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GASIFICATION AS VIEWED BY A HYDROGEN PRODUCER

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Outline

- **Keys to Success for a Hydrogen Supplier**
- **Performance Benchmarks**
  - **Challenges & Opportunities**
- **Hydrogen From Pet Coke & Asphaltenes Gasification**
  - **Flowsheets**
  - **Cost of Hydrogen vs. Steam Methane Reforming**
- **Reliability**
- **Hydrogen Purity**
- **Perspective on CO_2 Capture**
- **Outlook**

Air Products Hydrogen Background

- **We Own & Operate Hydrogen Production Facilities**

  Worldwide Fleet - 57 Plants:
  - **Mostly Steam Methane Reforming**
  - **Some Secondary Reforming**
  - **Some Partial Oxidation**
  - **One Facility Processing Raw Syngas from Asphaltenes Gasification**
- **80 customers**
- **Connected to:**
  - **>30 refineries**
  - **6.5 MM BPD**
- **2008 Global Hydrogen Capacity = 2 Billion SCFD**

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Air Products Experience With Gasification Technology

Natural Gas POX - facility includes the basic building blocks of gasification

Air Products Experience With Gasification Technology

Recitisol for AGR, deep sulfur removal prior to CO separation

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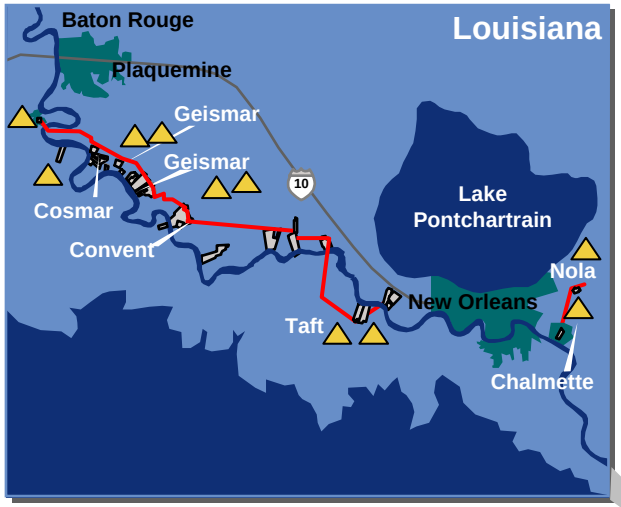
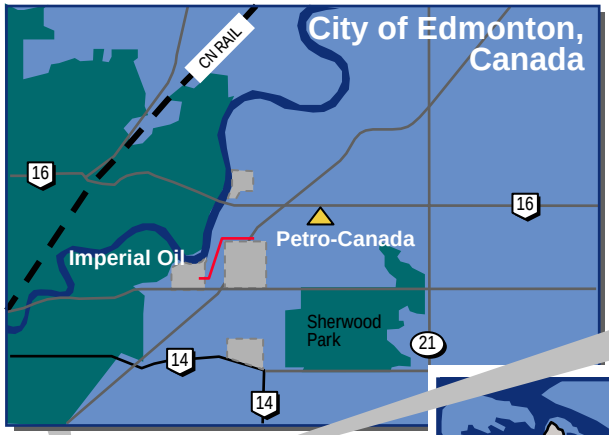
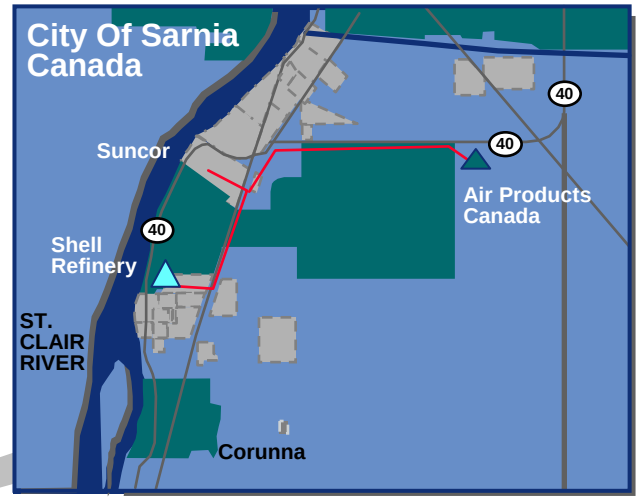
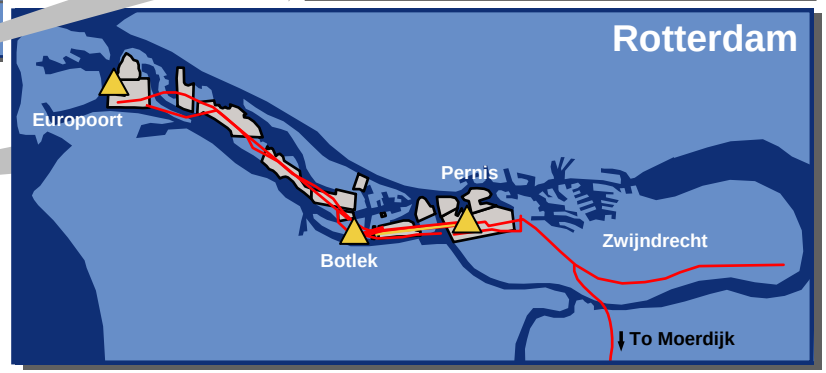
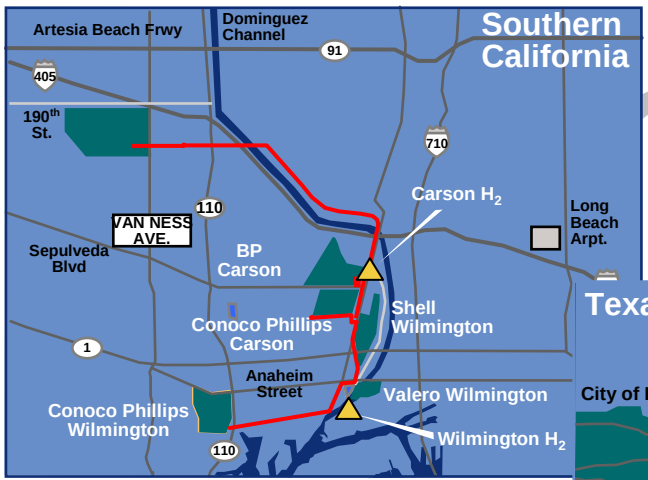
Leading Global Franchise Positions: USGC, California, Rotterdam, Canada

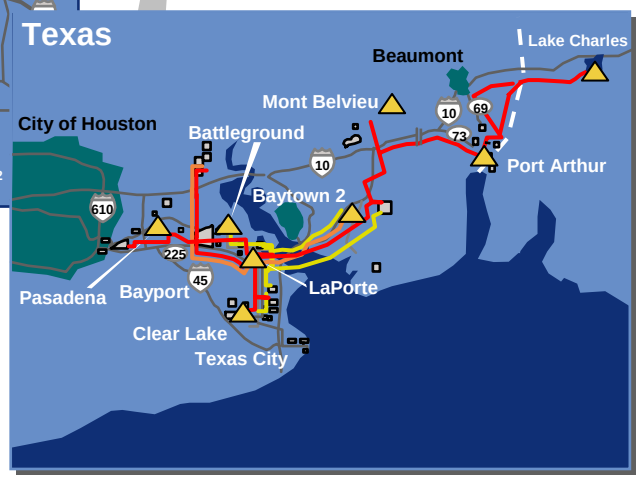












- APD HyCO facilities
- H_2 pipeline
- CO pipeline
- Syngas pipeline

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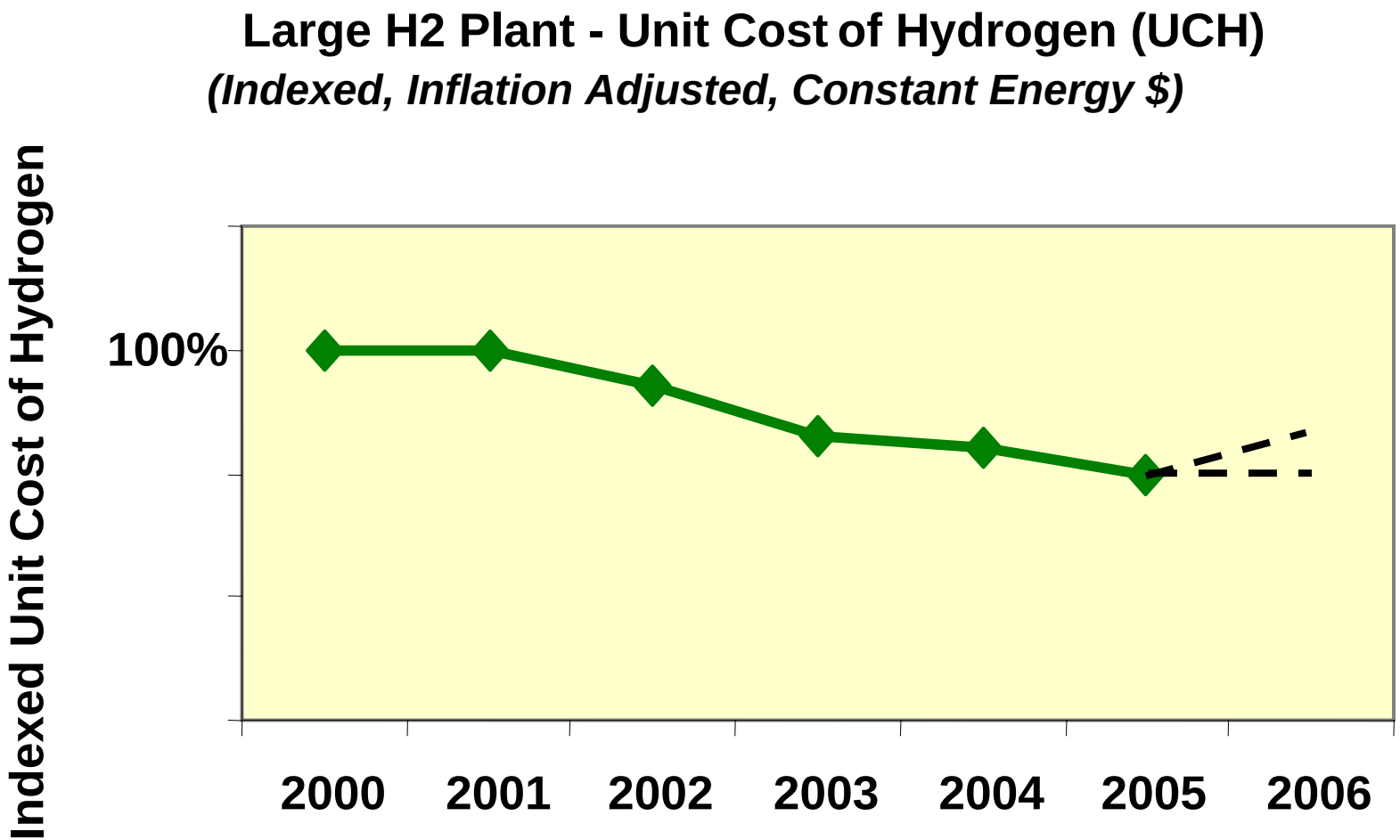
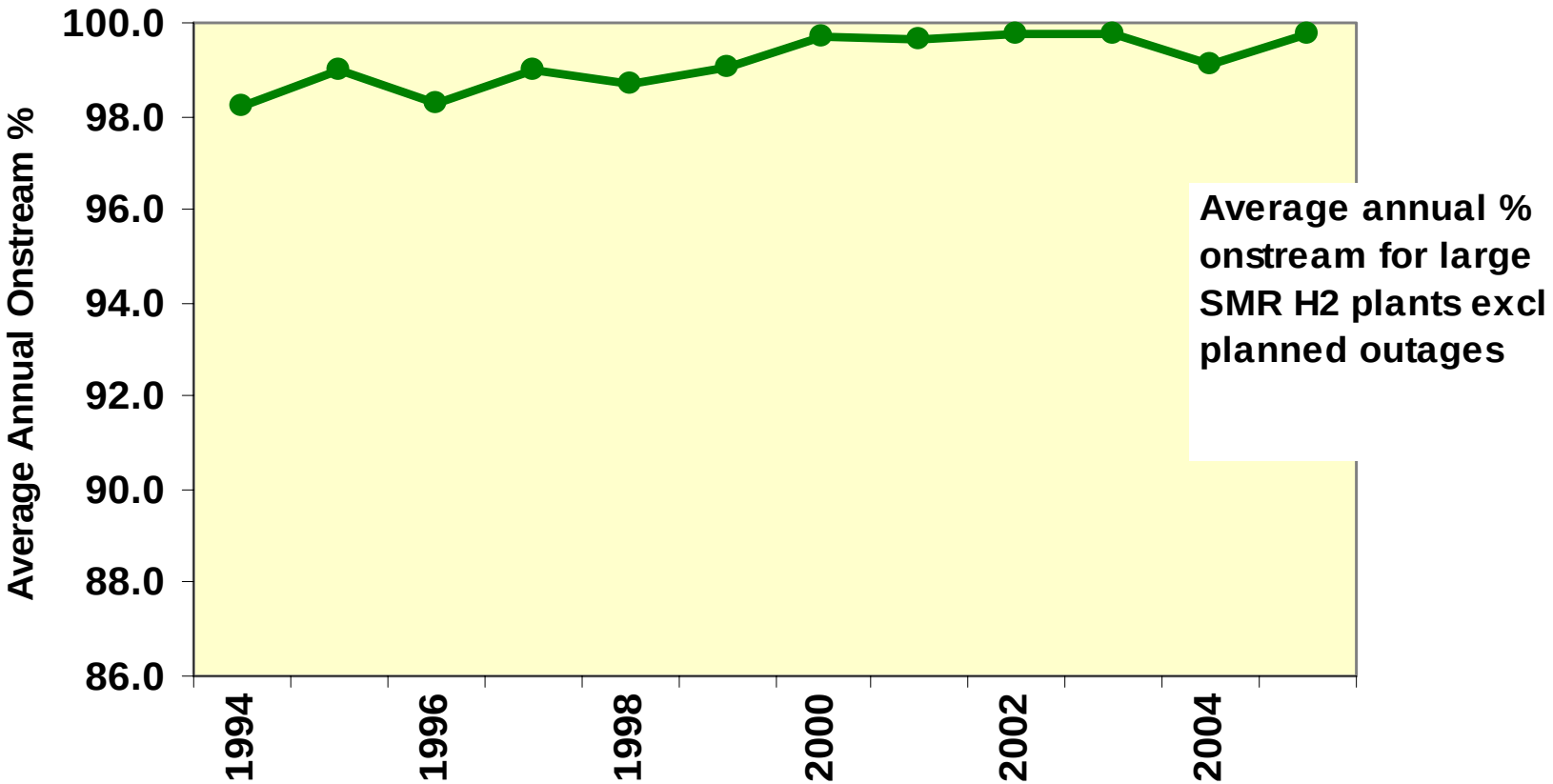
Keys To Success To A Hydrogen Supplier

- **Providing the Lowest Cost, Reliable Hydrogen Supply**
- **Performance Benchmarks:**
  - **Cost**
  - **Reliability**
  - **Quality**
  - **Safety**
- **A Core Enabler:**
  - **Product Improvement via multi generation product planning (MGPP)**

Cost of Producing Hydrogen Is a Continuous Effort



Hydrogen Reliability Is Critical



Hydrogen Product Quality Generic Pipeline Spec

Purity, vol % or ppmv

Hydrogen	**99.9% min**
CO + CO_2	**10 ppmv max**
N_2 + CH_4 + C_2^+ + Ar (inerts)	**<1000 ppmv**
Total Sulfur	**Nil**
Water	**-40F dew point**

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Safety

American Chemistry Council Recordable and Lost Workday Incidence Rates

	Total Recordable			Deaths and total lost workday cases away from work	
Company	**2005**	**2004**		**2005**	**2004**
Air Products and Chemicals	**0.78**	**0.77**		**0.14**	**0.15**
Next Best Industrial Gas Company	**1.06**	**0.87**		**0.16**	**0.04**
Group Average	**1.27**	**1.47**		**0.29**	**0.31**

Category : 2-20 million exposure hours

Basis : Events per 200,000 hours

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The Challenge = The Opportunity

- **The hydrogen supply performance benchmarks are high.**
- **They should be. It's core business.**
- **The same discipline and principles also have to be applied to gasification-based hydrogen supply in order to achieve comparable performance.**
- **From our perspective, it's a must.**

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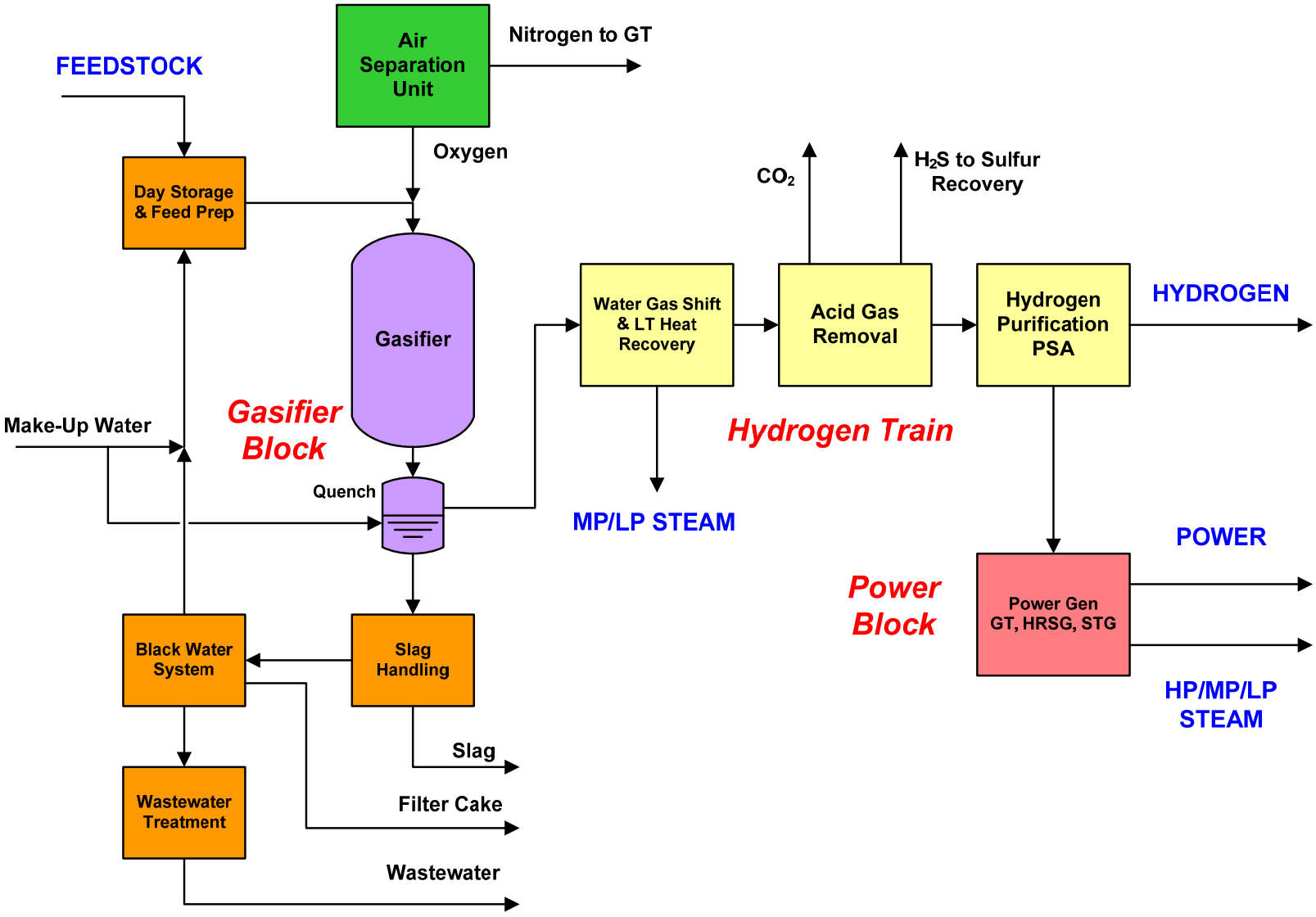
Gasification-Based Hydrogen Flowsheets

1. **Traditional Shift**
2. **IGCC Coproduct Hydrogen Skimming**

Traditional Shift Flowsheet -- Primarily Hydrogen Product



Cost Of Hydrogen – Hydrogen Product

Basis:

- **USGC, 2005$, screening level**
- **$6/MMBtu cost for natural gas**
- **$0/MMBtu feedstock cost for asphaltenes and pet coke**
- **98% minimum H_2 reliability**
- **99.9% H_2 purity, 615 psia delivery**
- **No CO_2 credit or penalty**

	SMR	Asphaltenes Gasification	Pet Coke Gasification
H_2 Product Rate, MMSCFD	200	200	200
Feedstock Rate: ST/D	-	2,500	3,900
Cost of H_2, $/MSCF	$3.00	2.50	3.25

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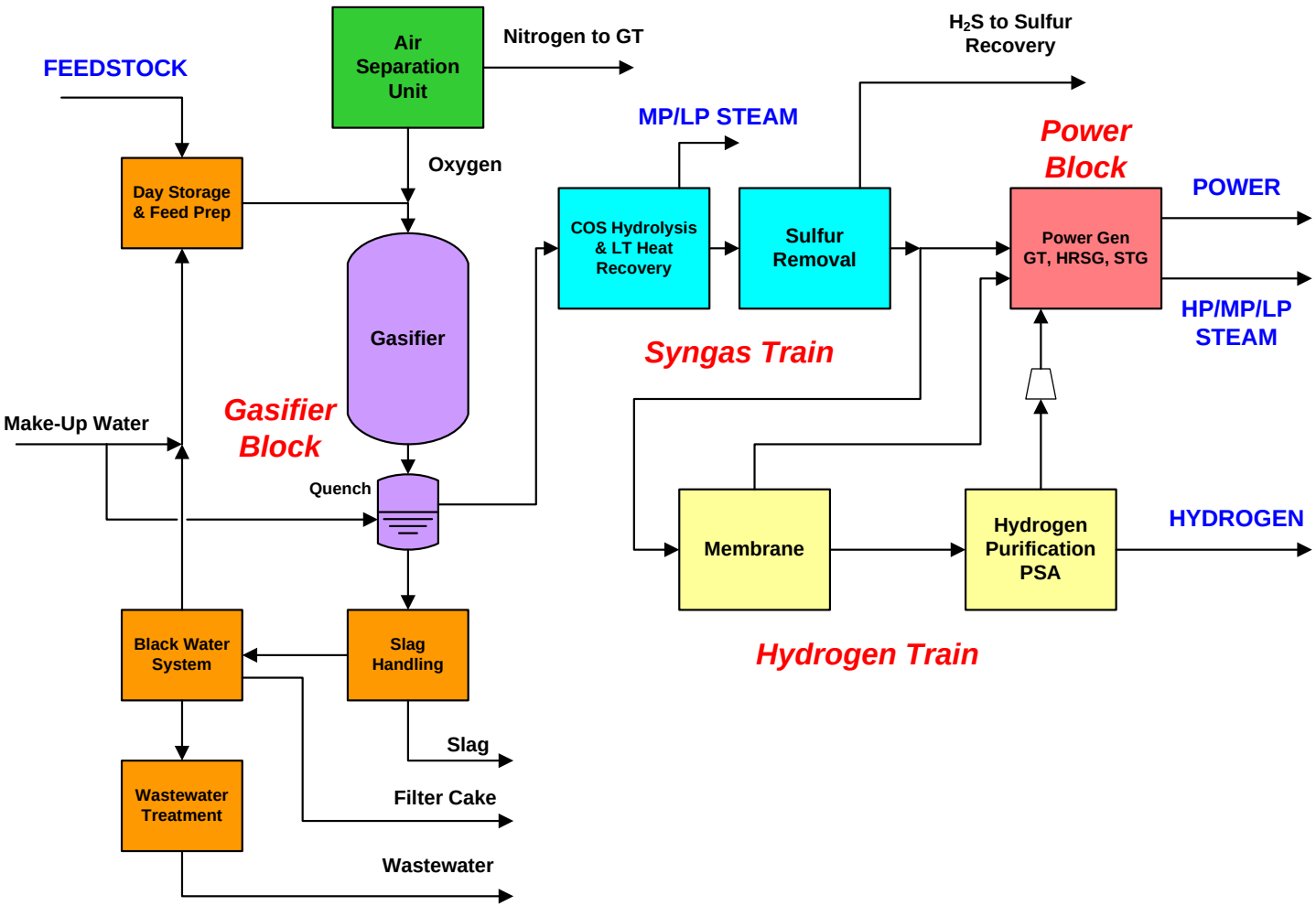
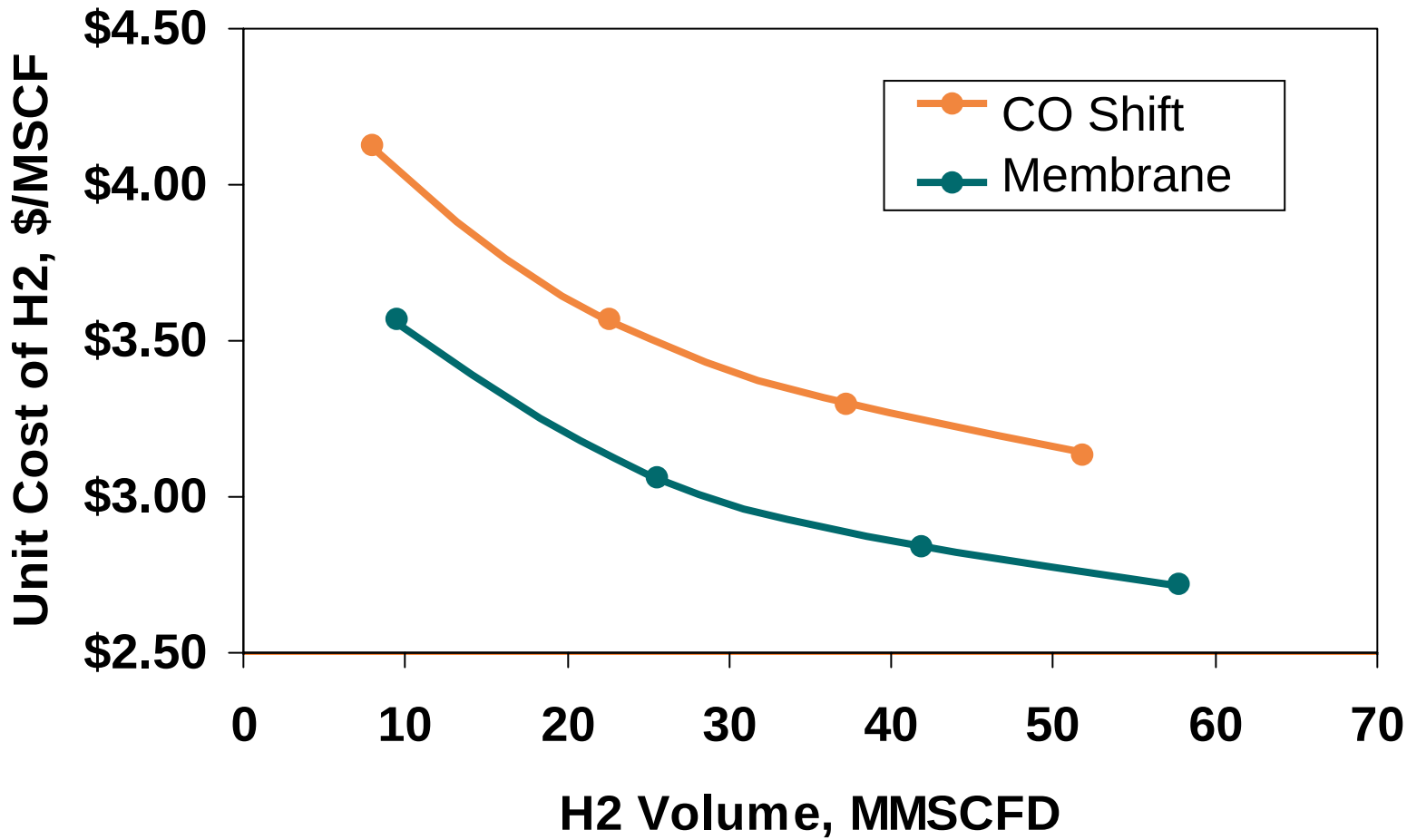
Skimming Flowsheet -- IGCC With Coproduct Hydrogen Production



Cost Of Hydrogen With IGCC Coproduction Skimming



Reliability Of Gasification - Based Hydrogen

- Normally a given that multiple gasifiers are required
- Normally some LOX backup required
- World-class, single gasifier reliability
  - Natural gas POX 97-98%
  - Asphaltenes gasification 94-95%
  - Coal/pet coke gasification 89-90%
- 98% minimum reliability all-hydrogen requires, in the simplest case:
  - 100% x 2 gasifiers
  - 50% x 3 gasifiers
- "Spare" gasifier can also be used with downstream flywheel operation to better utilize installed investment, e.g., Shell Pernis
  - In this case, 3 x 33% gasifiers
  - 2 gasifiers dedicated to hydrogen,
  - 1 gasifer dedicated to power (flywheel)
- Upstream ASU and downstream shift/AGR/PSA and power island reliabilities in hand from our own-and-operate perspective

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Hydrogen Purity With Gasification

- **Beyond high purity specification, need to pay attention to many more cats and dogs that are not specified:**

Iron carbonyl	**NH_3**	**Chlorides**	**HCN**
Nickel carbonyl	**Arsenic**	**Mercury**	**Vanadium**
Particulates	**Methanol**	**MDEA**	**Selexol**

- **High hydrogen purity sets preference for high oxygen purity to gasifier**
  - **Tradeoff 95% O_2 vs. 99.5% O_2**
  - **Inerts impact downstream systems**

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CO_2 Capture With Hydrogen Production

- **With conventional, uncontrolled plants, SMR looks much better than gasification:**

	CO_2 emission, ton/MMSCF H_2
SMR	25
Asphaltenes gasification	37
Pet Coke gasification	50

- **With 90% capture of the process CO_2, gasification easily beats SMR:**

	CO_2 emission, ton/MMSCF H2
SMR (syngas stream capture)	10.1
Asphaltenes gasification	4.6
Pet Coke gasification	5.2

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CO_2 Capture With Hydrogen Production Ctn'd

- **Gasification CO_2 capture and sequestration (with compression to 2,215 psia) is less energy intensive and more cost effective than SMR**

	$/ton CO_2
SMR	35
Asphaltenes gasification	15
Pet Coke gasification	16

- **Cost includes recovery, compression**

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CO_2 Product Quality Generic Pipeline Spec

	Dixon Consulting EOR, Aug 2001	Kinder Morgan EOR, 2003	Industry Working Group Prelim Spec 2005	Dakota Gasification Aug 2005	Canyon Reef EOR, Dec 05	Strawman Composite
CO_2		95% min	95% min	96.80%	95% min	97% min
CH_4	<1.0%			0.30%		<1.0%
C_2H_6	<1.0%			1.0%		<1.0%
C_3+	<1.0%					<1.0%
Total HC's		5% max	5% max		5% max	<3.0%
H_2	<1.0%					<1.0%
CO			0.1% max			0.5% max
N_2	<2.0 N_2 & H_2	4% max	4% max		4% max	1-3% max TBD
Other Inerts						
Total Inerts						<3%
O2	<2.0 ppmw	10ppm	100 ppmv max		10 ppmv max	2 ppmv
H_2S	<100 ppmw	10-200 ppm	10-200 ppmv max	1.10%	1,500 ppmv max	10-200 ppmv TBD
SO_2	<5.0 ppmw					5 ppmv
Total Sulfur	<300 ppw				1,450 ppmv max	10-200 ppmv
H_20	<-5C DP @ 300 psia	30 lbs/MMCF max	<-40C DP	Bone dry	28 lbs/MMCF max	<1 ppv
Hg			Controlled			TBD
Other				0.90%		TBD
Glycol		0.3 gal/MMCF max	0.174 m3/MMm3		0.3 gal/MMCF max	TBD
Methanol						TBD
Selexol						TBD
Amine						TBD
Delivery Pressure			2,000 psia	2,190 psia		2,200 psig
Temperature		120F max	120F max	(2,700 psig @ source)	120F max	120F max

Additional Hydrogen Cost Observations

- **Facility size**
  - **Larger scale is desirable for both lower unit cost and higher reliability (more trains),**
  - **BUT what to do with all that hydrogen?**
  - **H_2 is viewed as a high value product but large quantities with lower reliability don't have value**
- **Capital costs**
  - **Recent increased capex costs have hurt gasification's margin**
  - **The capital cost of pet cost gasification for hydrogen is higher than asphaltenes gasification**
- **Other factors**
  - **Beyond standalone hydrogen cost per se, other factors can drive gasification selection:**
    - **The value of integrating with the user's facility -- the user's value proposition**
    - **Disposal of bottom of the barrel**
    - **Insulation from natural gas cost, availability, volatility**
- **The big dilemma**
  - **What is the cost of natural gas over 2010-2030?**

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Conclusion

- **The hydrogen supply performance benchmarks are high, driven by customer expectations**
- **Gasification-derived hydrogen can be supplied with world class performance with a disciplined, principled approach**
- **The economics for gasification-derived hydrogen are always interesting**
  - **Frequently difficult, situational**
  - **In some circumstances, near-compelling**
  - **Ideas to reduce cost further need to be exploited**
- **Carbon capture may assist gasification over SMR**
- **Is gasification for hydrogen at the tipping point for wider deployment?**
  - **Difficult to know**
  - **Key is the natural gas outlook, and the strategy to deal with it**
  - **Petcoke outlook**

Thank you

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