industrial processes for customers:
  - ✓ energy, metals, food, chemicals, pharmaceuticals, automotive...

## Health



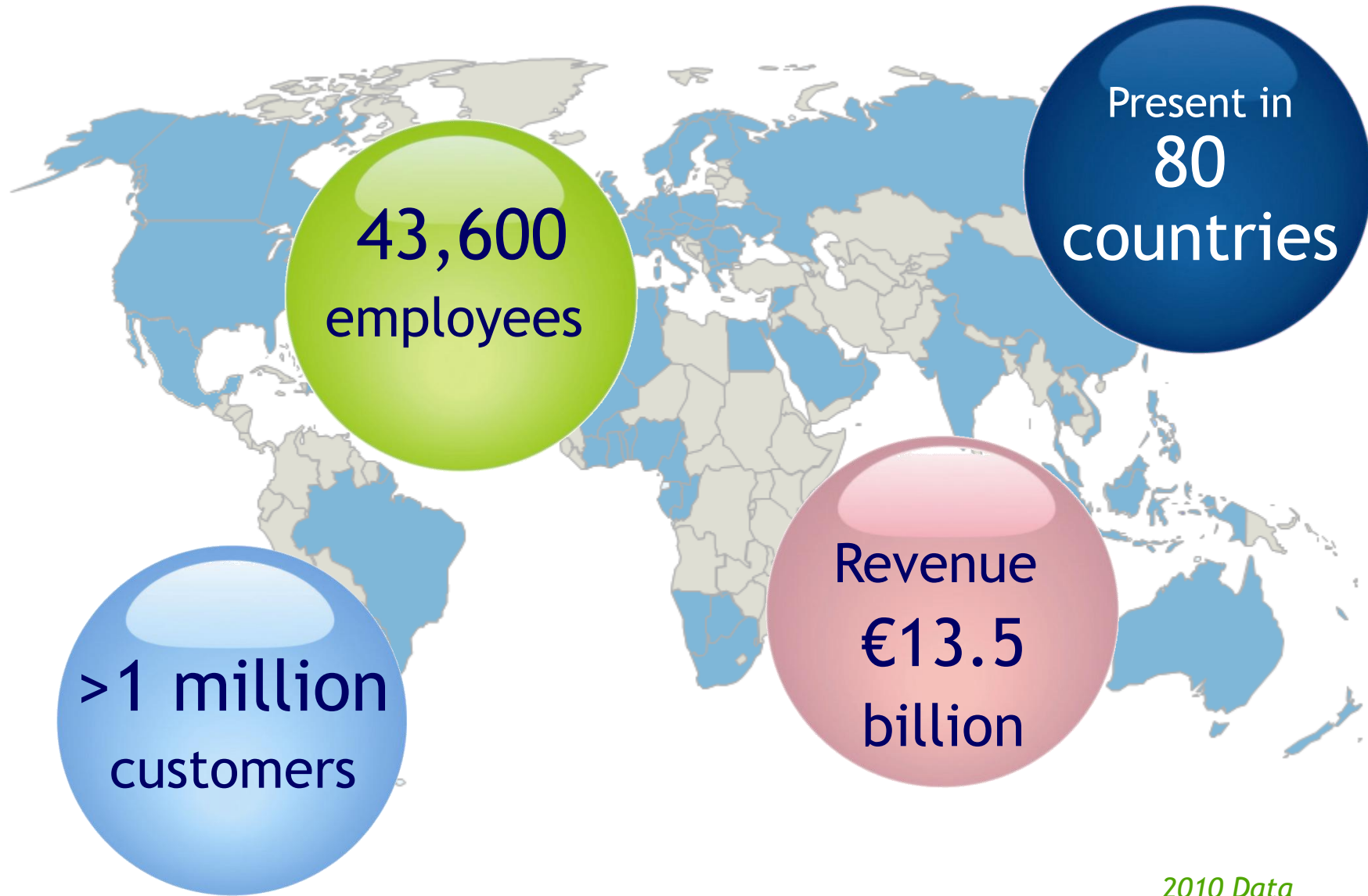
- For hospitals
- For homecare patients
- For hygiene and disinfection

## Environment



- For reducing polluting emissions
- For producing the energies of tomorrow

# Air Liquide – by the numbers

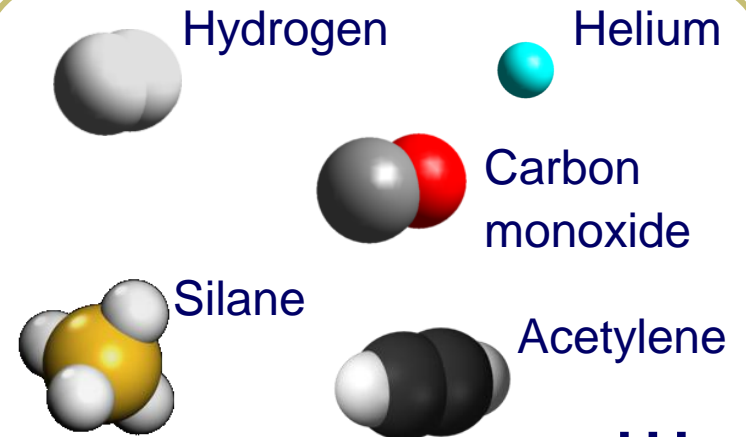
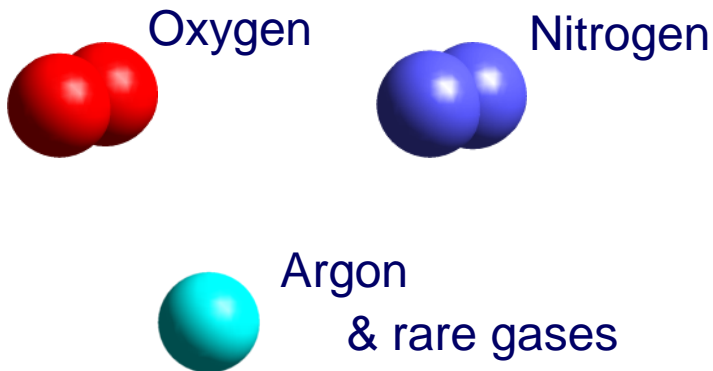


# Unique expertise and skills

Separating the components of the **air** to take advantage of their properties

Producing molecules from **natural resources** of the Planet

**Air Liquide Technologies**





# A technological powerhouse

## ■ Innovation

- ✓ **€235m** innovation budget in 2010
- ✓ **8** R&D centers
- ✓ **2,500** active patented inventions
- ✓ **300** new inventions in 2010
- ✓ **100** industrial partnerships
- ✓ **120** partnerships with universities and research institutes



## ■ Molecules and innovative technologies



**H<sub>2</sub> + filling station**



**LENOXe™ + anesthesia workstation**



**O<sub>2</sub> + burners**



*Construction*

*Laboratories*



*R&D/Pilot Facilities*

## ■ Process gases

- ✓ Hydrogen for hydrotreating
- ✓ Oxygen for gasification
- ✓ Carbon dioxide for algae production

## ■ Analytical gases

- ✓ Carrier gases
- ✓ Calibration standards

## ■ Construction and maintenance gases

- ✓ Argon mixtures for welding
- ✓ Oxygen and FLAMAL for cutting



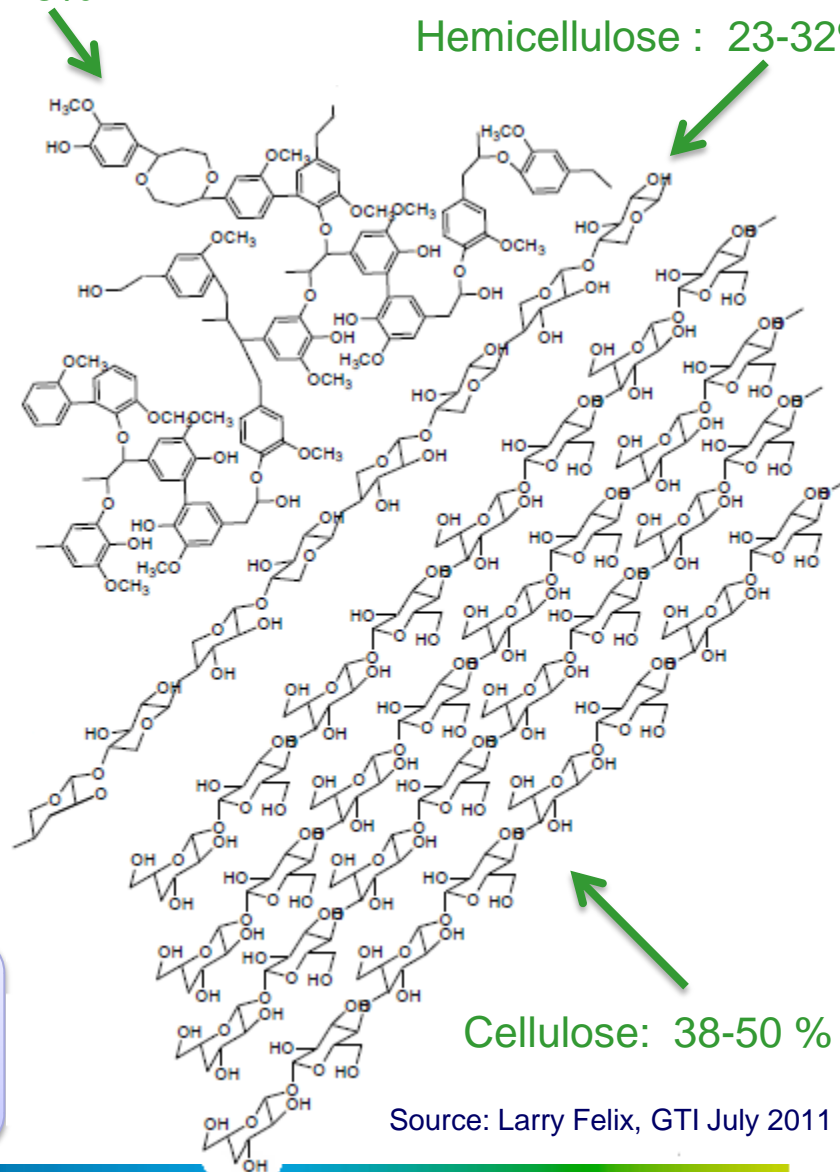
*Biorefineries*

# Hydrogen Requirements for Biofuels

- Major components of lignocellulosic biomass are: lignin, hemicellulose, and cellulose
  - Biomass contains significantly more oxygen and moisture than fossil hydrocarbons
  - Hydrogen is used to
    - ✓ De-oxygenate biomass-derived hydrocarbons
    - ✓ Saturate double / triple bonds from high temperature processes
- Hydrogen needs per barrel for biofuels can be significantly greater than for fossil fuels

Lignin: 15-25%

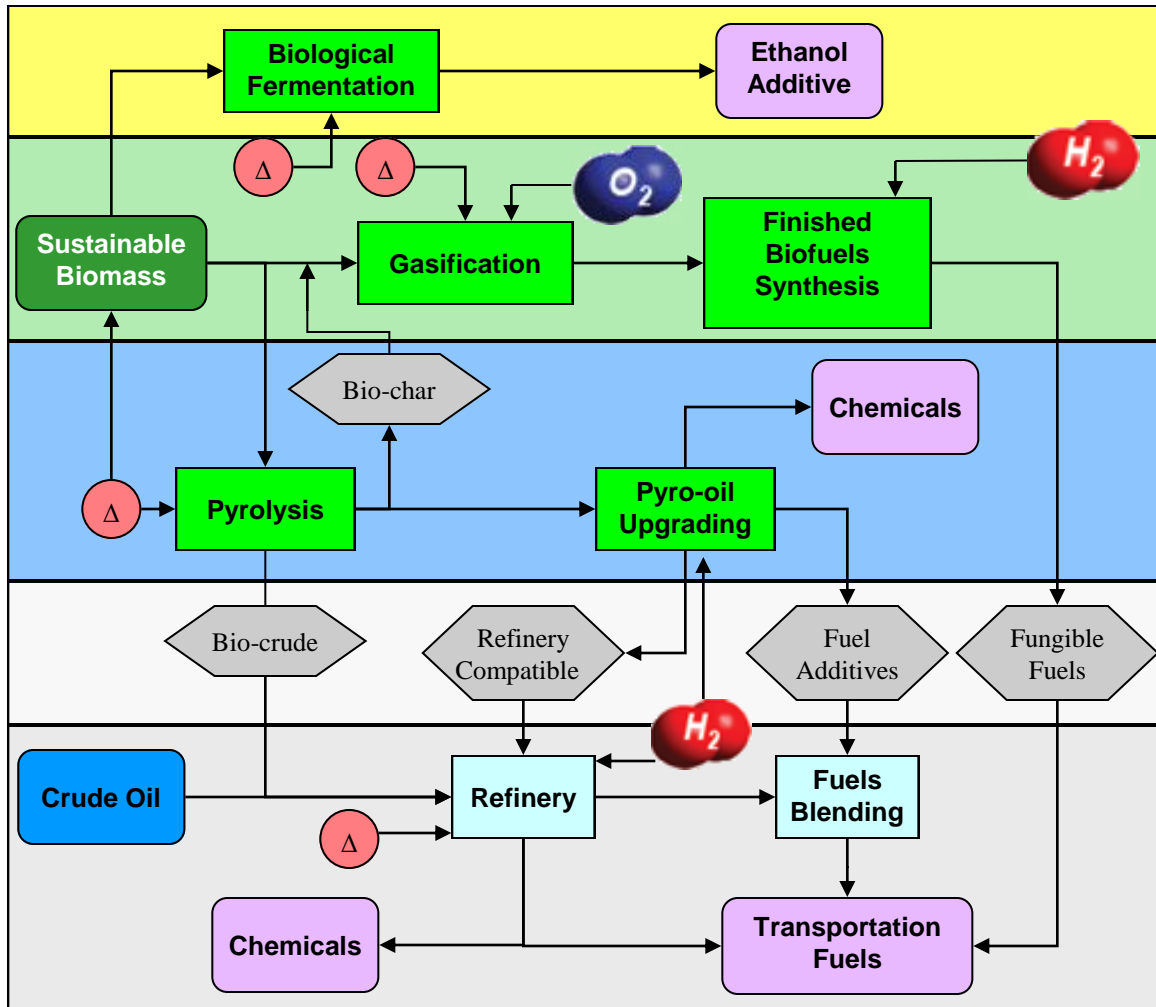
Hemicellulose : 23-32%



Source: Larry Felix, GTI July 2011



# Biofuels Processing Options



Several options for biofuels processing

- Fermentation
- Gasification and catalytic synthesis
- Pyrolysis with product upgrading

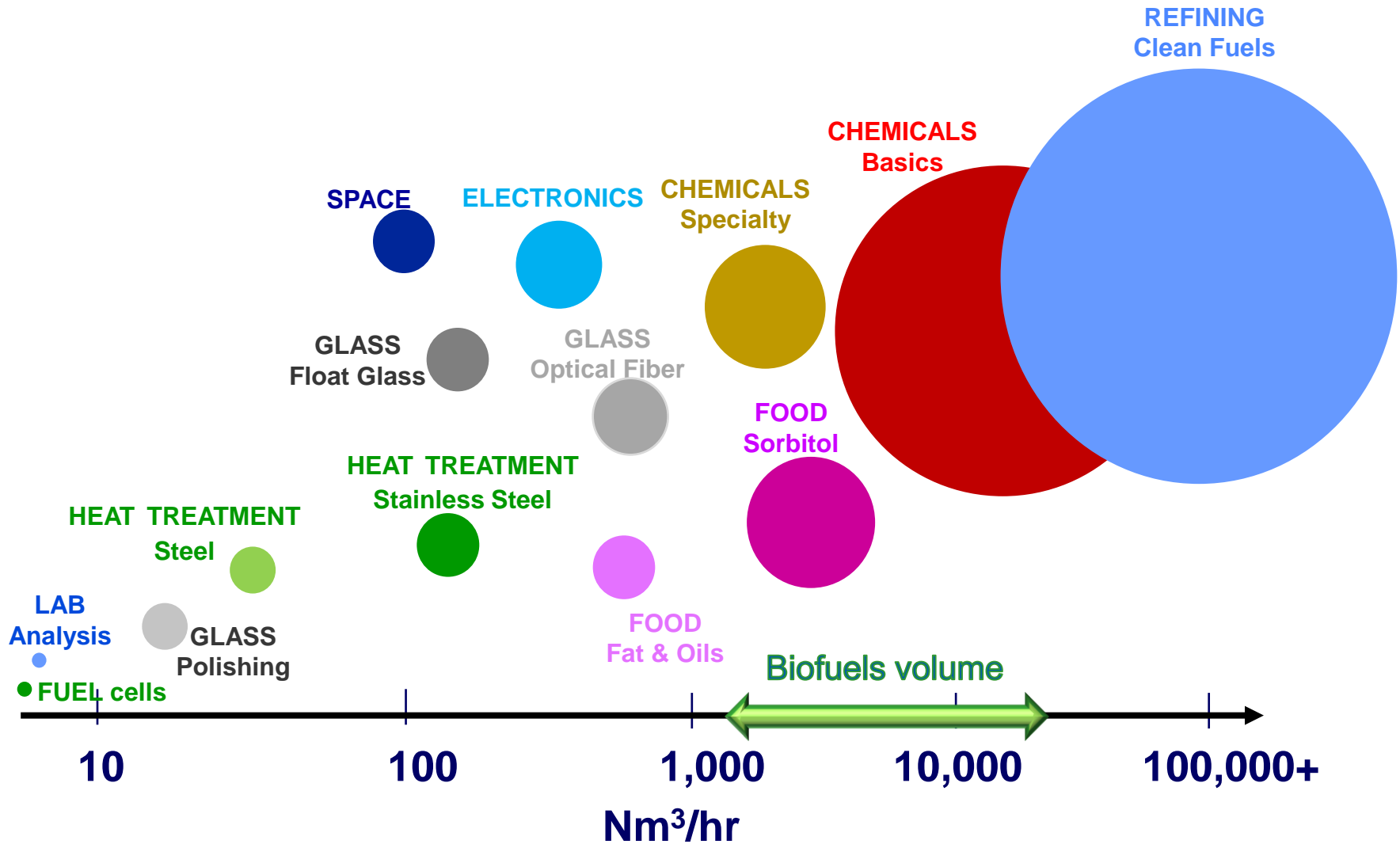
With many final products

- Ethanol
- Methanol
- Gasoline
- Jet fuel
- $NH_3$  / Urea
- Mixed alcohols
- Waxes
- MTBE
- Acetic Acid
- Aldehydes
- Fischer-Tropsch hydrocarbons

△ Heat, steam and electrical power required

Source: Richard Boardman, Idaho National Laboratory, July 2011

# Uses for Hydrogen, Volume and Market Size



# Needs of Biofuels Producers

***Hydrogen  
must be:***



***Cost effective***



***Sustainable***



***Scalable***

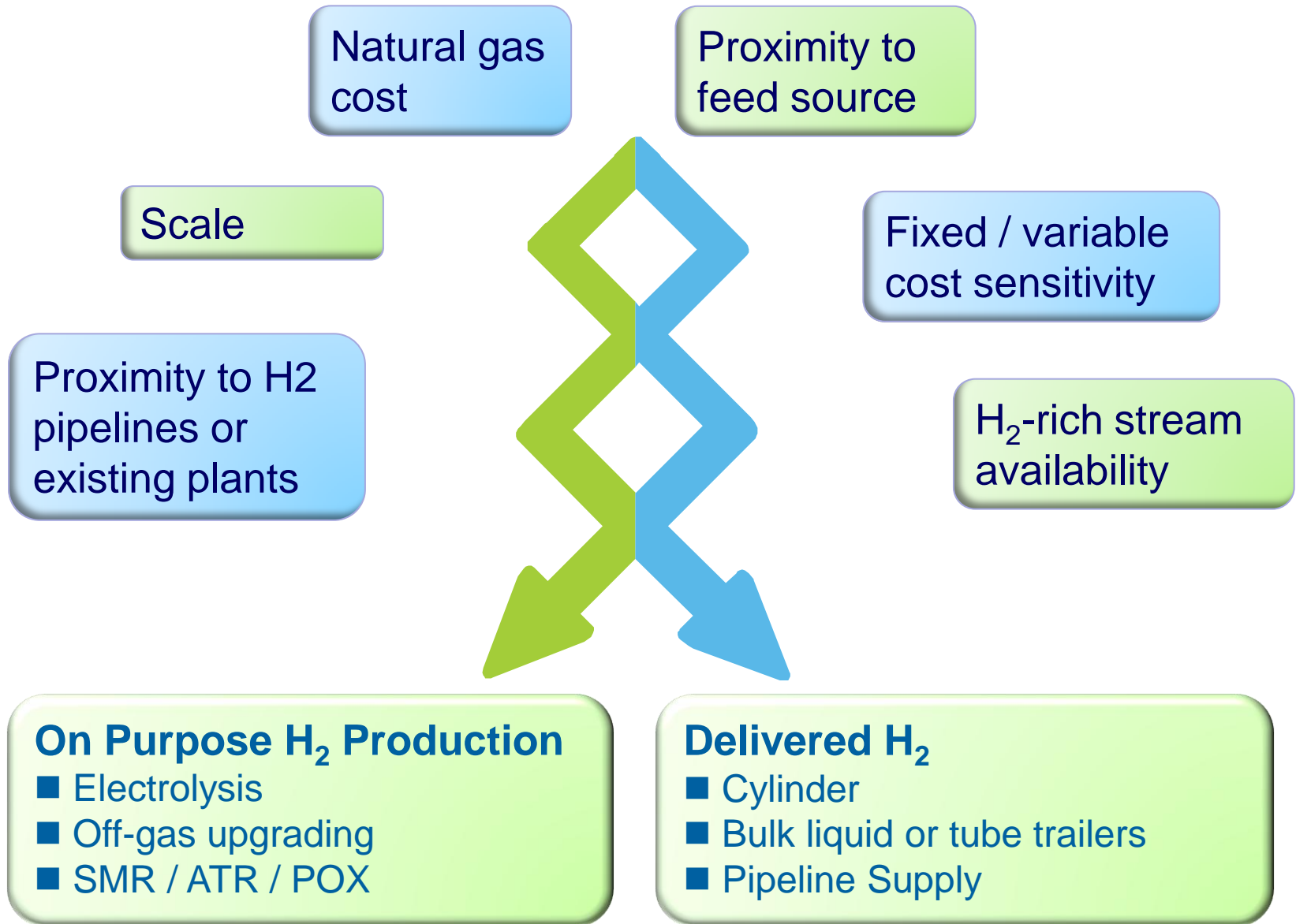


***Safe***

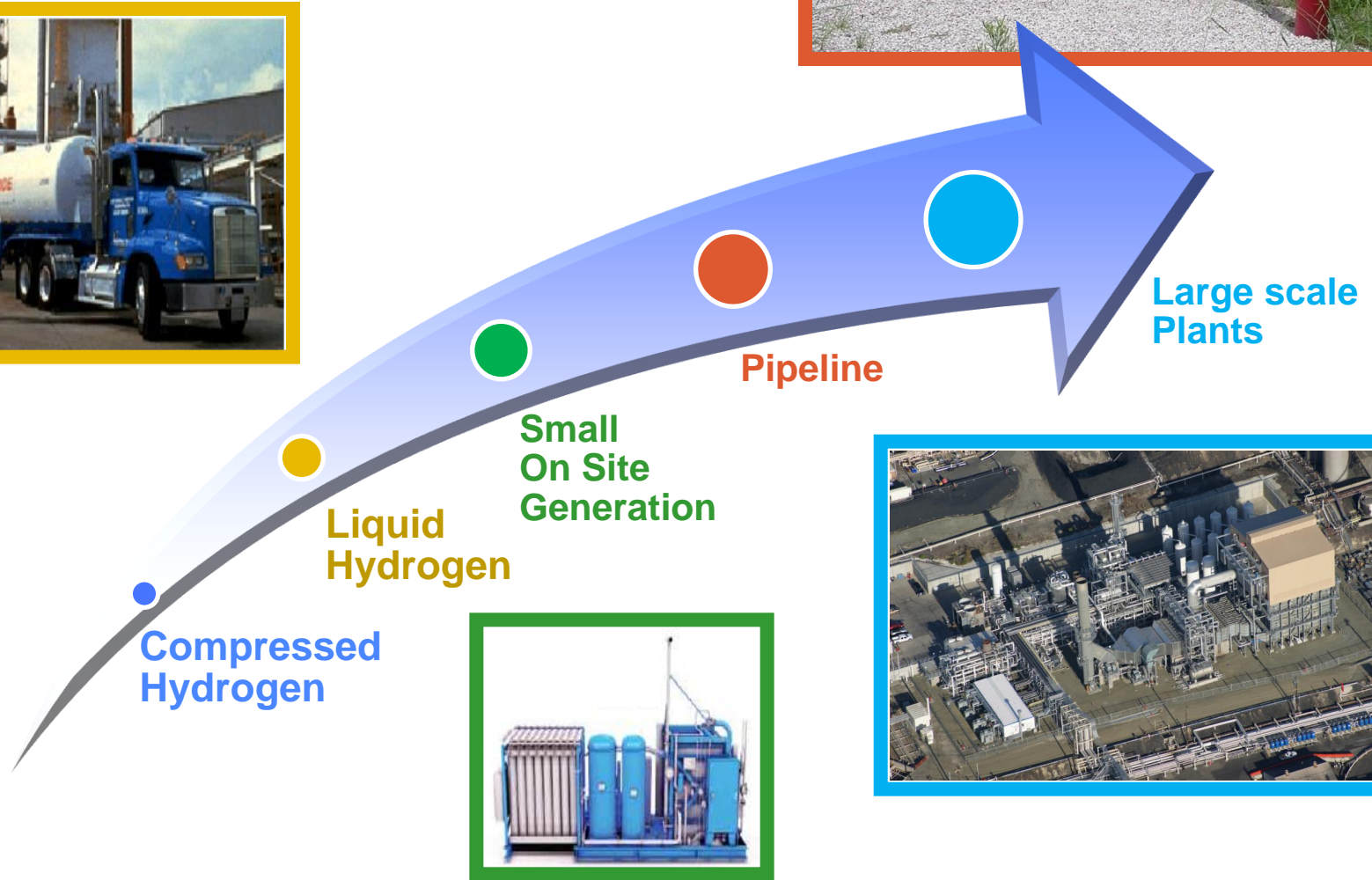


***Reliable***

# Factors in H<sub>2</sub> Supply Mode

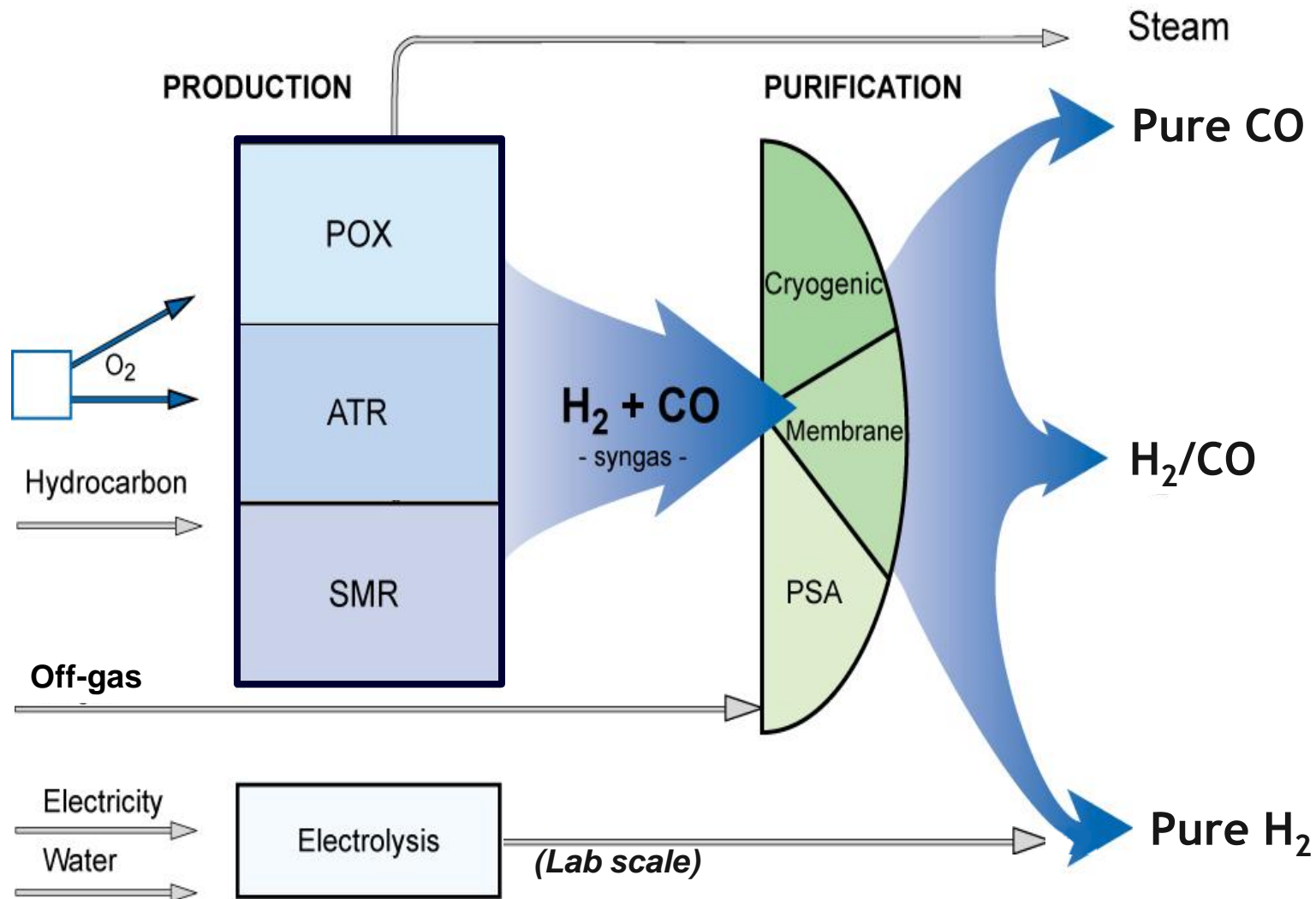


# Scalable Supply





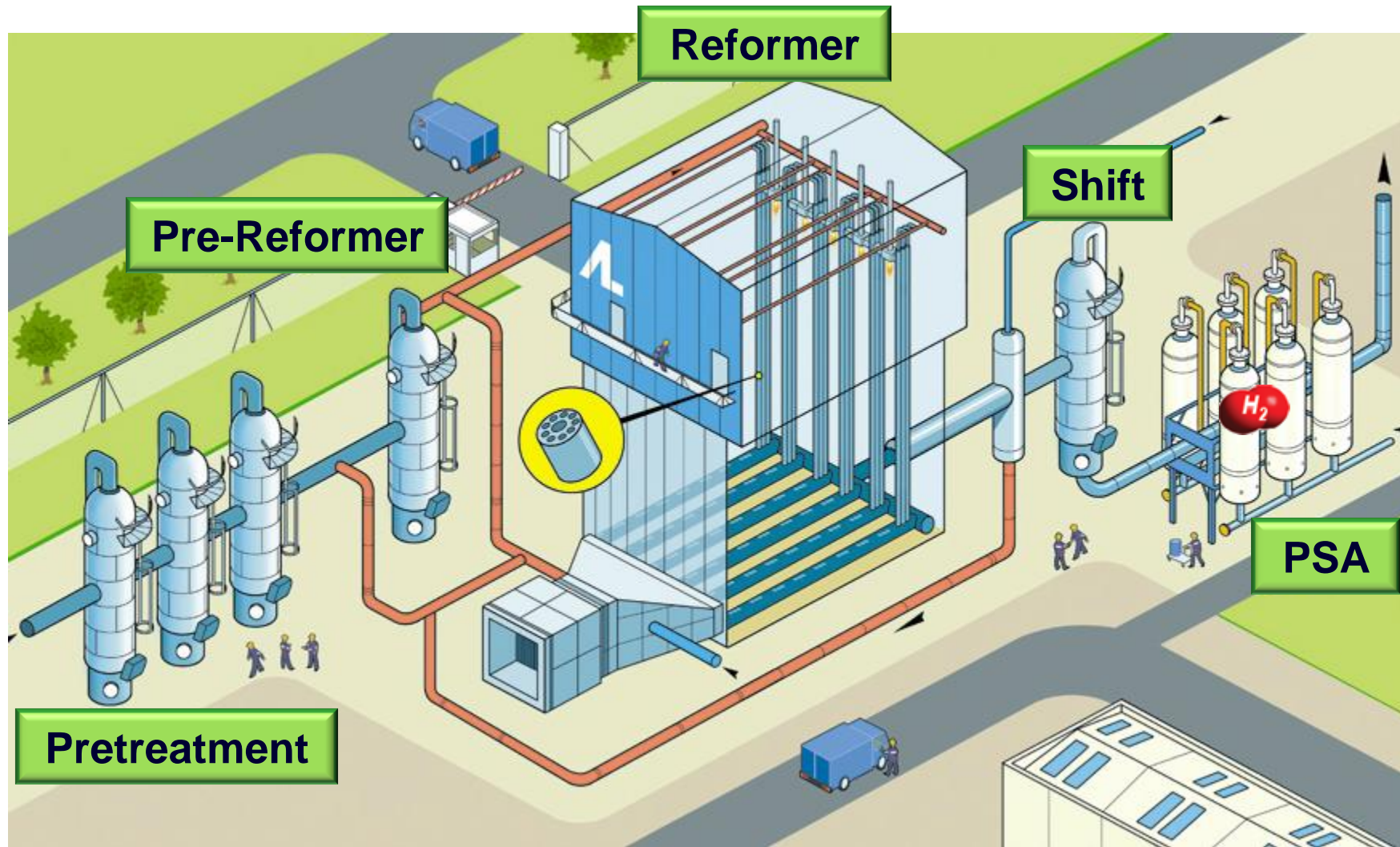
# Hydrogen Production Technologies



SMR: Steam Methane Reformer  
POX: Partial Oxidation

ATR: Auto Thermal Reformer  
PSA: Pressure Swing Adsorption

# Standard SMR Plant



# Large Scale H<sub>2</sub> Production Plant

Reformer

PSA

Shift





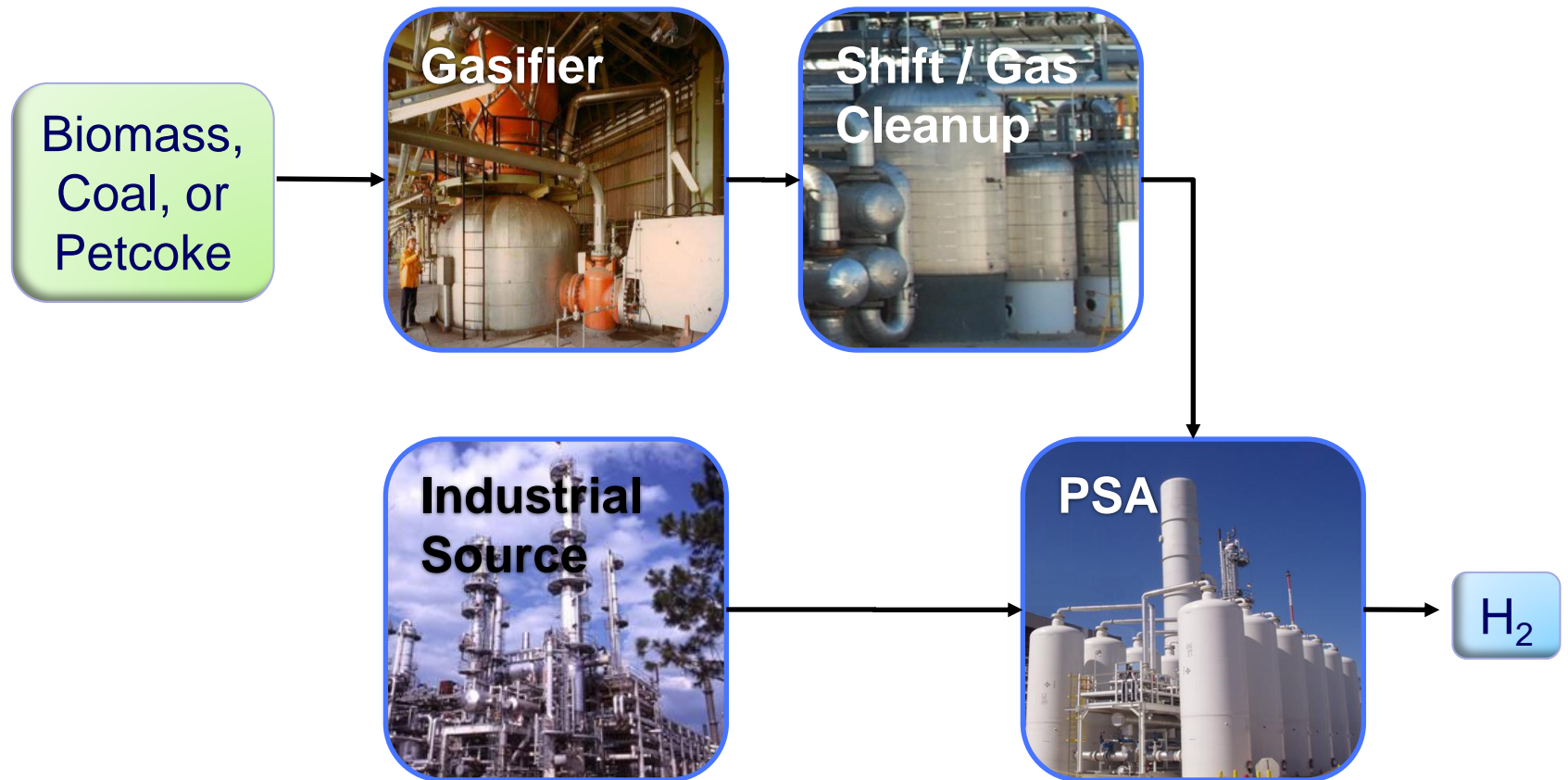
## ■ How we reduce CO<sub>2</sub> emissions

- ✓ Improve efficiency and reduce fugitive emissions
- ✓ CO<sub>2</sub> separation and capture
- ✓ Burn hydrogen in the SMR



Lurgi CryoCap™ Reformer

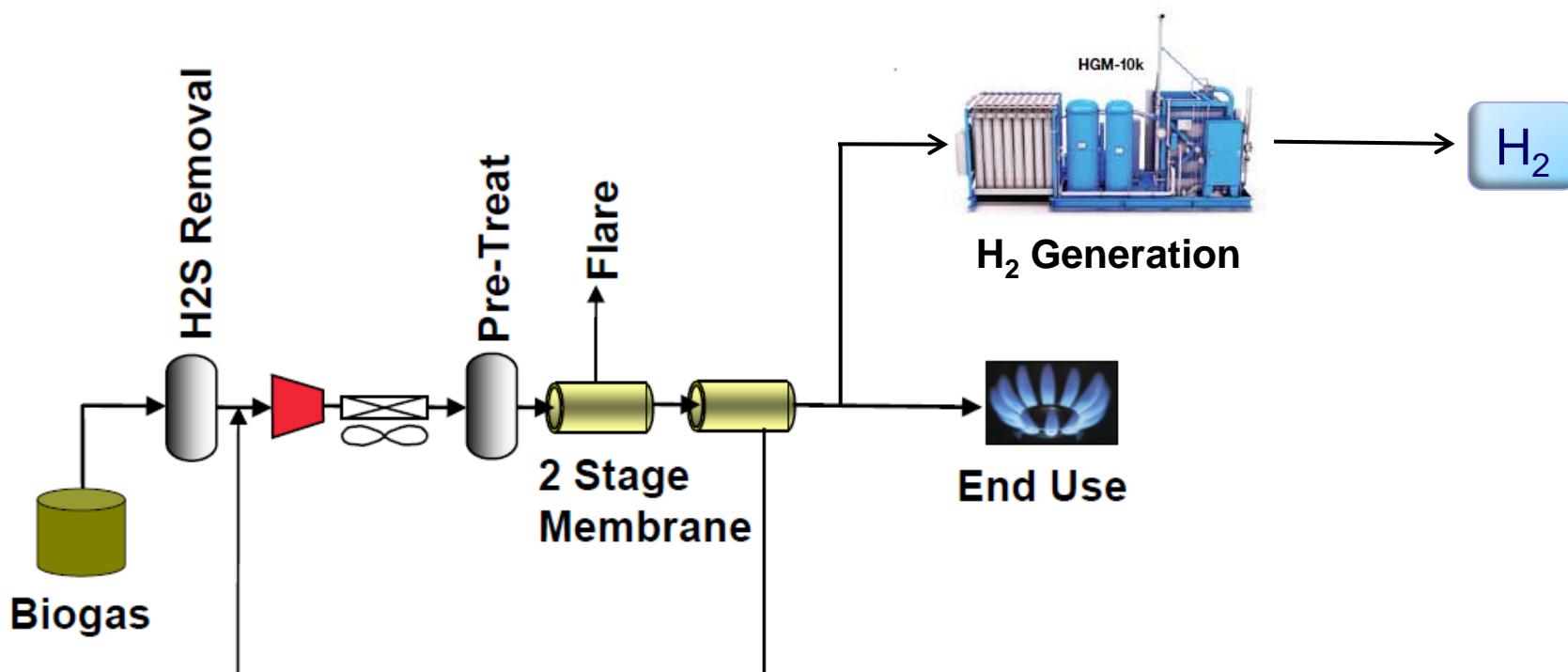
# Off-gas Recovery and Purification





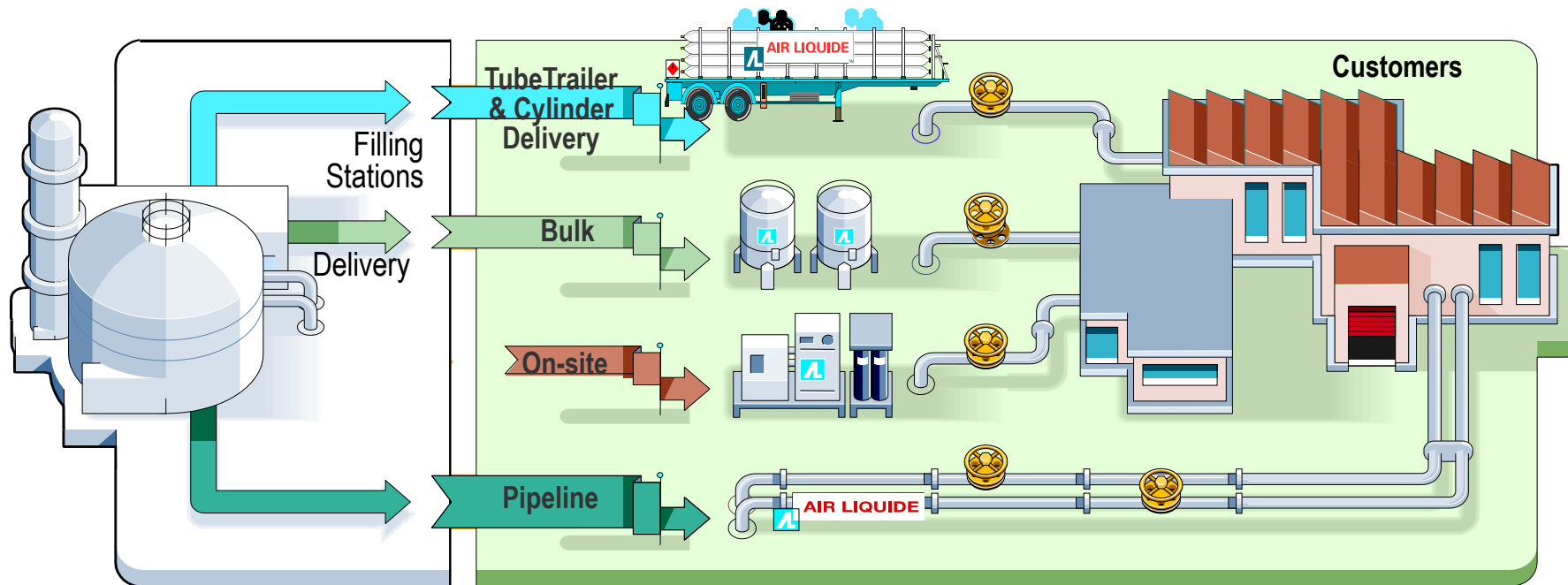
# Biosourcing of Hydrogen

- Methane from landfill gas can be feedstock for H<sub>2</sub> production via SMR
- Biosourcing is viewed as an off-gas source; not a primary production source



# Distribution Methods

## Small Quantity Users (1 - 50 m<sup>3</sup>/hr)



## Large Quantity Users (1,000 to 100,000 m<sup>3</sup>/hr)

# U.S. Hydrogen Smaller Usage Operations



Small Quantity Users  
1 - 500 m<sup>3</sup>/hr

- Increased volume scalability
- Lower commitment levels
- Usage flexibility
- Reduced CAPEX



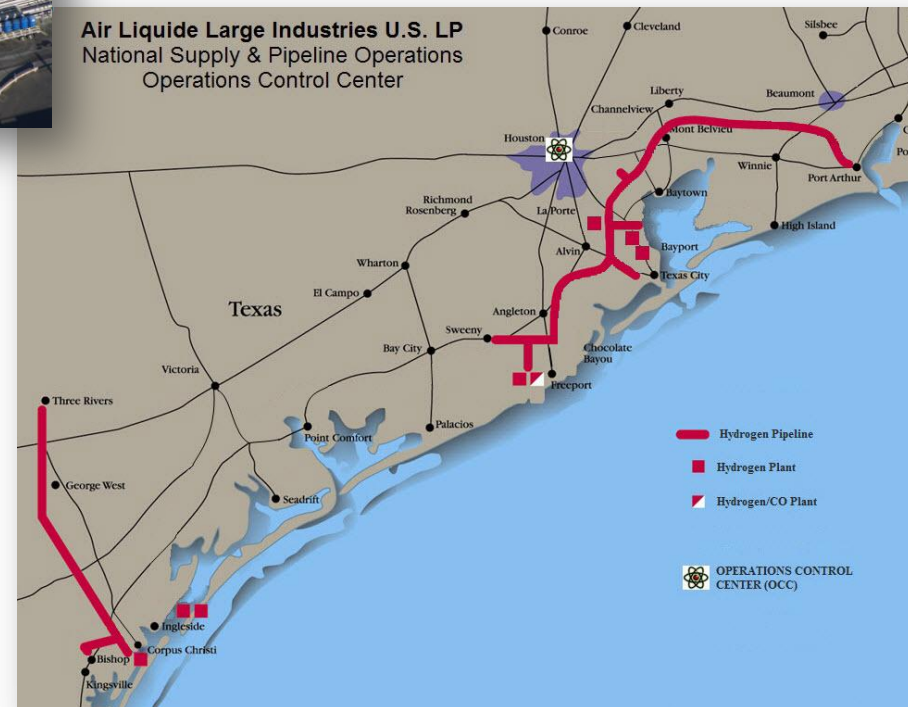
# U.S. Hydrogen Large Usage Options



Large Quantity Users  
1,000 – 100,000 m<sup>3</sup>/hr

## Pipeline Network

Air Liquide Large Industries U.S. LP  
National Supply & Pipeline Operations  
Operations Control Center



## On-purpose Production

- Dedicated supply
- Improved reliability
- Increased economies of scale

- Biofuels represent a growth opportunity for the hydrogen market
- Hydrogen production is well established commercially
- Hydrogen can become a critical factor in the planning process of biorefinery projects
- New hydrogen sources and new applications using hydrogen will play an important part in the development of a renewable fuels portfolio







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FOR INDUSTRY,  
HEALTH AND THE ENVIRONMENT



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