Carbon Capture

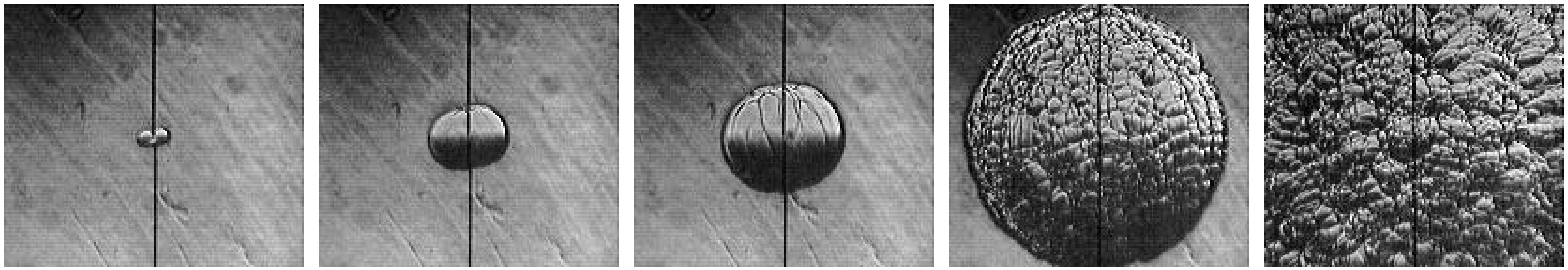
Robert H. Williams
H_2/Electricity Economy Group
Princeton Environmental Institute

First Annual CMI Meeting
15 January 2002
Princeton University

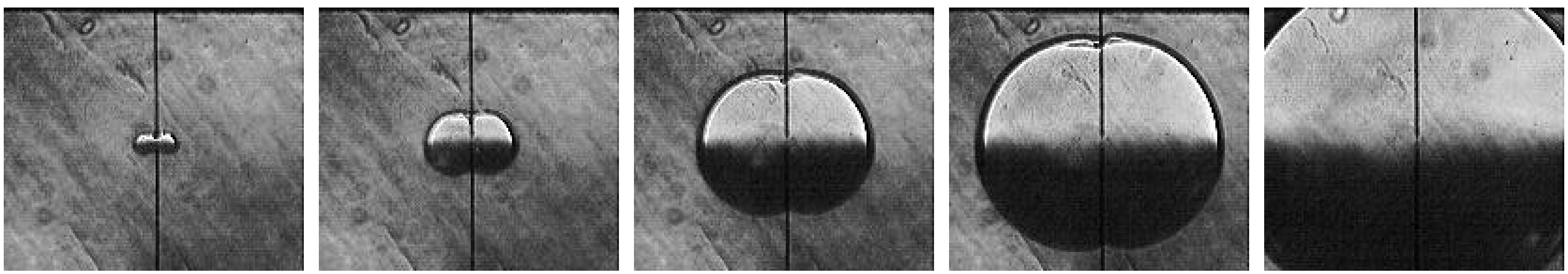
Activities

- H_2/electricity production
  - Membrane reactors
  - Incremental modifications of conventional technology
  - H_2 production with co-sequestration of sulfur (H_2S or SO_2) and CO_2.
- H_2/CO_2 infrastructure
- H_2 combustion
- Princeton-Tsinghua collaboration on low emission energy technologies for China
- H_2 utilization technologies

Differences in Propagation Mode between Lean Hydrogen-Air and Propane-Air Flames



Sequence of an expanding spherical lean hydrogen-air flame, showing the phenomena of flame surface wrinkling and self-acceleration



Sequence of an expanding spherical lean propane-air flame, showing the absence of flame surface wrinkling and self-acceleration

- Above result suggests the potential to suppress the tendency for a hydrogen-air mixture to self accelerate and detonate by adding a hydrocarbon

Princeton-Tsinghua Project: Modeling Coal Syngas-Based Energy Systems – “Syncity”

Princeton Tasks

- Polygeneration process design and cost modeling: DME,F-T liquids, methanol, H_2, syngas, chemicals, heat, electricity.
- Carbon sequestration analysis for near-term EOR and CBM; aquifer CO_2 storage for long term.
- Integrated strategic analysis.

Tsinghua Tasks

- Energy-data collection for Yanzhou and Jincheng.
- Coal-based polygeneration process design, simulation.
- Lifecycle environmental impact and cost analysis.
- Integrated strategic analysis.
- Outreach to Yangzhou Mining Group Ltd., Shanxi Jincheng Anthracite Coal Mining Group Ltd., and other decision makers.

Renewables/Fossil Energy Competition, Carbon-Constrained World

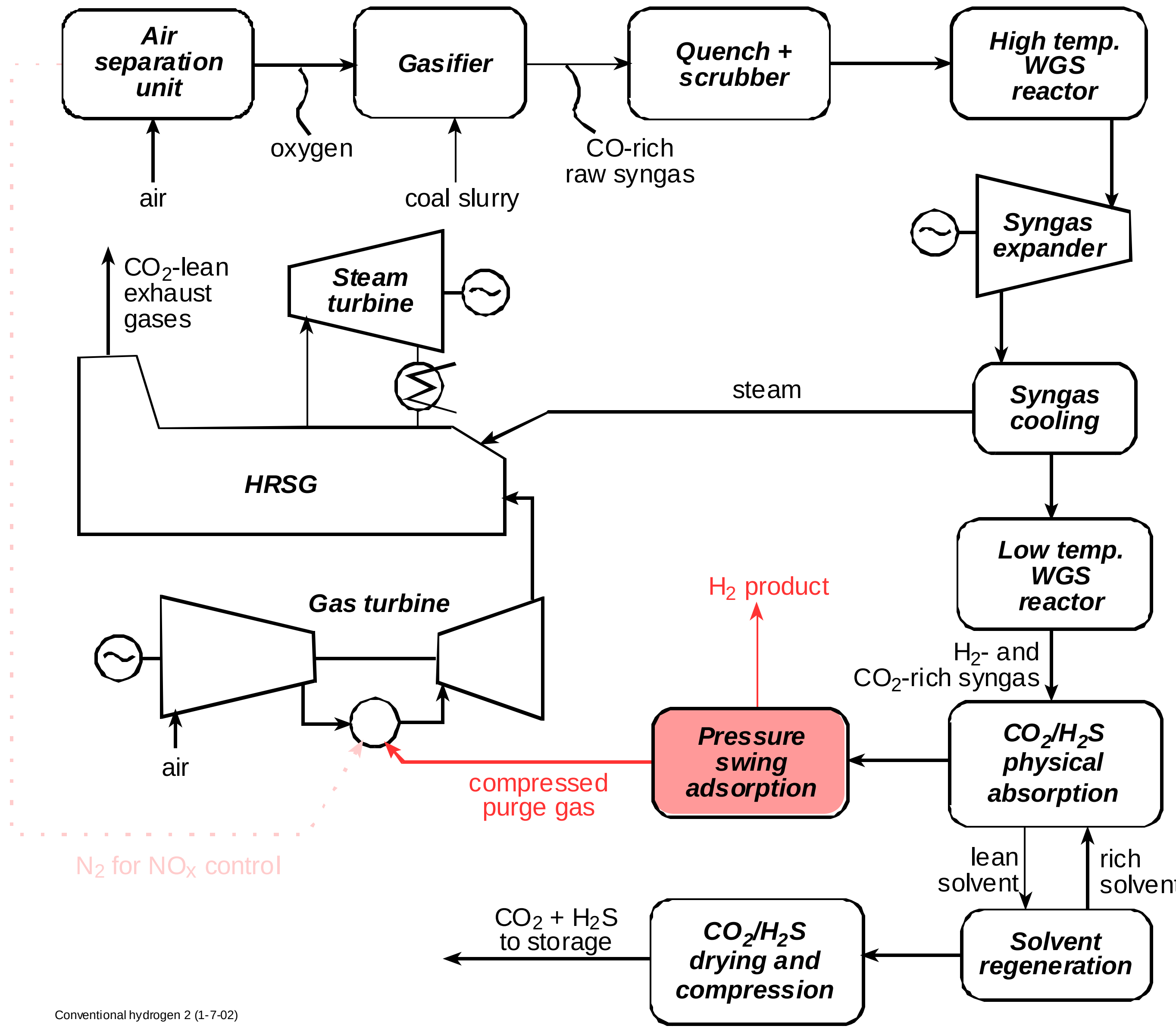
- For electricity, renewables will be strong competitors to decarbonized fossil fuels
  - Esp. for wind (central station), PV (distributed, grid-connected)
  - Large-scale electric storage problem solved (CAES)

- Poor economic prospects for making H_2 via electrolysis/thermochemical cycles from renewables for markets that use fuels directly (2/3 of CO_2 emissions today)—relative to H_2 from fossil fuels with CO_2 removal/sequestration

Implications of Renewable/Fossil Energy Competition for Carbon Management

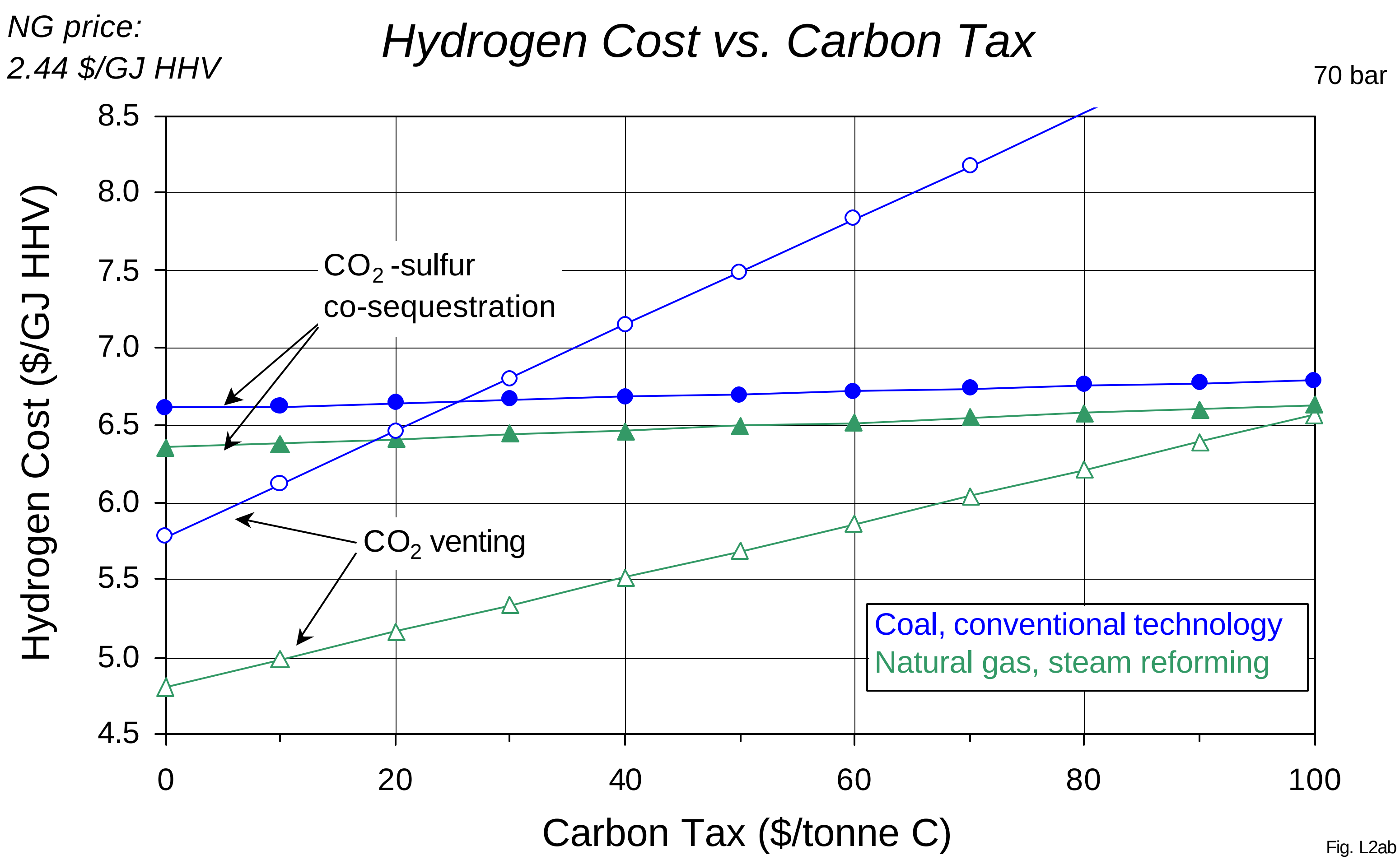
- No carbon problem if fossil fuels = conventional oil/NG
- Serious carbon problem if coal, tar sands, heavy oils, unconventional NG are consumed as "fuels used directly" w/o decarbonization, even if electricity 100% decarbonized
- But gasification-based H_2 production/CO_2 sequestration technologies offer good prospects for decarbonizing low-quality fossil energy feedstocks at attractive costs
- Residuals gasification at refineries: promising early step on path to large-scale gasification-based H_2 production

“Conventional Technology” H_2 Production with CO_2 Capture



Conventional hydrogen 2 (1-7-02)

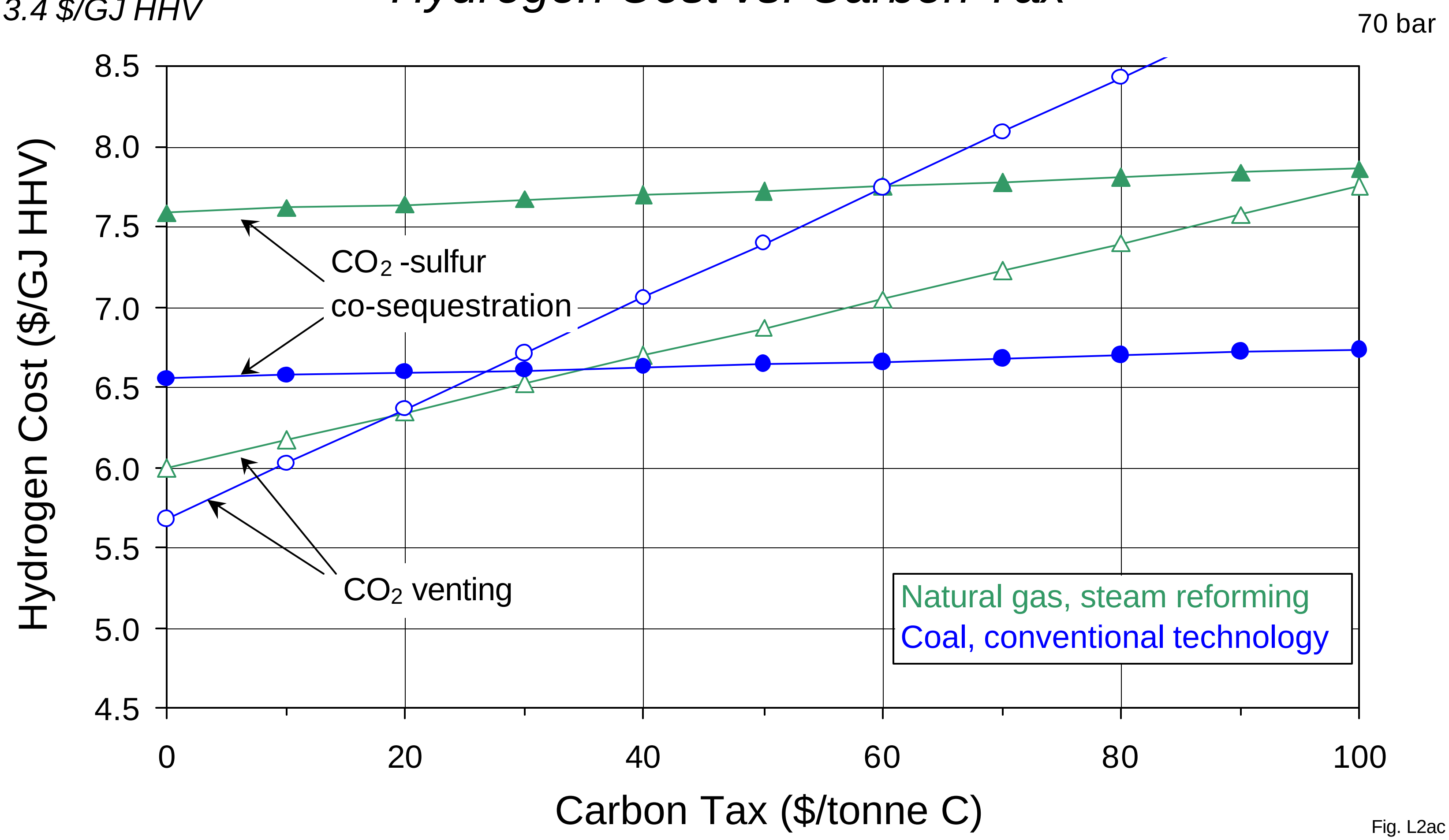
Hydrogen Cost vs. Carbon Tax



- With CO_2 venting, cost of H_2 from NG SMR always lower than H_2 from coal
- But, even at today's low NG prices (2.44 \$/GJ $\rightarrow$ 2.96 ¢/kWh), H_2 from coal with CO_2-sulfur co-sequestration is comparable to H_2 from NG
- Note: 70 bar conventional technology is commercially available today

NG price: 3.4 $/GJ HHV

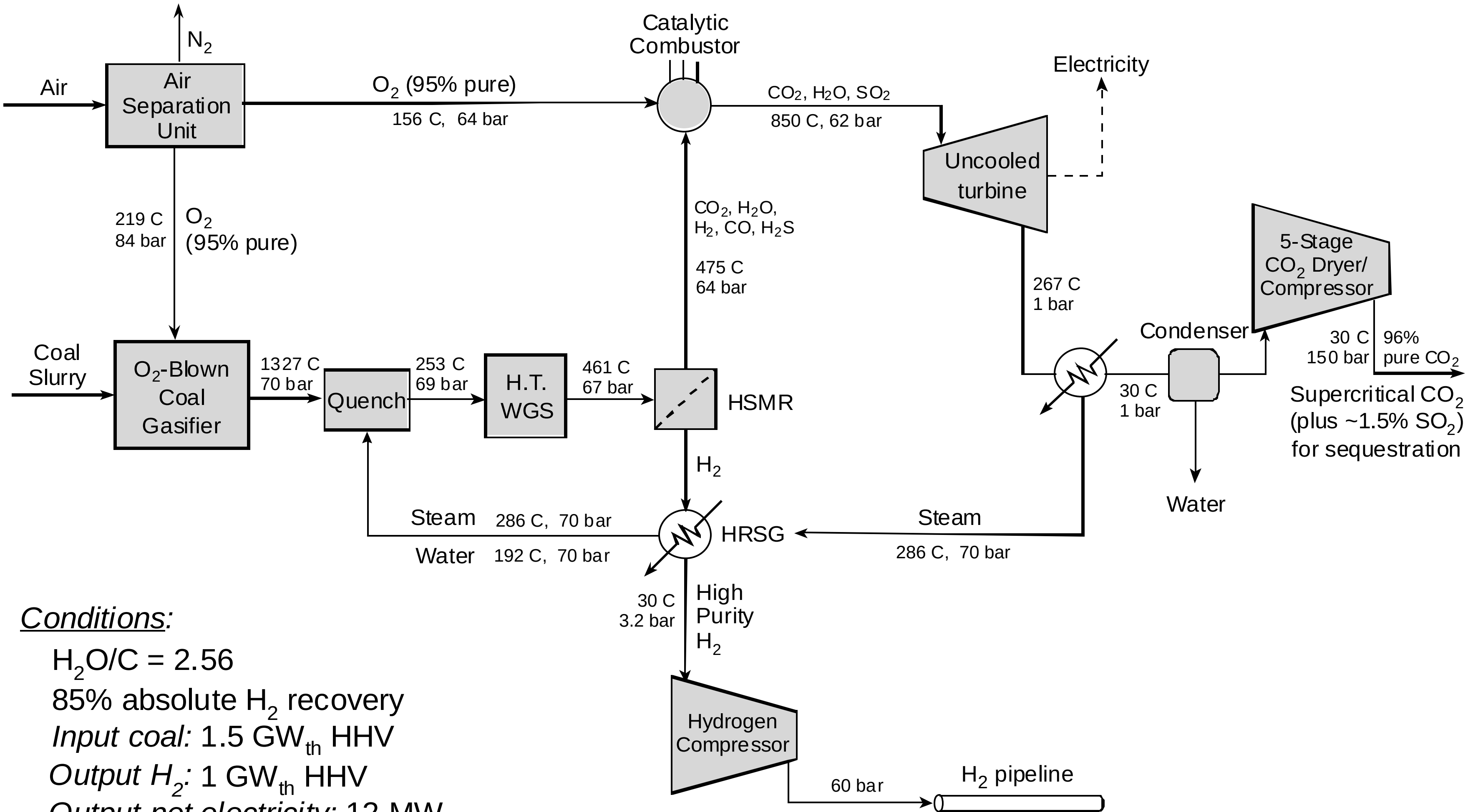
Hydrogen Cost vs. Carbon Tax



- At higher NG prices (3.4 \$/GJ HHV → 3.59 ¢/kWh), cost of H_2 from coal with CO_2-sulfur co-sequestration is significantly lower than H_2 from NG SMR
- Caveats: 1) NG SMR analysis not ours, 2) some benefits from ATR expected

HMSR-Based Production of Hydrogen and Electricity

- Uncooled Raffinate Turbine -



Conditions:

$H_2O/C = 2.56$

85% absolute H_2 recovery

Input coal: 1.5 GW_{th} HHV

Output H_2: 1 GW_{th} HHV

Output net electricity: 12 MW_e

Effective H_2 Conversion Efficiency (= 100[H_2 out] / [coal feed - coal saved])* = 69.0% (HHV)

CMI slide uncooled turbine 4 (#93) (1-9-02)

Hydrogen Cost vs Gasifier Pressure

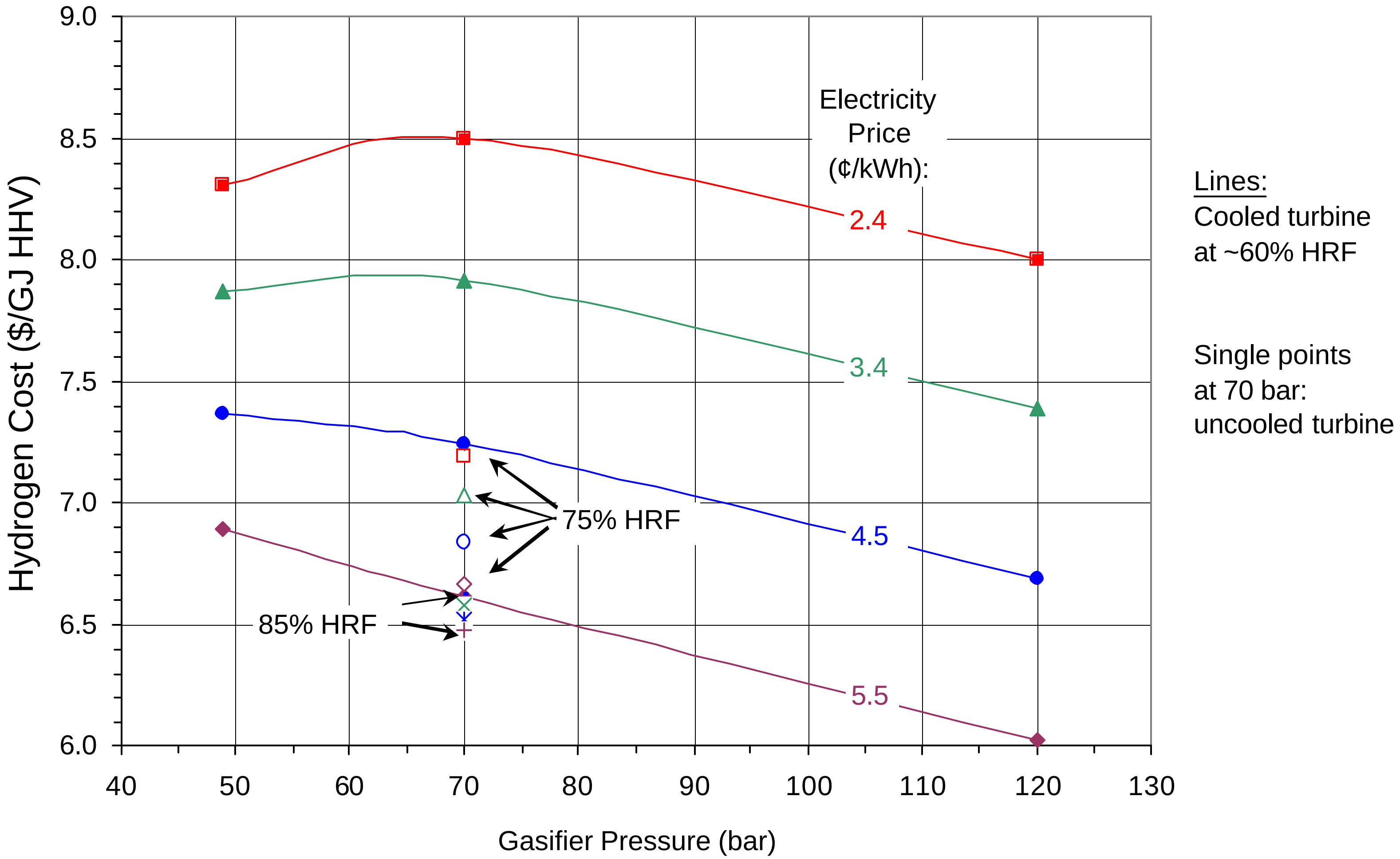
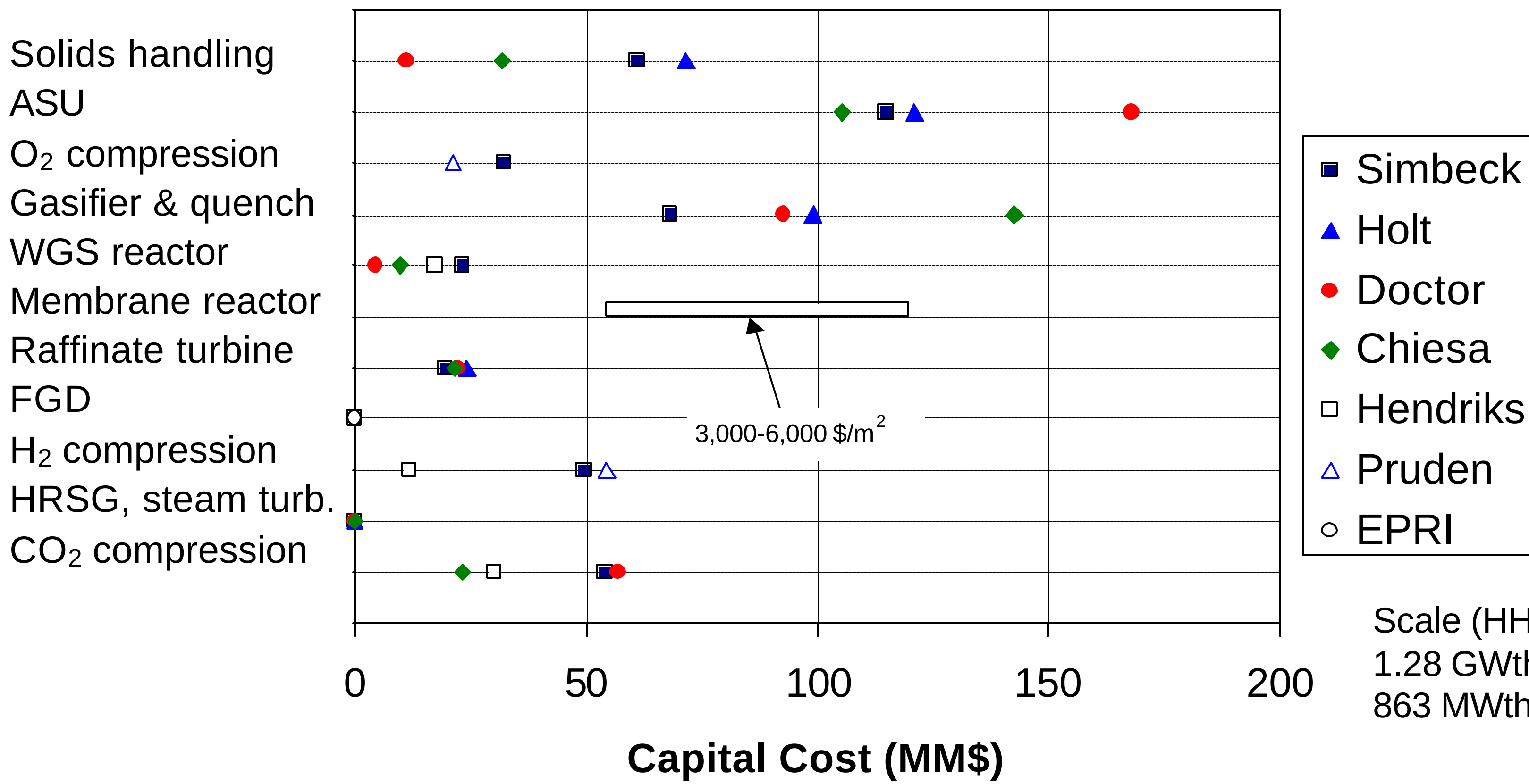


Fig. H2

- Increasing pressure can significantly reduce cost of decarbonized hydrogen
- Cooled raffinate turbine typically requires low HRF to realize high TIT
- Uncooled turbine/high H_2 recovery: greater promise, esp. at low elec. prices

Component Capital Cost Estimates



Scale (HHV): 1.28 GWth coal, 863 MWth H_2

Including installation, 23% BOP, 15% engineering, and variable process/project contingencies; exclusive of IDC

- Significant variation found in cost values, methodology, and depth of detail
- Our cost model consists of a self-consistent set of values from the literature
- Cost database is evolving; less reliable values removed; range is narrowing

Lessons Learned—Year 1
Major Technical Findings

- Optimal H_2 plant makes electricity coproduct—sensitive to electricity price
- Higher gasifier pressure ➔ lower H_2 cost
- Co-sequestration of S (H_2S or SO_2) with CO_2 ➔ substantial cost reduction—viable?
- Relative merits of HSMR & conventional gasifier-based technologies unclear

Lessons Learned—Year 1
Integrated Cost Analysis

Costs ($/GJ) of H_2 production from coal and NG

Feedstock	Feedstock cost	with CO_2		
		Vented	Seq.	Co-seq.
Coal	1.0	5.8	7.4	6.7
NG	3.2	5.8	7.4	7.4

Carbon tax ($/tC) needed to induce sequestration

	Natural Gas	Coal
Hydrogen	100	25
Electricity	250	50

Lessons Learned—Year 1
Strategic Considerations

- Near-term opportunity: gasify petroleum residuals at refineries to make H_2. For petcoke @ \$10/t, H_2 cost same as for SMR and \$2.5/GJ NG
  - CO2 coproduct much cheaper than from SMR…EOR opportunities?
- Feedstocks for gasification in longer term: heavy oils, tar sands, coal—delivered to city gate "carbon refineries" for H_2 manufacture