



# **The Challenge of Climate Change and the Promise of Fuel Cells**

## ***2003 Canadian Fuel Cells Systems Symposium***

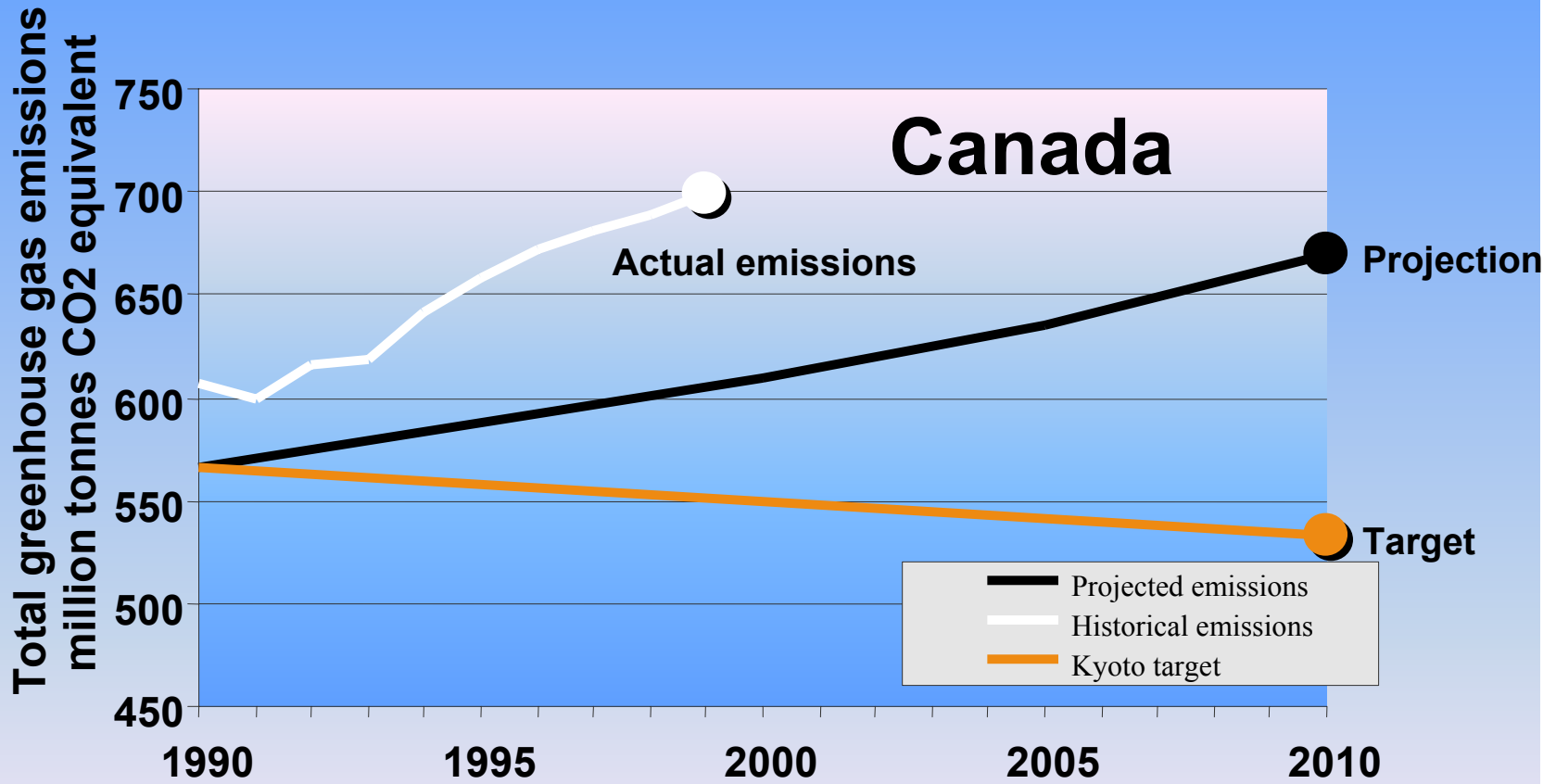
February 26 - 28, 2003

Eddy Isaacs

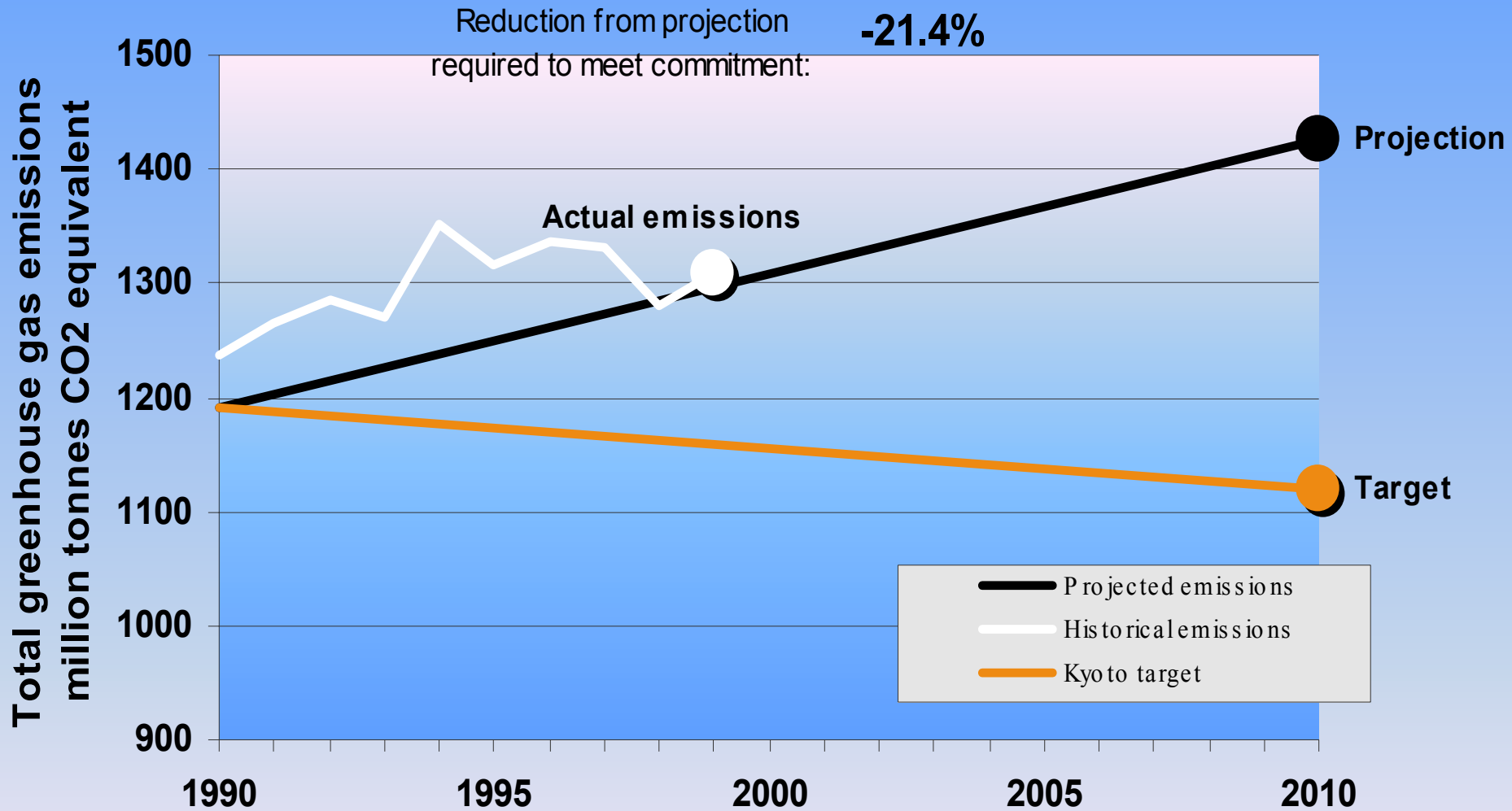
[WWW.AERI.AB.CA](http://WWW.AERI.AB.CA)



# How fit is Canada for a carbon constrained future?



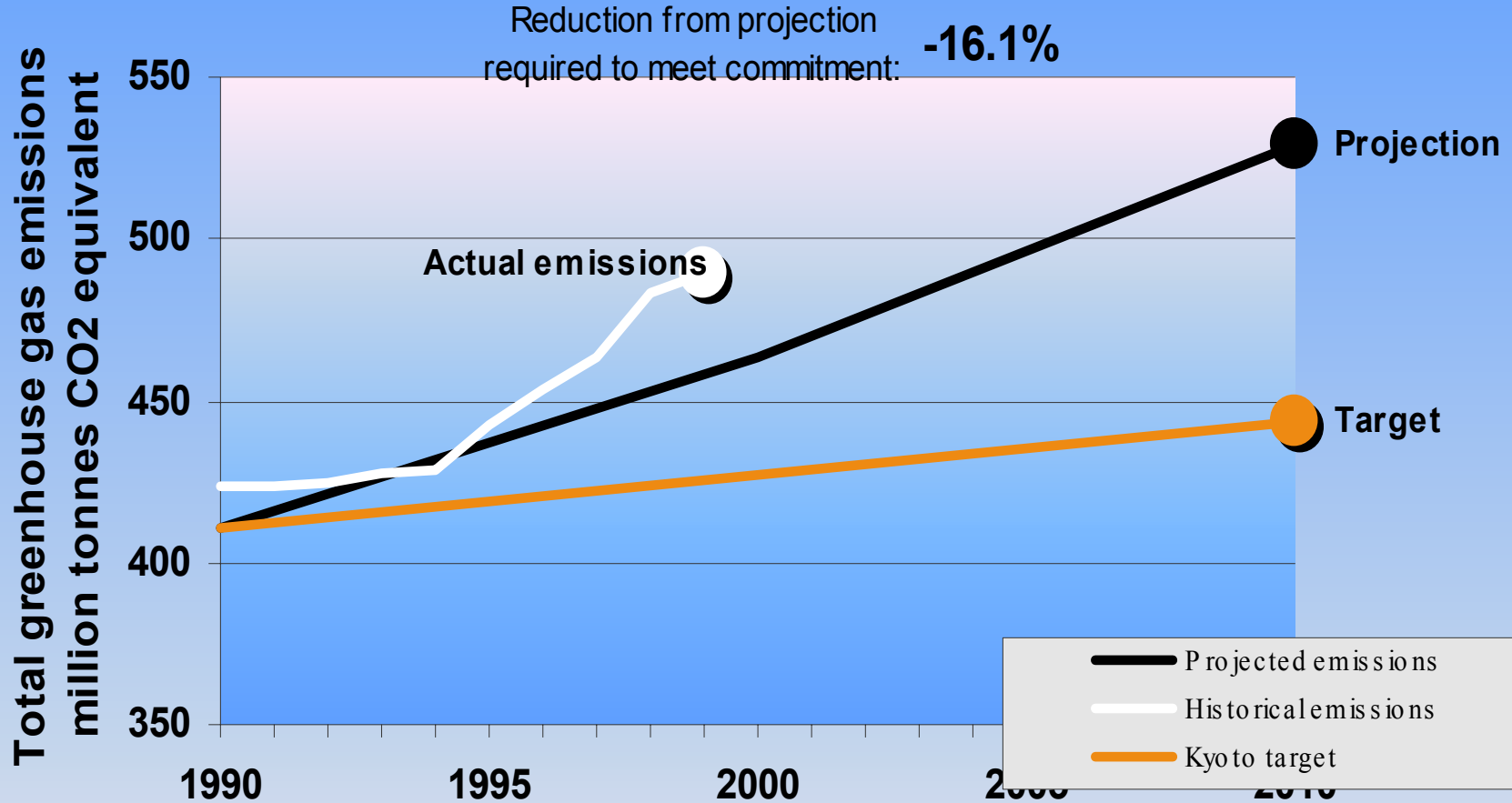
# Japan



Actual and projected emissions of six greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs, SF<sub>6</sub>)

Sources: Actual emissions UNFCCC/SBI/2000/11 Table B.1. Projected emissions UNFCCC/1998/Add.2 Table C.6.

# Australia

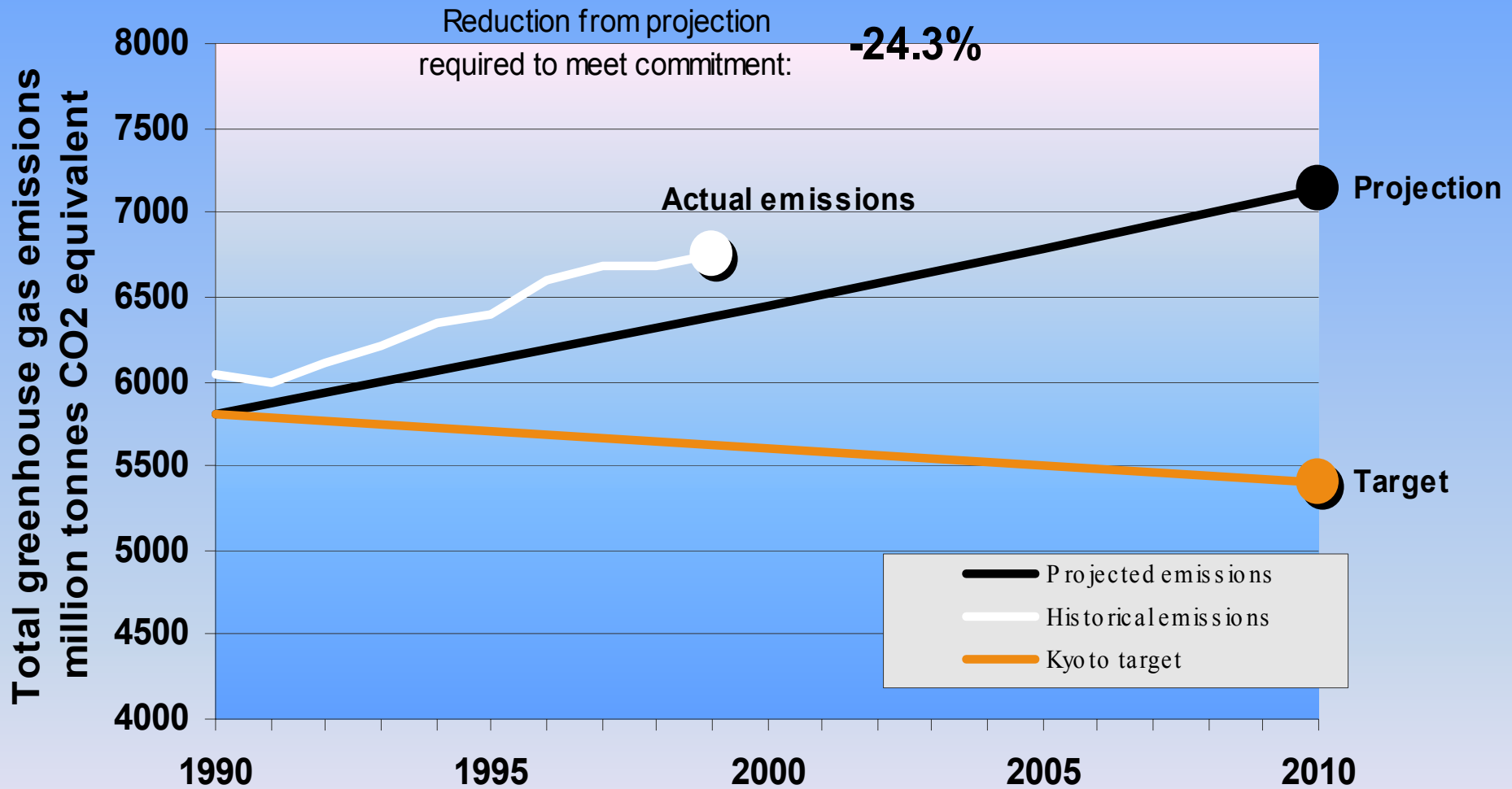


Actual emissions of CO<sub>2</sub>, CH<sub>4</sub>, NO<sub>2</sub>, PFCs, SF<sub>6</sub>.

Sources: Actual emissions UNFCCC/SBI/2000/11 Table B.1. Projected emissions UNFCCC/1998/Add.2 Table C.6.

Projected emissions are CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O and PFCs for 1990 and 2010

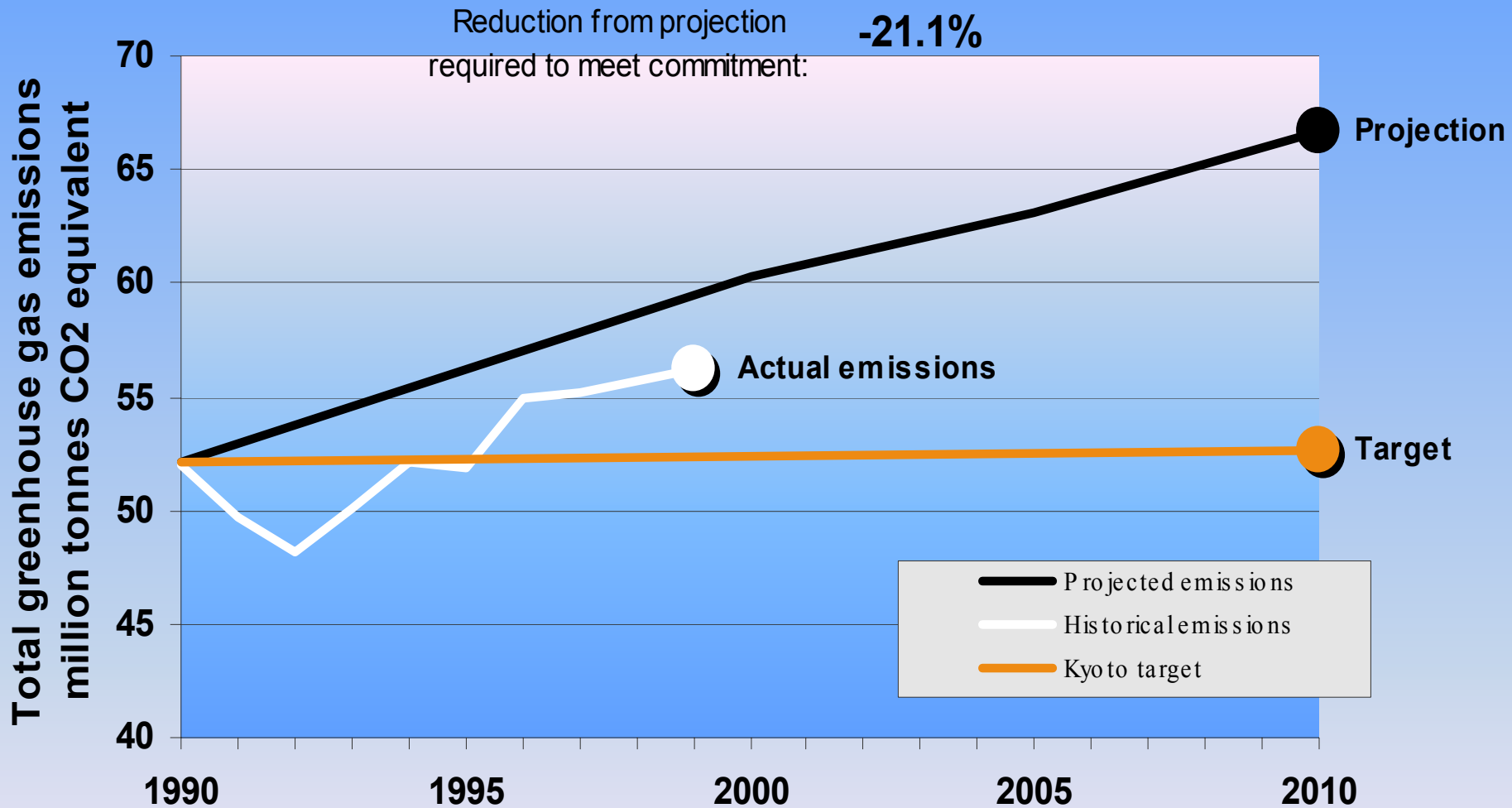
# United States



Actual and projected emissions of six greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs, SF<sub>6</sub>)

Sources: Actual emissions UNFCCC/SBI/2000/11 Table B.1. Projected emissions UNFCCC/1998/Add.2 Table C.6.

# Norway

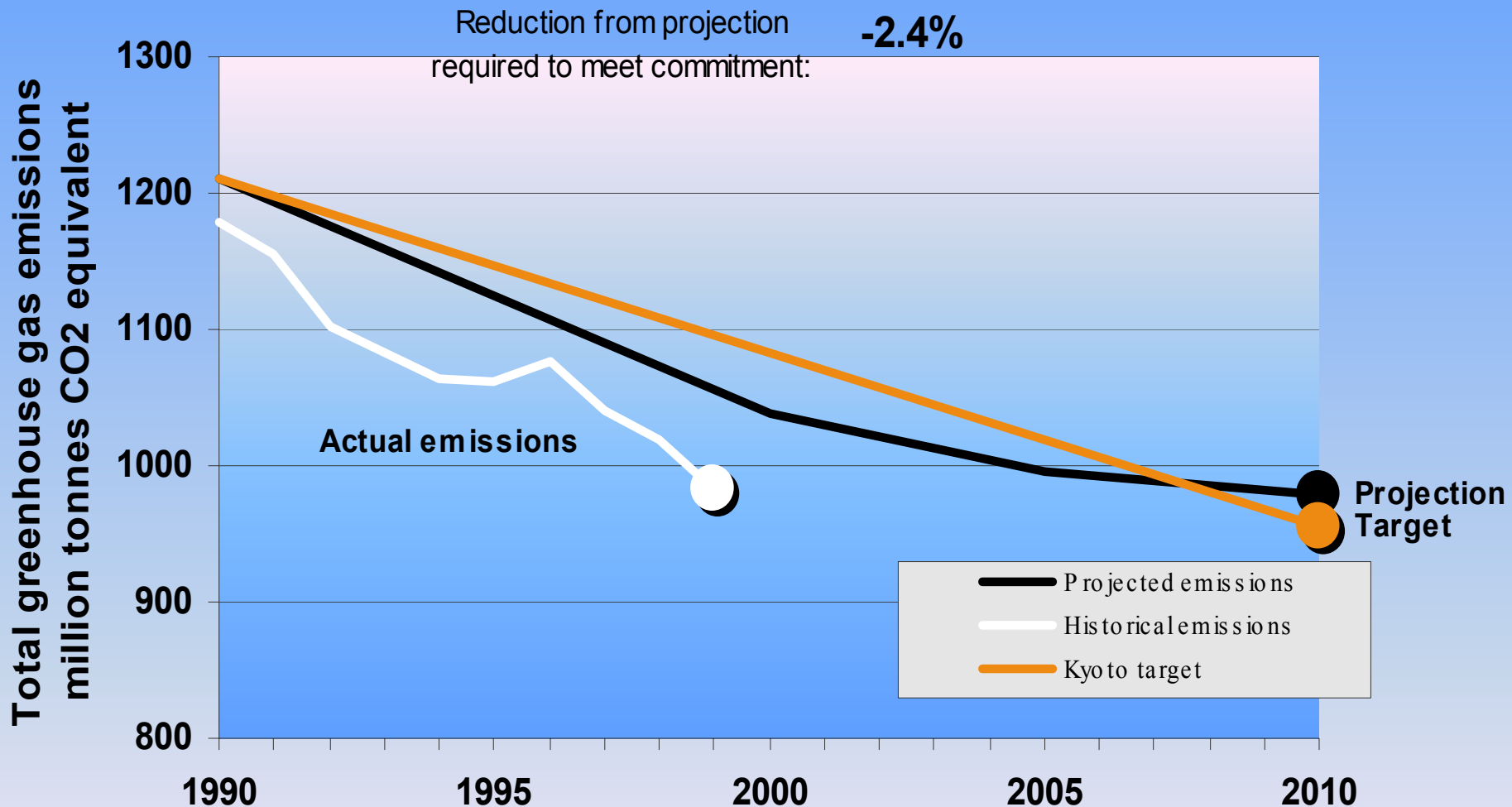


Actual and projected emissions of six greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs, SF<sub>6</sub>)

Sources: Actual emissions UNFCCC/SBI/2000/11 Table B.1. Projected emissions UNFCCC/1998/Add.2 Table C.6.

Source: Miljøstatus i Norge, Statens forurensningstilsyn (SFT), <http://www.mistin.dep.no/>

# Germany

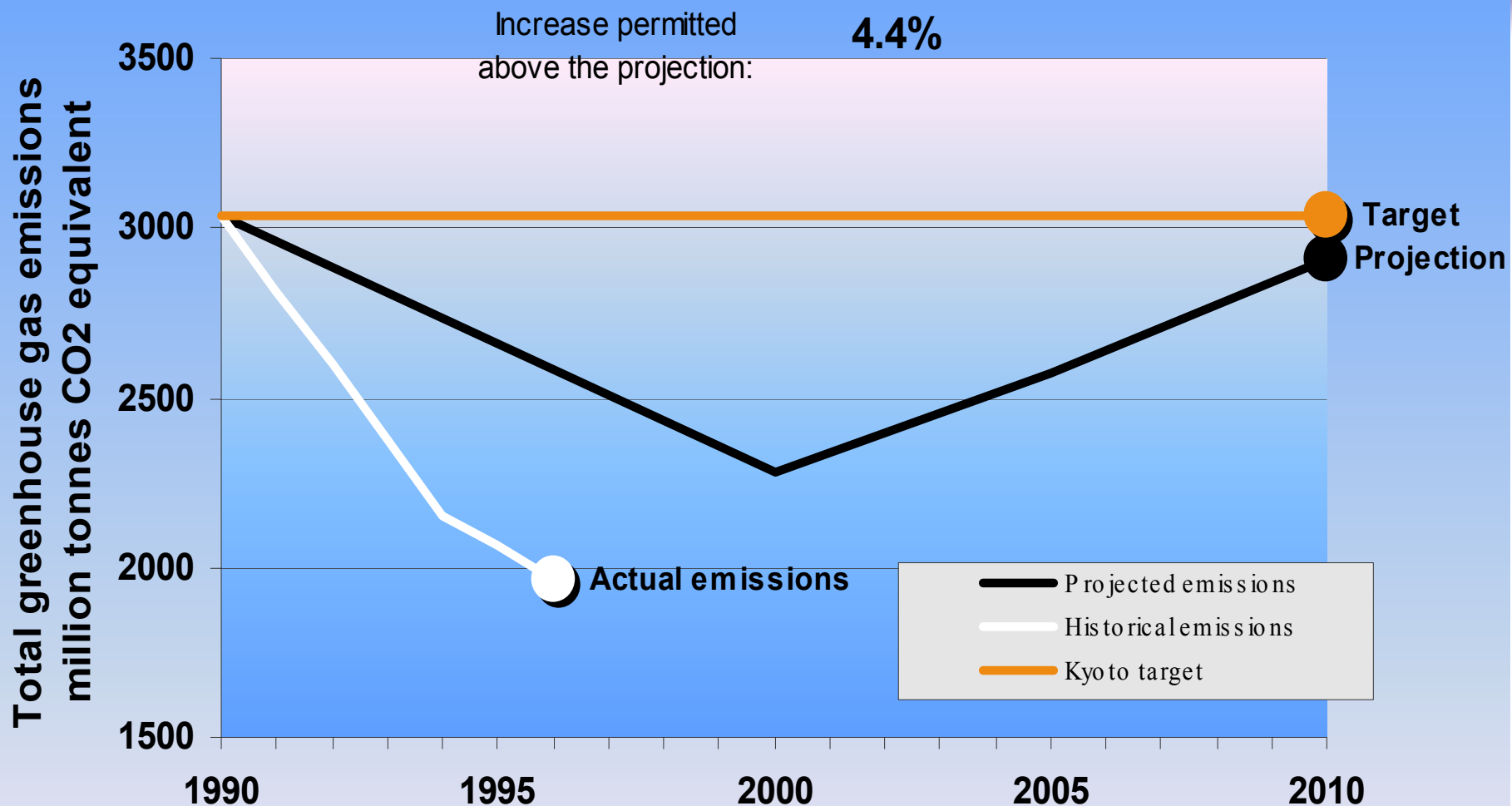


Actual and projected emissions of six greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs, SF<sub>6</sub>)

Sources: Actual emissions UNFCCC/SBI/2000/11 Table B.1. Projected emissions UNFCCC/1998/Add.2 Table C.6.

Source: Updated 2000 Report of the Federal Republic of Germany

# Russian Federation

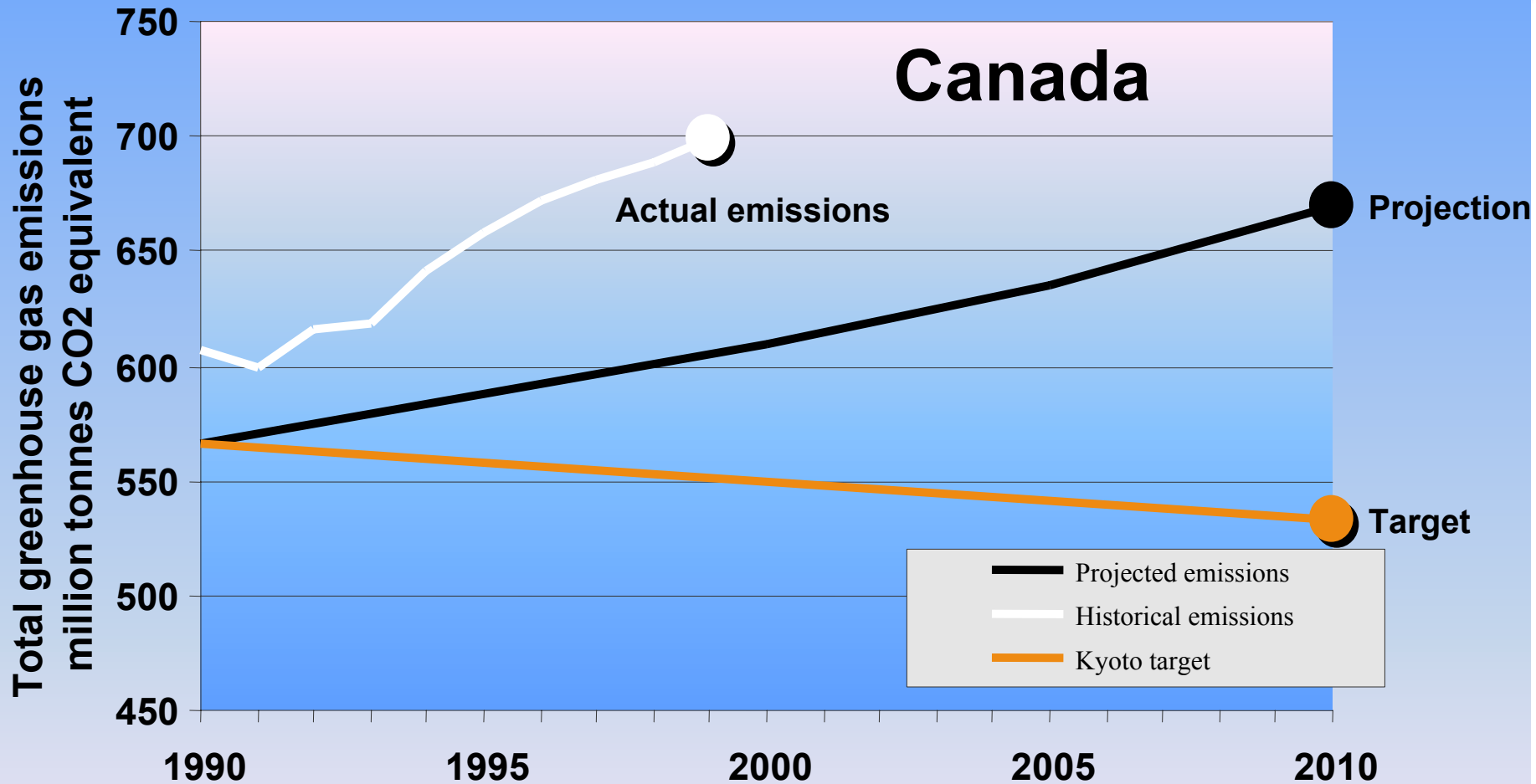


Actual and projected emissions of CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, and PFCs.

Sources: Actual emissions UNFCCC/SBI/2000/11 Table B.1. Projected emissions UNFCCC/1998/Add.2 Table C.6.

Projected emissions are CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs and SF<sub>6</sub> for 1990 and 2010

# Canada's Kyoto Dilemma



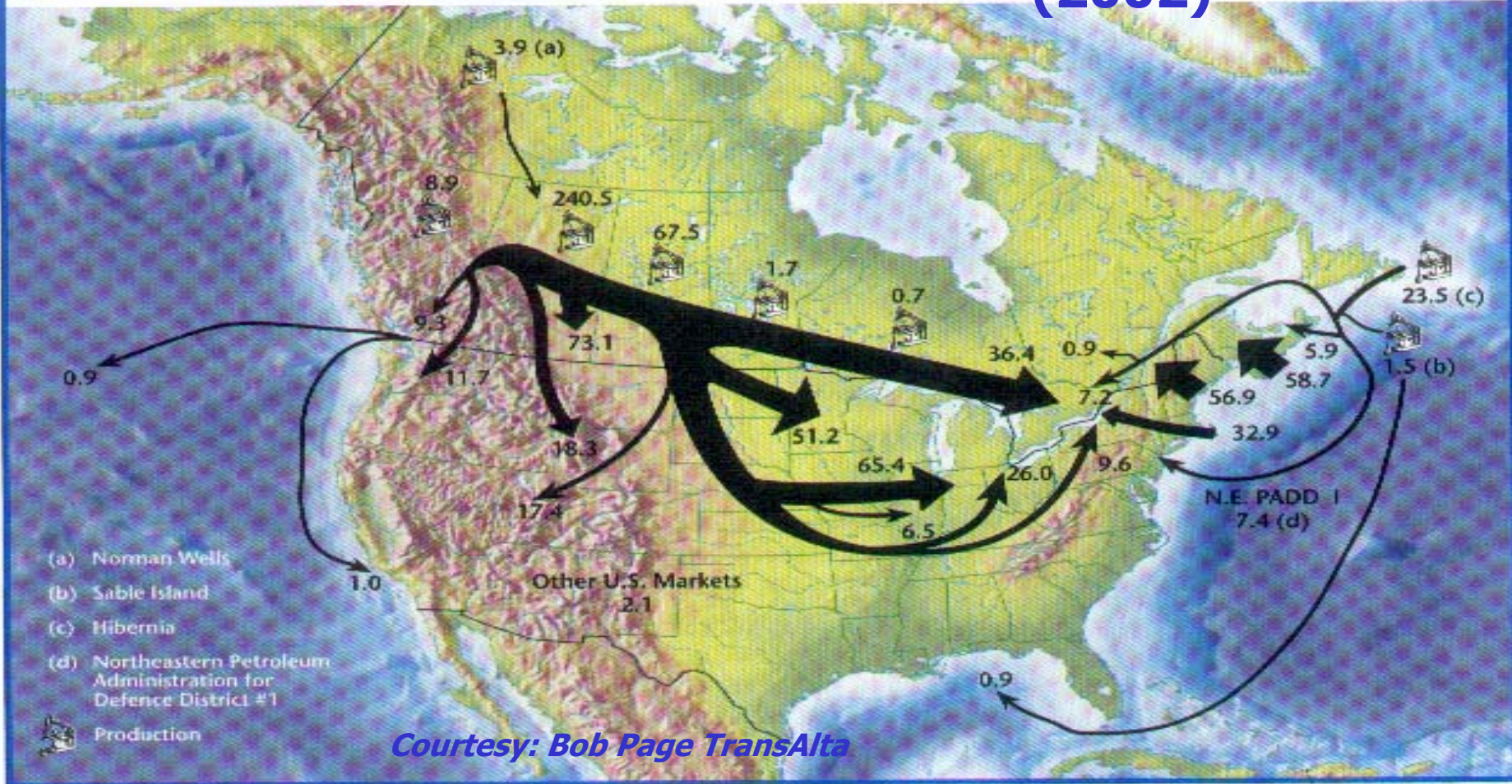
Actual and projected emissions of six greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs, SF<sub>6</sub>)

Sources: Actual emissions UNFCCC/SBI/2000/11 Table B.1. Projected emissions UNFCCC/1998/Add.2.



**FIGURE 5**  
**Crude Oil and Equivalent Supply and Disposition**  
 (thousand cubic metres per day)

## National Energy Board (2002)

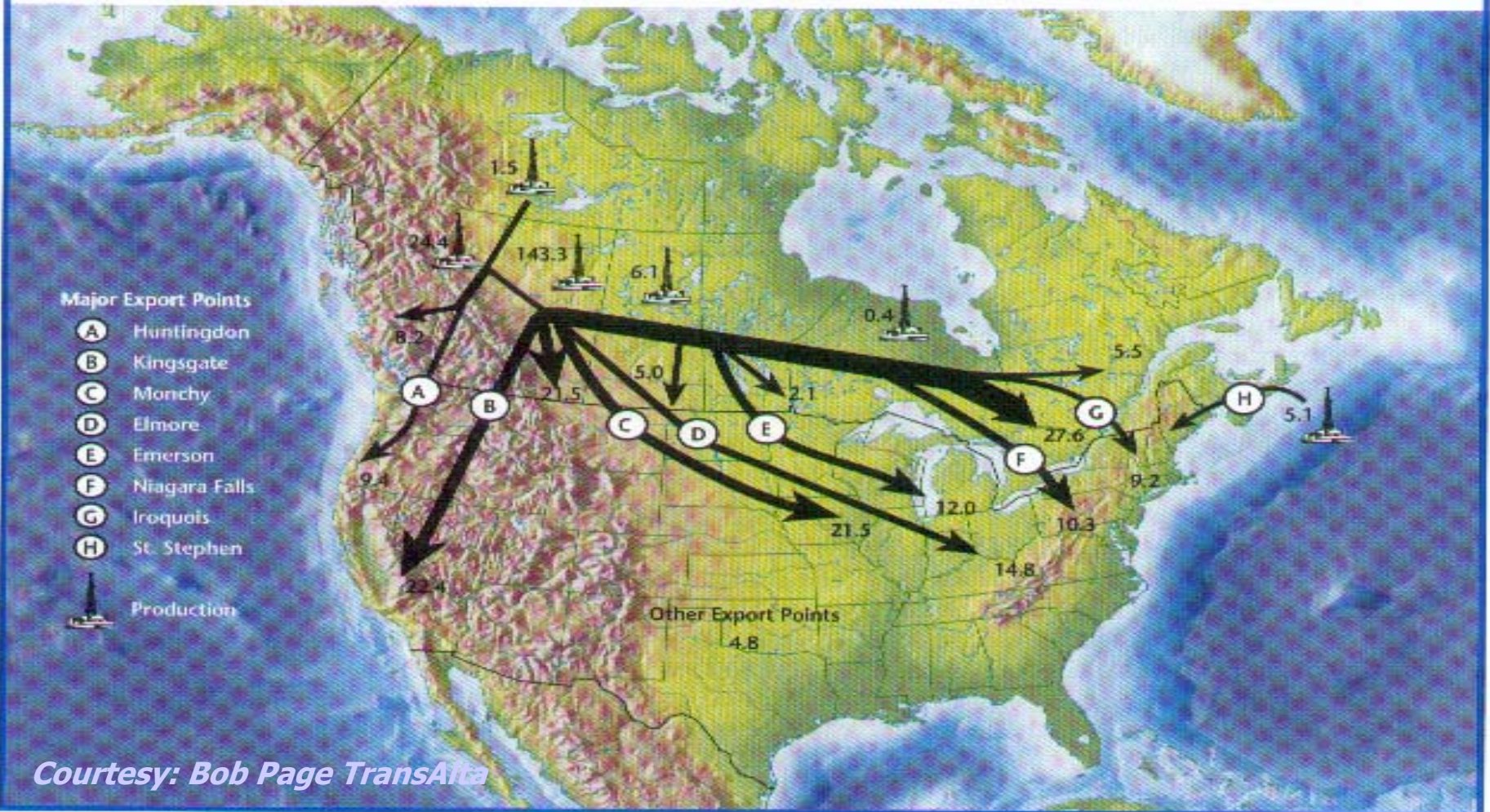


*Courtesy: Bob Page TransAlta*



# National Energy Board (2002)

**FIGURE 8**  
Natural Gas Supply and Disposition  
(billion cubic metres)



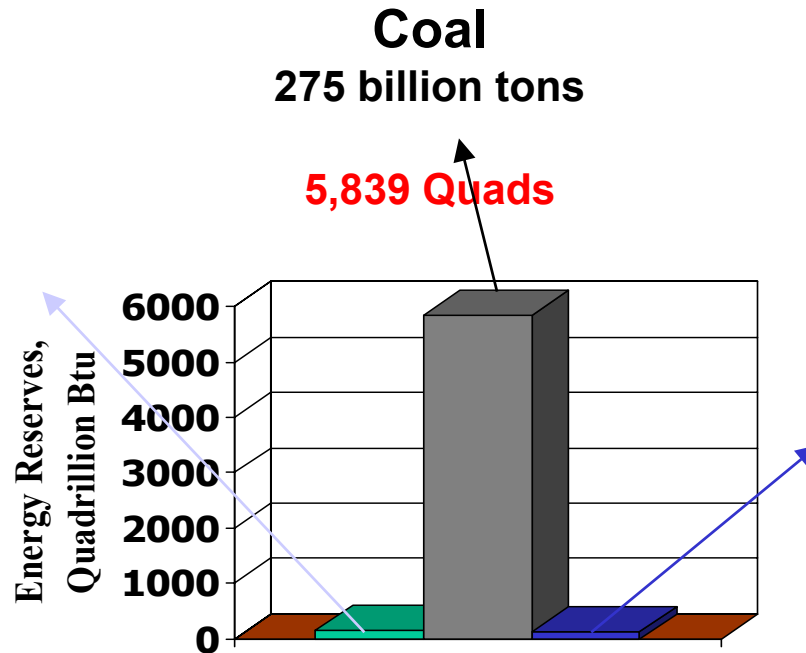
*Courtesy: Bob Page TransAlta*



## Proven Hydrocarbon Reserves of the U.S.



**Natural Gas**  
More than  
164 Tcf  
**168 Quads**

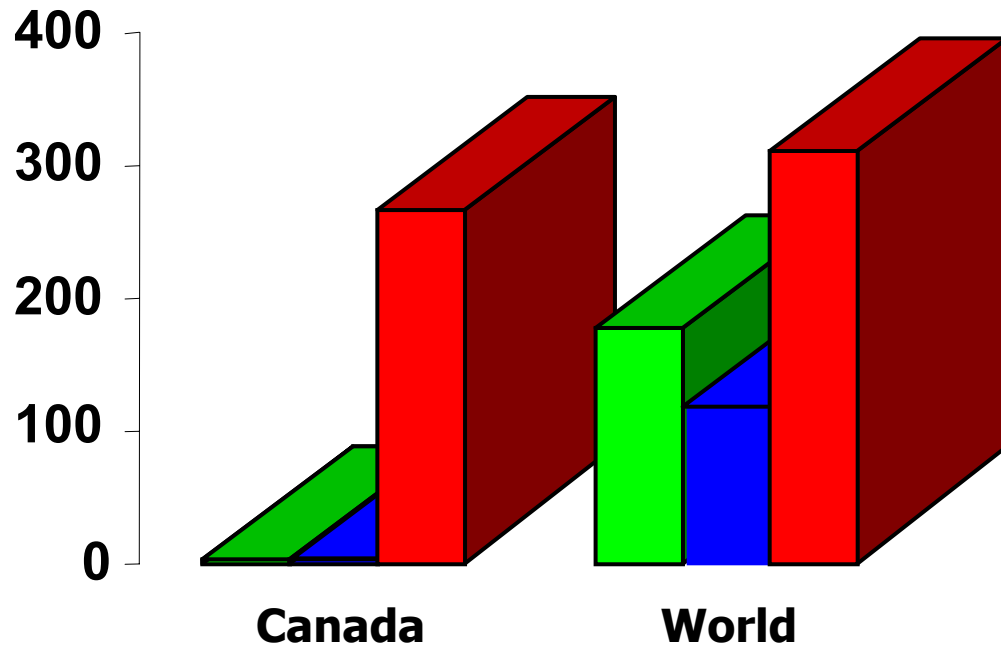


**Oil**  
21 billion barrels  
**122 Quads**



# Canadian vs. World Oil Resources

(billion m<sup>3</sup>)

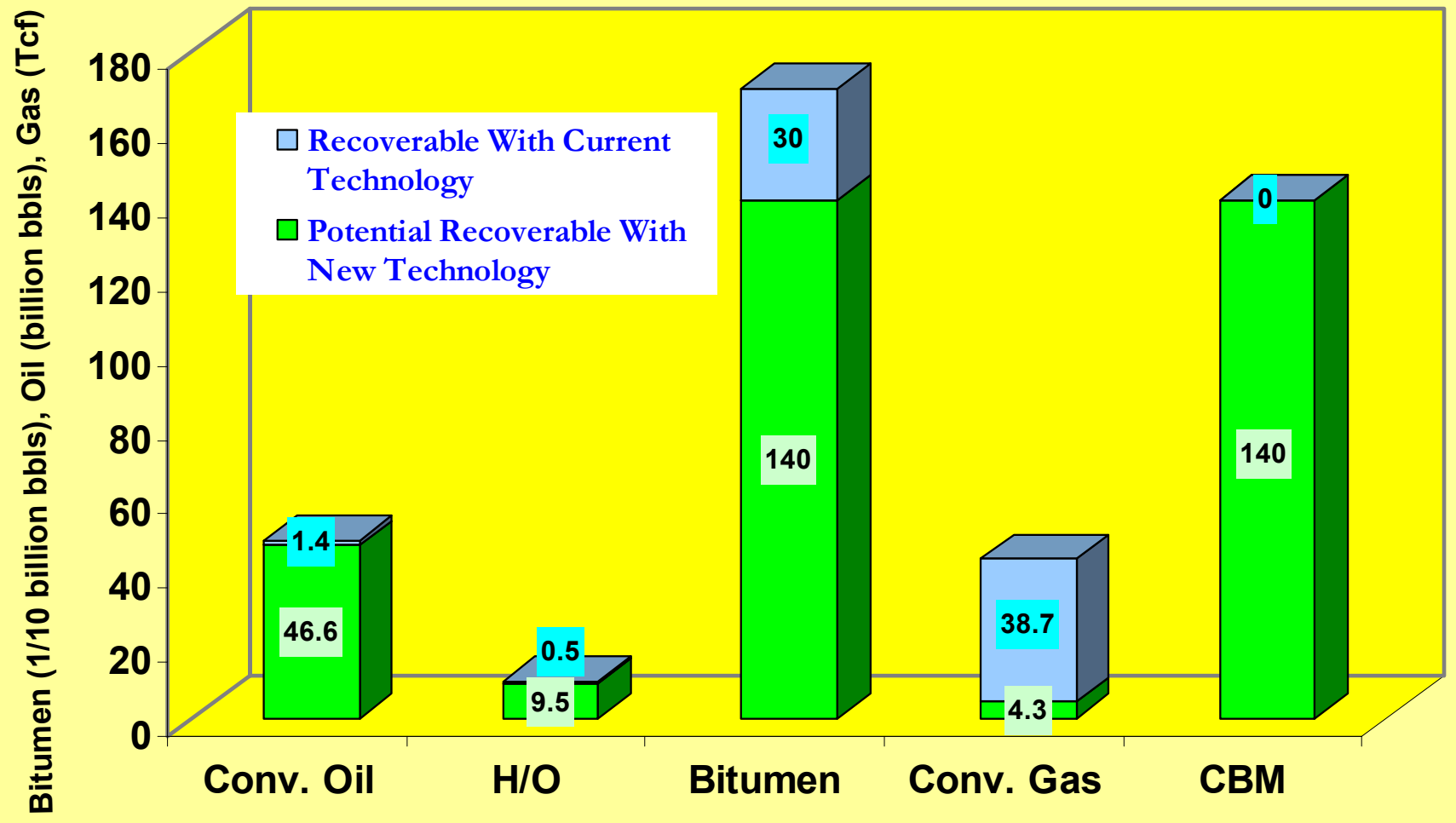


- Conventional
- Heavy Oil
- Bitumen

*Wightman (1997)*



# Alberta's Petroleum Outlook



Based on AEUB Data (2001)



# Alberta's Coal: Status

## ➤ **Source: Unlimited**

- ❑ Ultimate Potential: 620 billion tonnes
- ❑ Production (2000): 0.035 billion tonnes

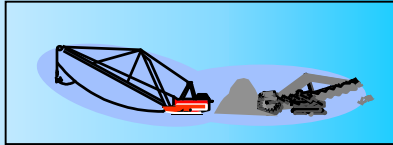
## ■ **Alberta's coal reserves**

- **70% of Canada's**
- **50% of coal produced in Canada**
- **2x the energy of all other natural resources (oil sands, oil and natural gas)**
- **7 Major mines**
  - **80% electricity generation**
    - **Sub-bituminous (low S, clean burning)**
  - **20% exported – valued at \$380 million**
    - **Metallurgical**

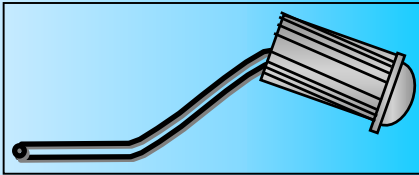


# Oil Sands: Improved Efficiency

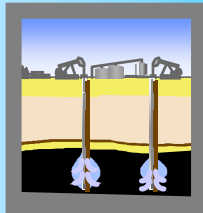
## OLD



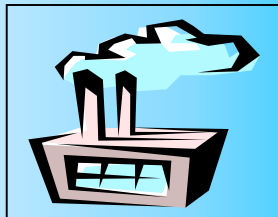
Dragline & Bucketwheel



Conveyor & Tumblers (80°C)



Vertical Wells

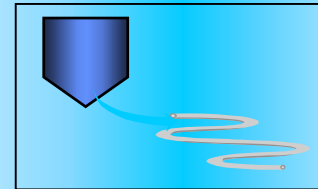


Coal fired Power Plant

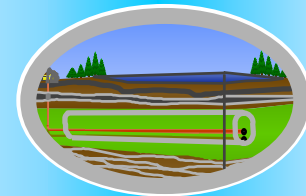
## NEW



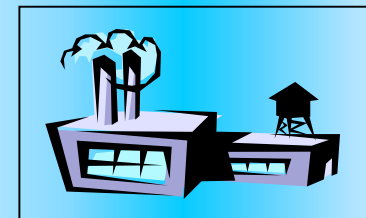
Truck & Shovel



Low Energy Extraction  
25 - 50° C  
Hydrotransport



SAGD Horizontal Wells



Co-Gen Power Plants

**Energy Efficiency**



**45%  
Reduction in  
CO<sub>2</sub> per  
barrel**

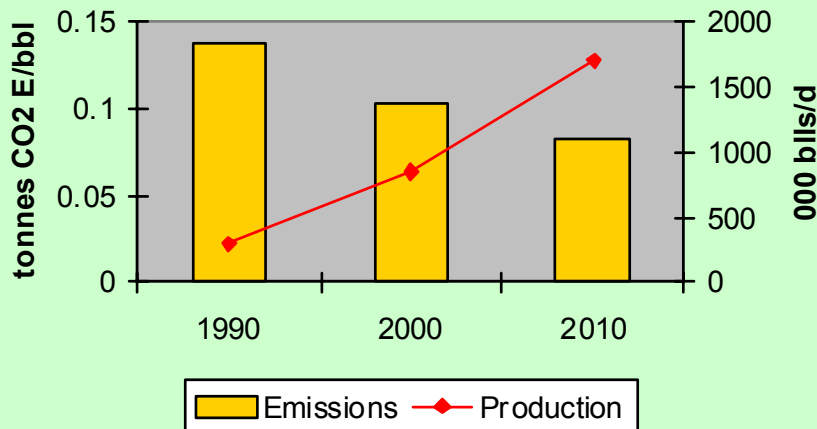
**(2008 vs 1990  
technology)**



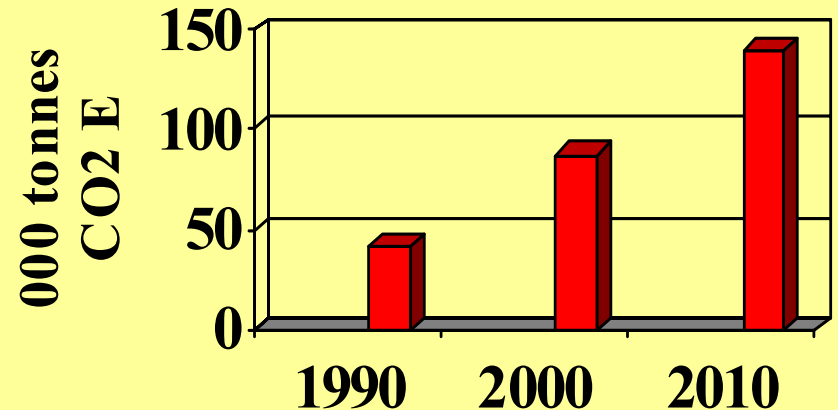
# Oil Sands Development & Emissions

- ❑ High growth in production rates
  - ❖ 0.35 million bbls/d in 1990 to 4.8 million bbls/d by 2011 (100 % case)
- ❑ Heavily dependent on natural gas
  - ❖ Hydrogen production
  - ❖ Steam generation
  - ❖ Co-generation

**Oil sands energy efficiency gains**

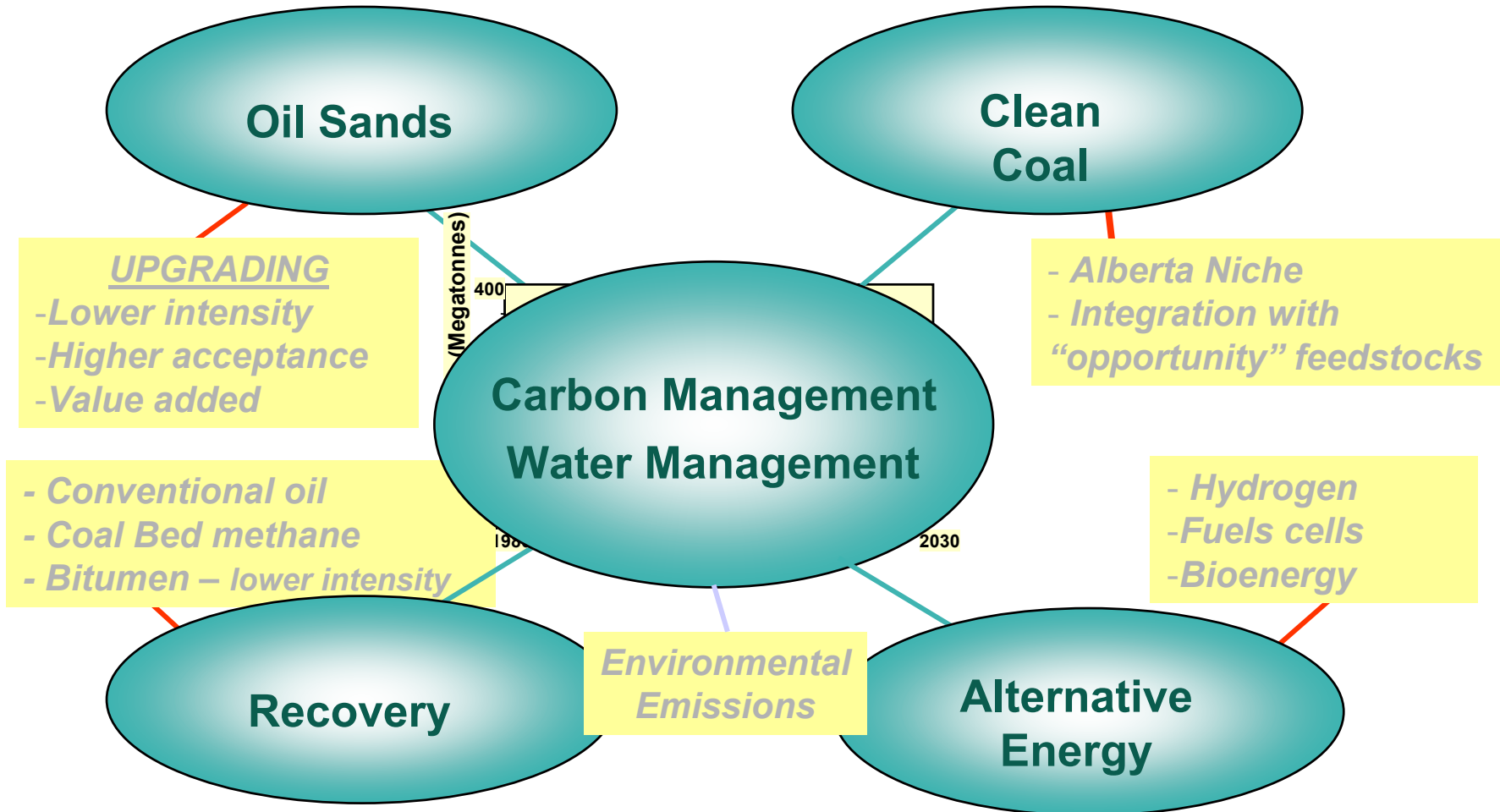


**Total emissions increase**



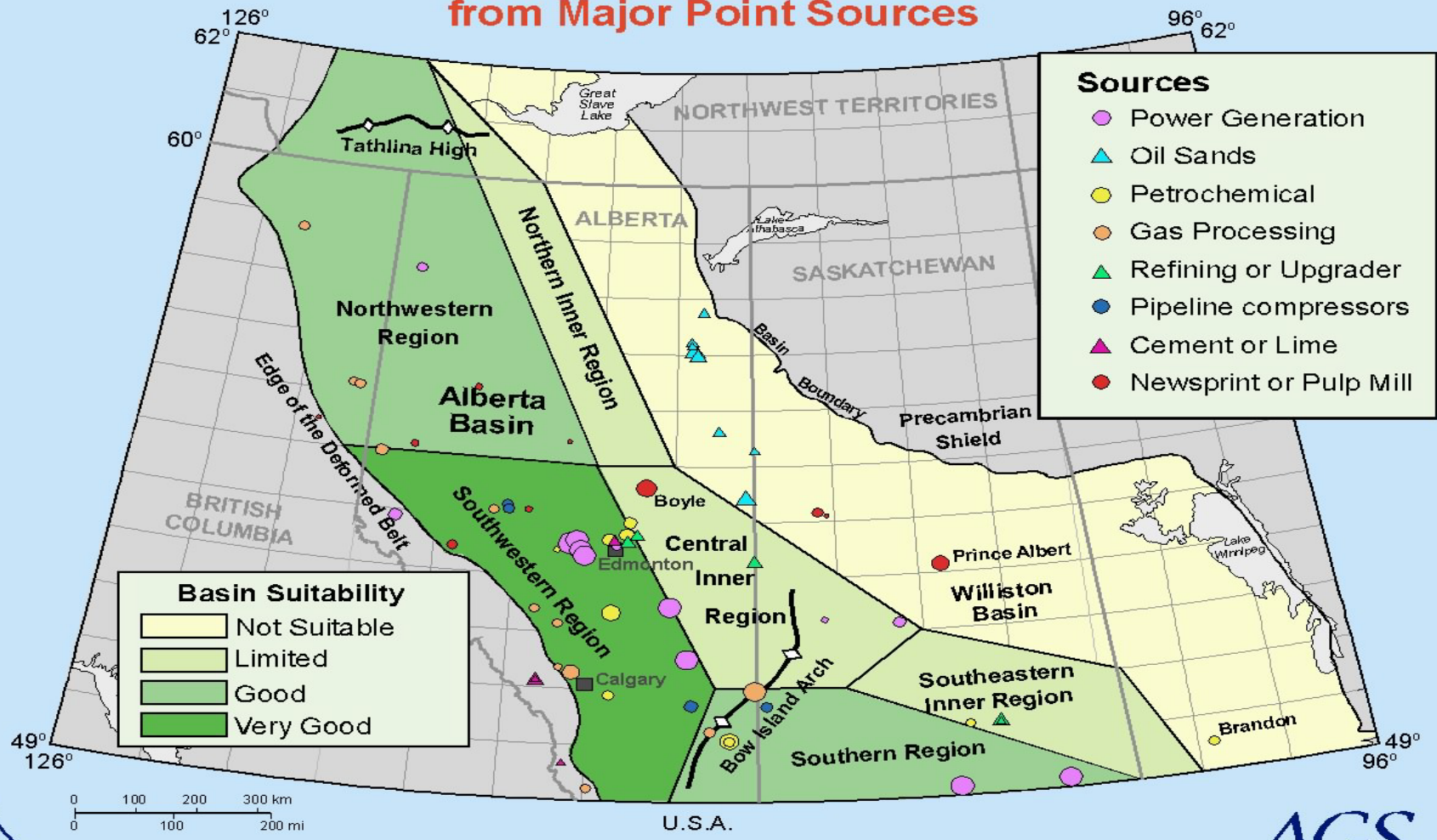


# Alberta Energy Research Institute (AERI) Priority Research & Technology Areas





## Basin Suitability for Geological Storage and Carbon Dioxide Emissions from Major Point Sources



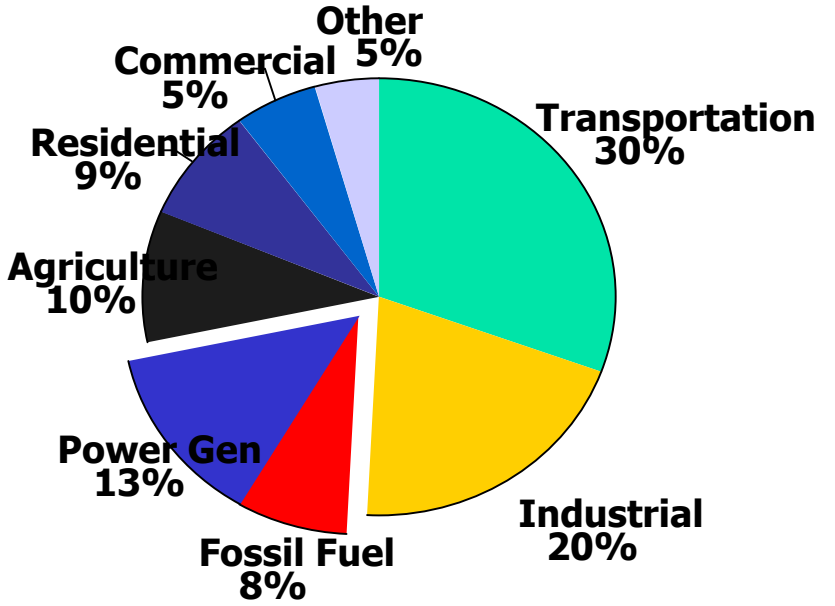
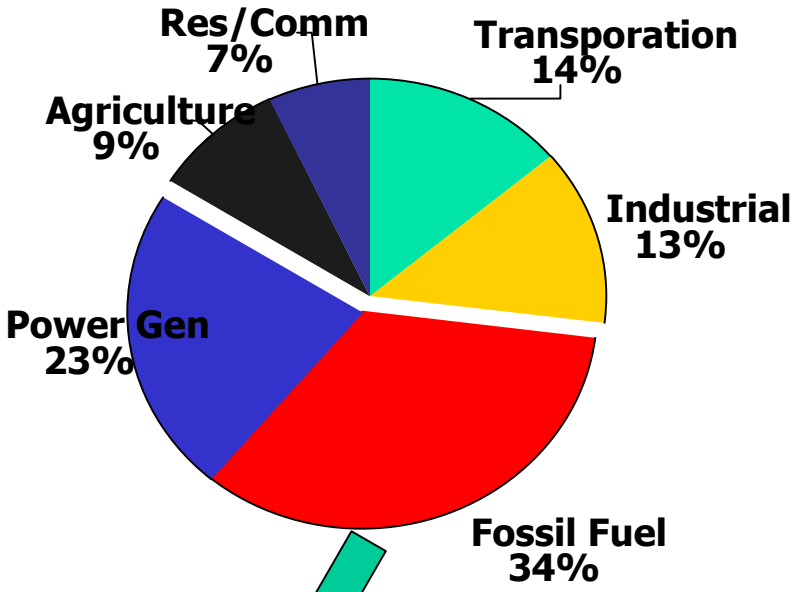


# CO<sub>2</sub> emissions for Alberta and Canada- separating energy production from the consumption cycle

**Alberta  
205Mt**

**1999 GHG Emissions**

**Rest of Canada  
490 Mt**

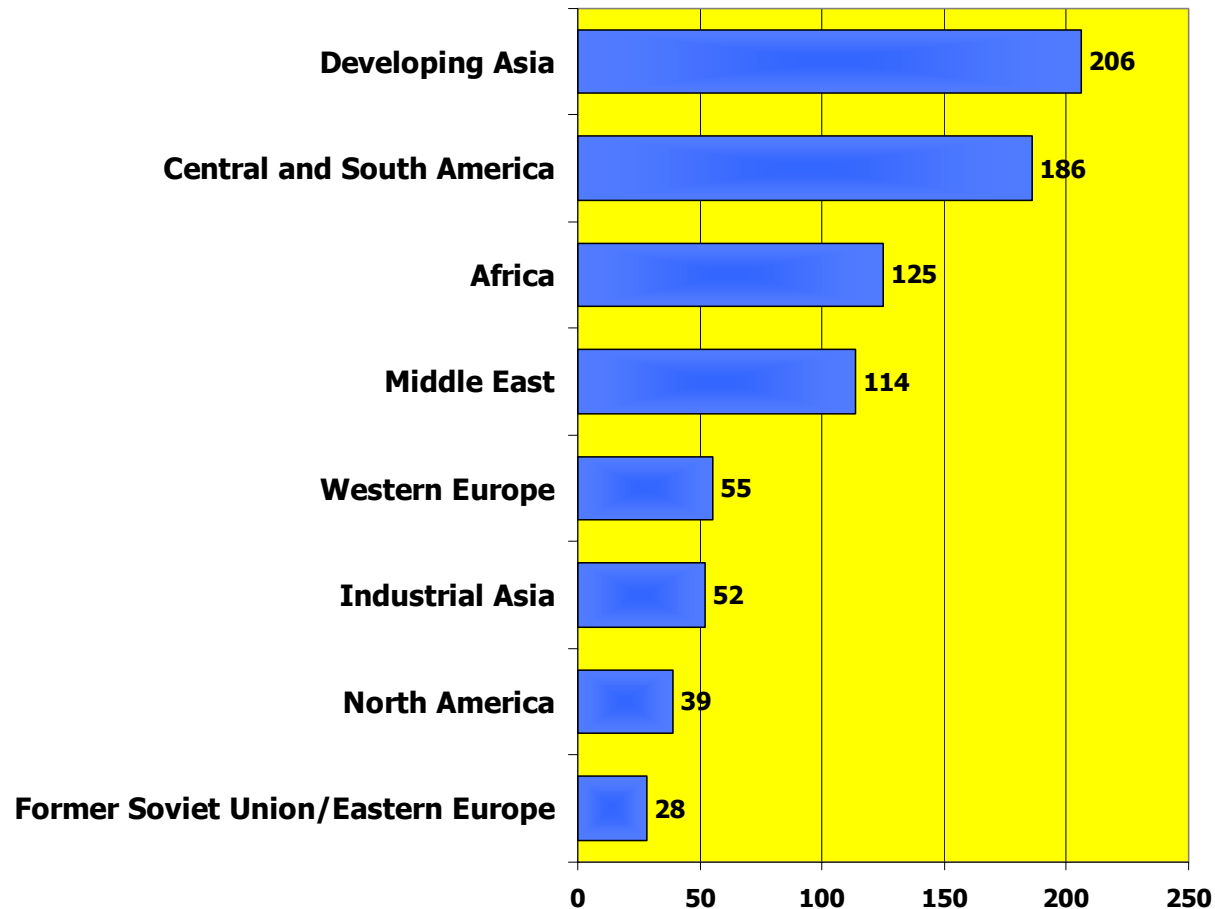


**40% of Alberta's GHG emissions associated with oil and gas exports**

Source : NRCAN: Canada's Emissions Outlook: An Update, 2000  
Courtesy of Climate Change Central



## Predicted growth in net electricity consumption by region 1996-2020





# Fuel Cells - Key Advantages

- Converts primary fuel (e.g. natural gas) to electricity
  - ❑ Improves fuel utilization and efficiency
  - ❑ Avoids losses associated with transmitting electricity over long distances
- "Waste" heat can be efficiently used
  - ❑ "waste" heat available at high temperatures

- Traditional utility
  - ❑ 30% efficiency
  - ❑ 8% lost due to transmission/distribution

- Fuel Cell Power Plant\*
  - ❑ 37% electrical efficiency
  - ❑ 87% including full heat recovery

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\*Phosphoric acid



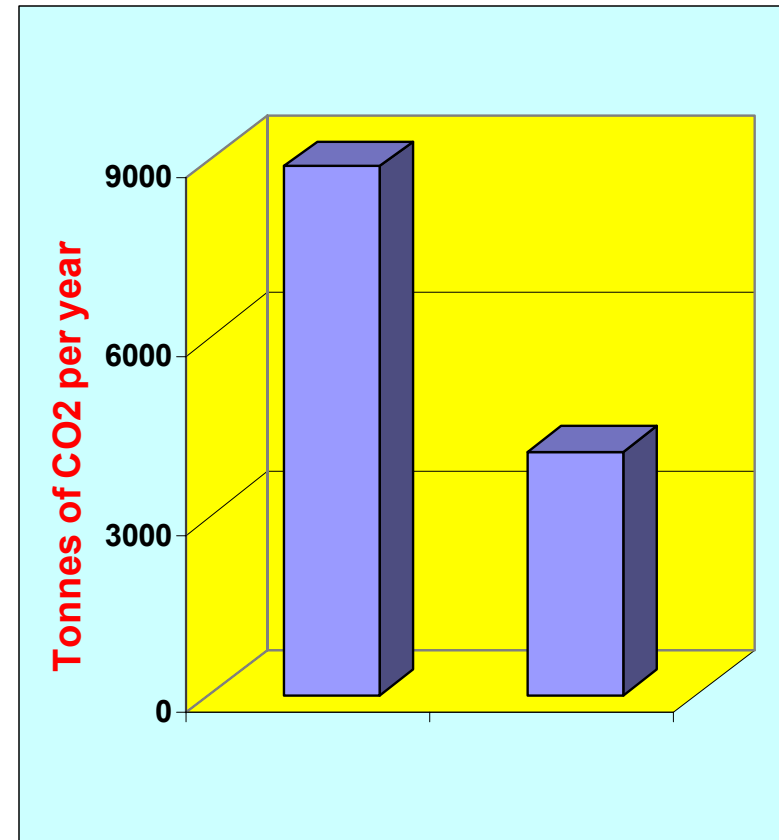
# Actual Case - GHG Emissions Advantage



***U.S. Postal Service in Alaska  
5 – PC25 (200 kW) Power Plants  
International Fuel Cells***

**Fuel Type**  
PC25 – 100% Natural Gas  
"Average US..." – 79% Coal, 16% Gas, 5% Oil

**"Average US Fossil Fuel Plant" vs. PC25 (x5)**





## Classification and Efficiencies of Fuel Cells for Industrial Stationary Applications (Toshiba Data)

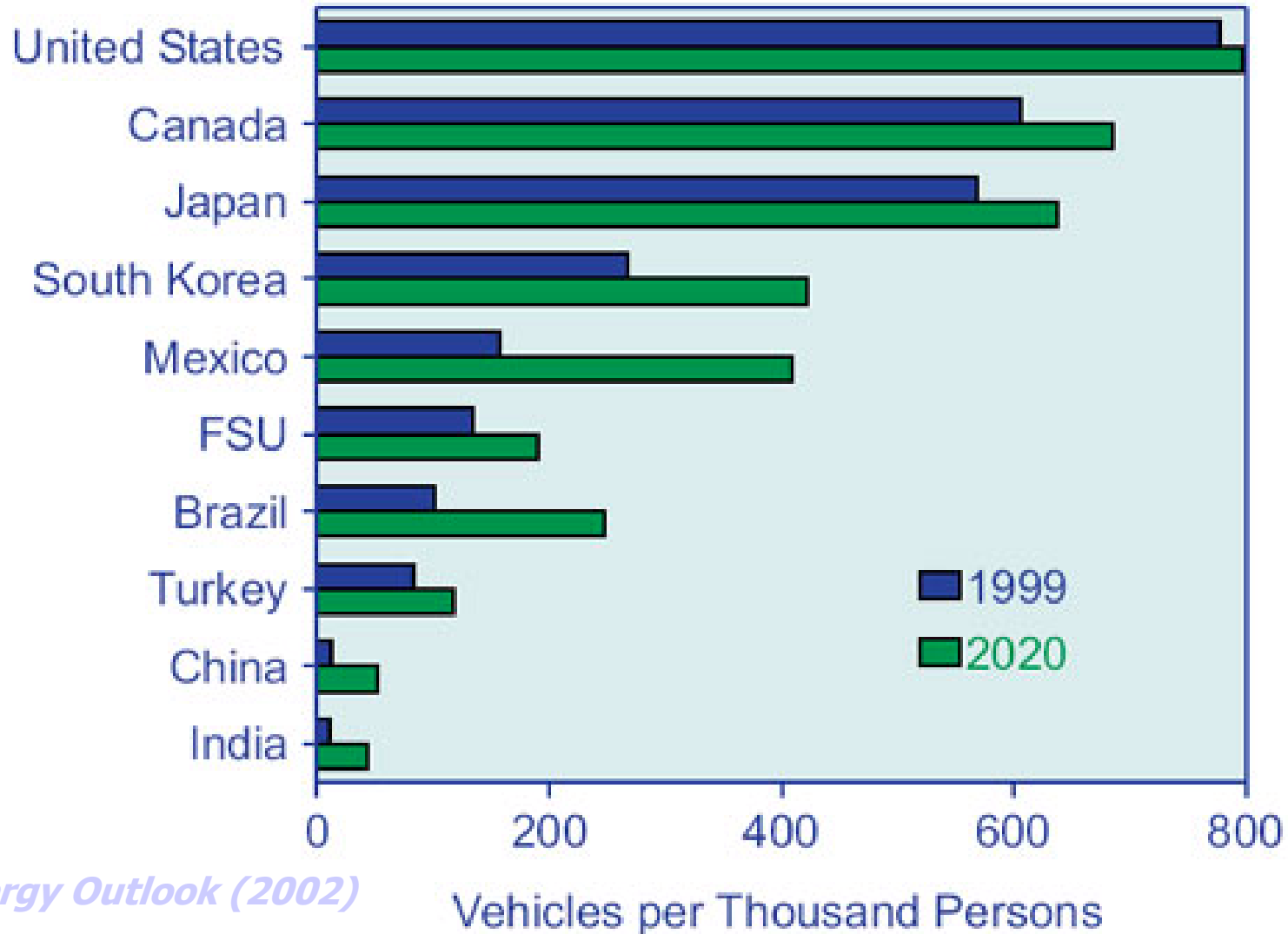
	PEM	PAFC	MCFC	SOFC
<b>Operating Temp, °C</b>	60-100	150-200	600-650	900-1000
<b>Efficiency, % HHV</b>	40-50	35-40	50-60*	55-65*
<b>Fuel:</b>				
- Natural gas	Yes	Yes	Yes	Yes
- Methanol	Yes	Yes	Yes	Yes
- Synthesis Gas/ (H <sub>2</sub> +CO)	No	No	Yes	Yes

\* Combined with Gas Turbine and Steam Turbine

PEM - Proton Exchange Membrane Fuel Cell  
 PAFC - Phosphoric Acid Fuel Cell  
 MCFC - Molten Carbon Fuel Cell  
 SOFC - Solid Oxide Fuel Cell



# Worldwide growth in Vehicle Use





## Transportation Application



***Toyota Kluger (Highlander)***

### Vehicle Characteristics

**Cruising Distance**      300 km

**Fuel Cell Type**        PEM Stack

**Output**                90 kW

**Max. Speed**            150 km/h

**Fuel**                     Pure H<sub>2</sub>

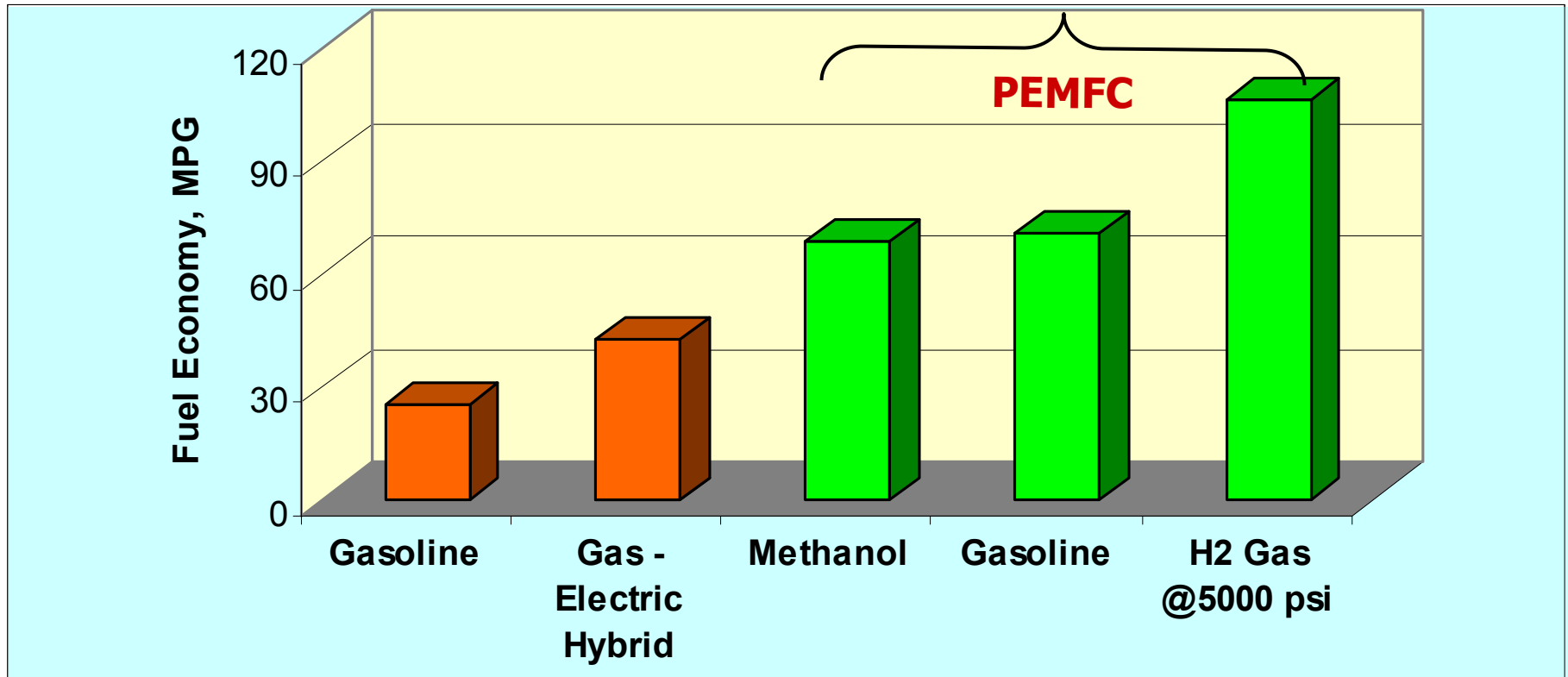
**Storing**                 H<sub>2</sub> absorbing alloy tank

**Battery**                 Ni-M Hydride

(regenerative braking capabilities)



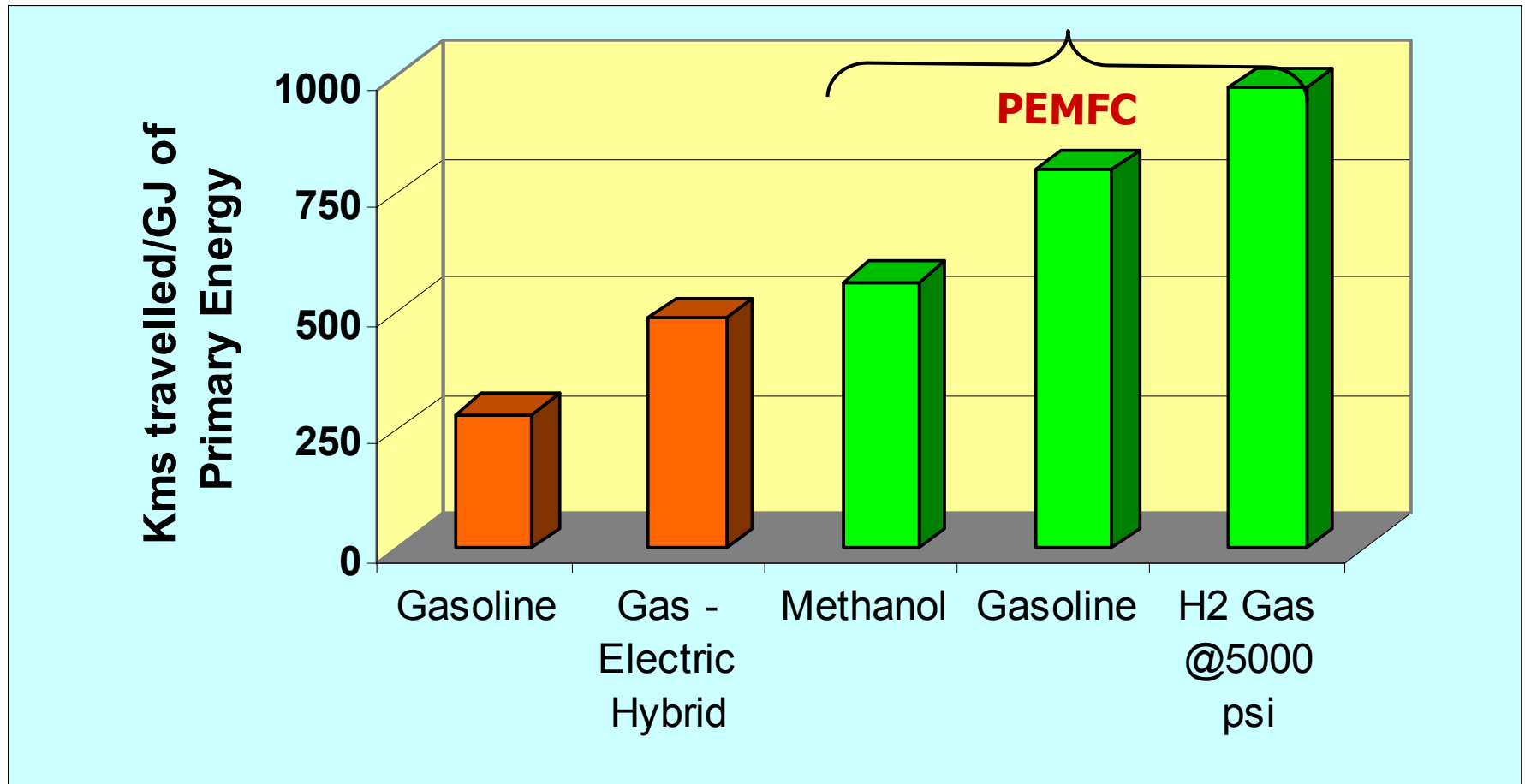
## Estimated Fuel Economy of Fuel Cell Automobiles



*Ogden et al. (1998) based on "assumed characteristics" for PEM; combustion engines are estimates*



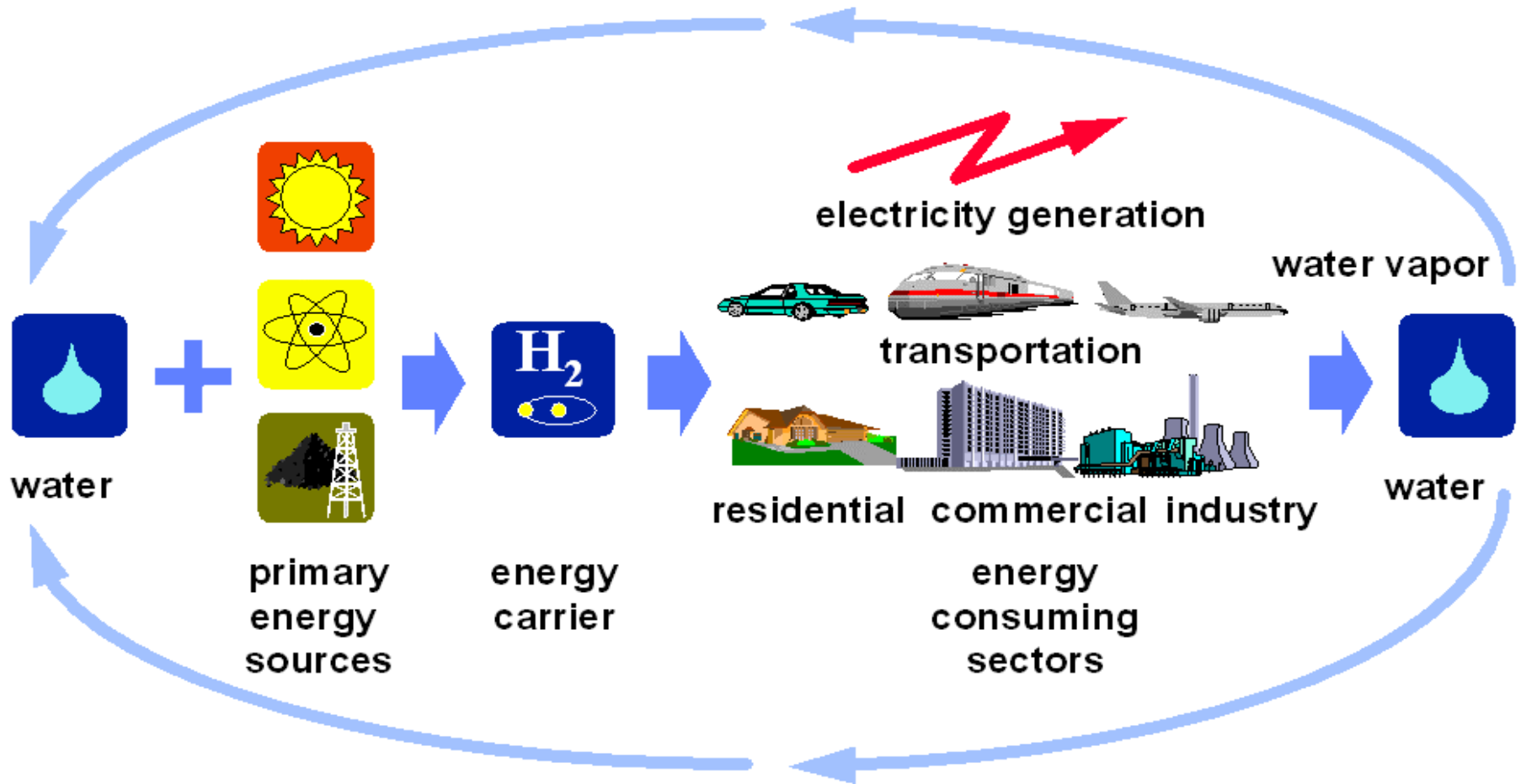
# Comparison of fuel economy on a primary energy use basis



*Calculated from Ogden et al. (1998) based on "assumed characteristics" for PEM*



# Hydrogen as an Energy Carrier





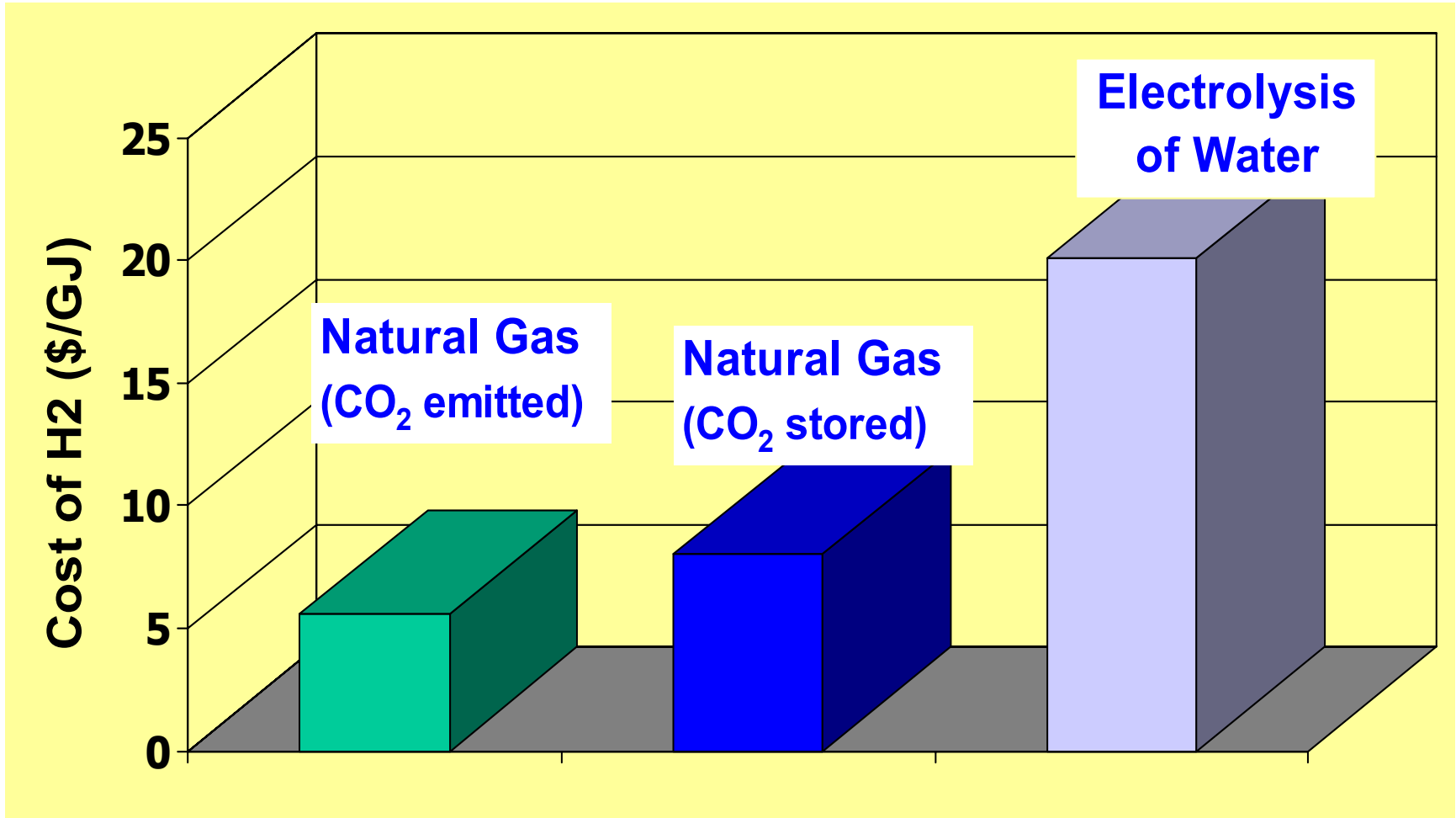
## Worldwide Hydrogen Production

<u>Raw Material</u>	<u>H<sub>2</sub> Production</u>
Natural gas	48%
Oil	30%
Coal	18%
Water (electrolysis)*	4%

**\* About 40 kW-h of electricity to produce 1 kg of H<sub>2</sub> which is equivalent to about 4 liters of gasoline**

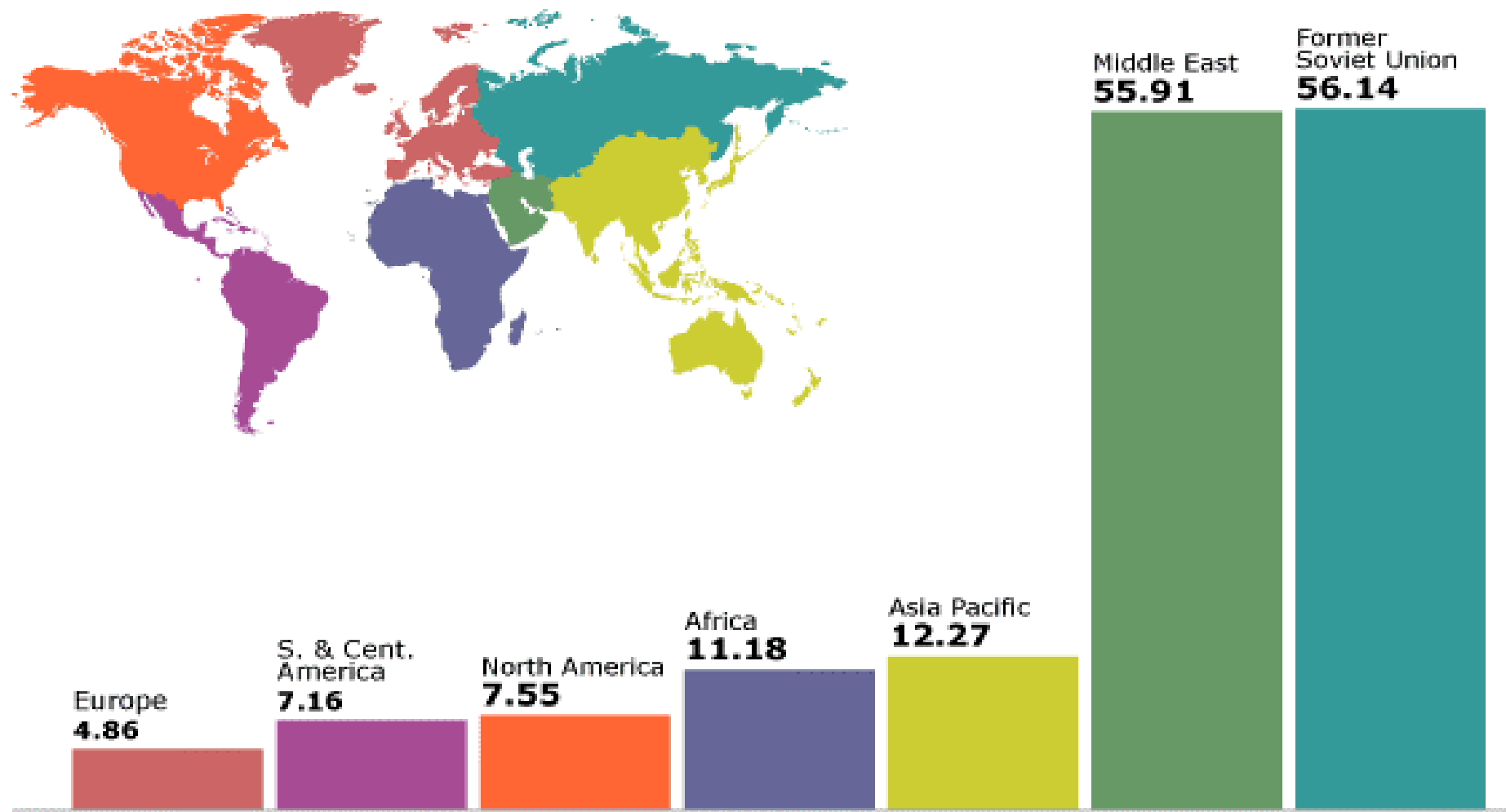


# Is Natural gas the fuel of the "H<sub>2</sub> economy" ?



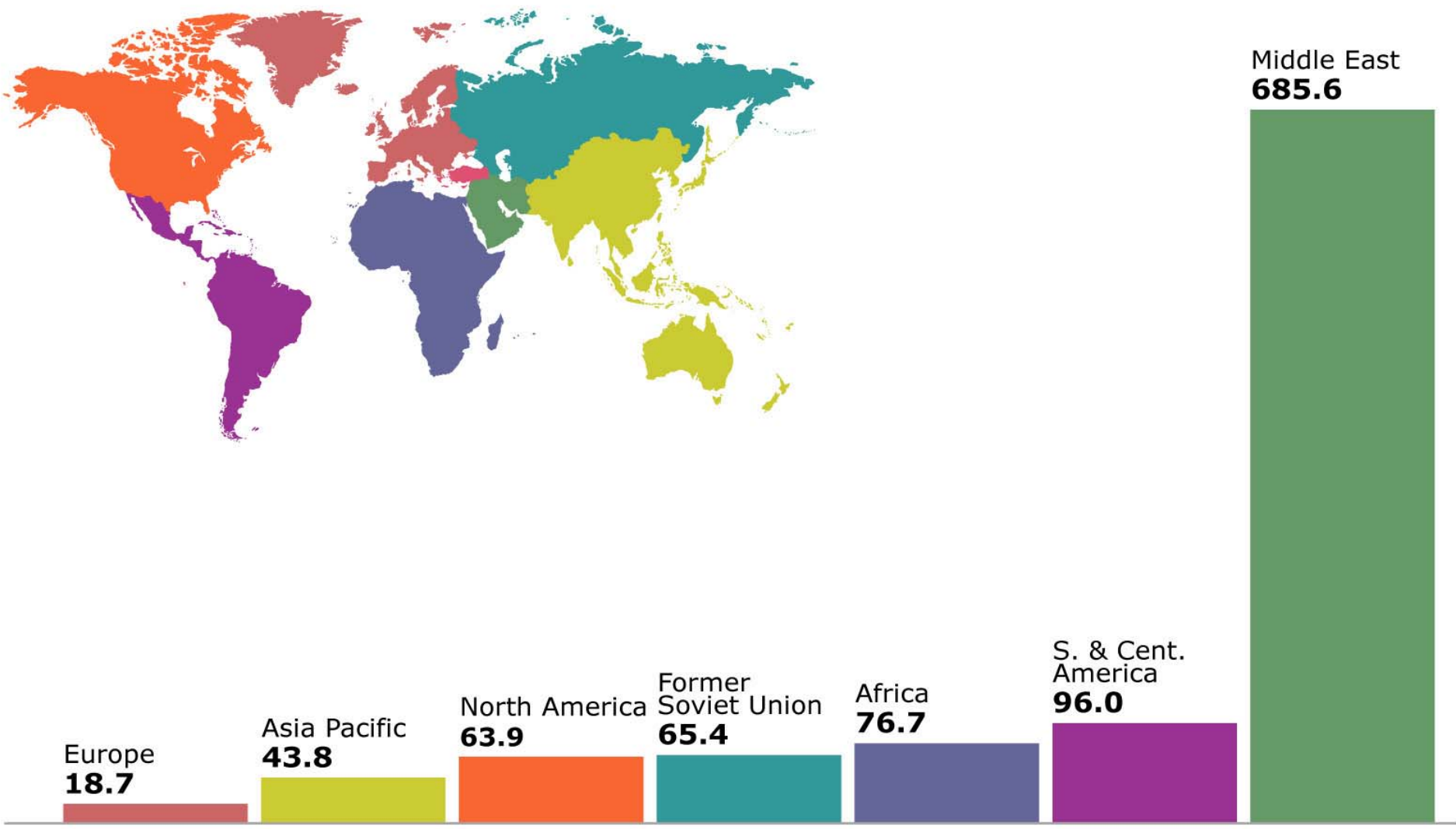
# map of proved gas reserves at end 2001

Trillion cubic metres



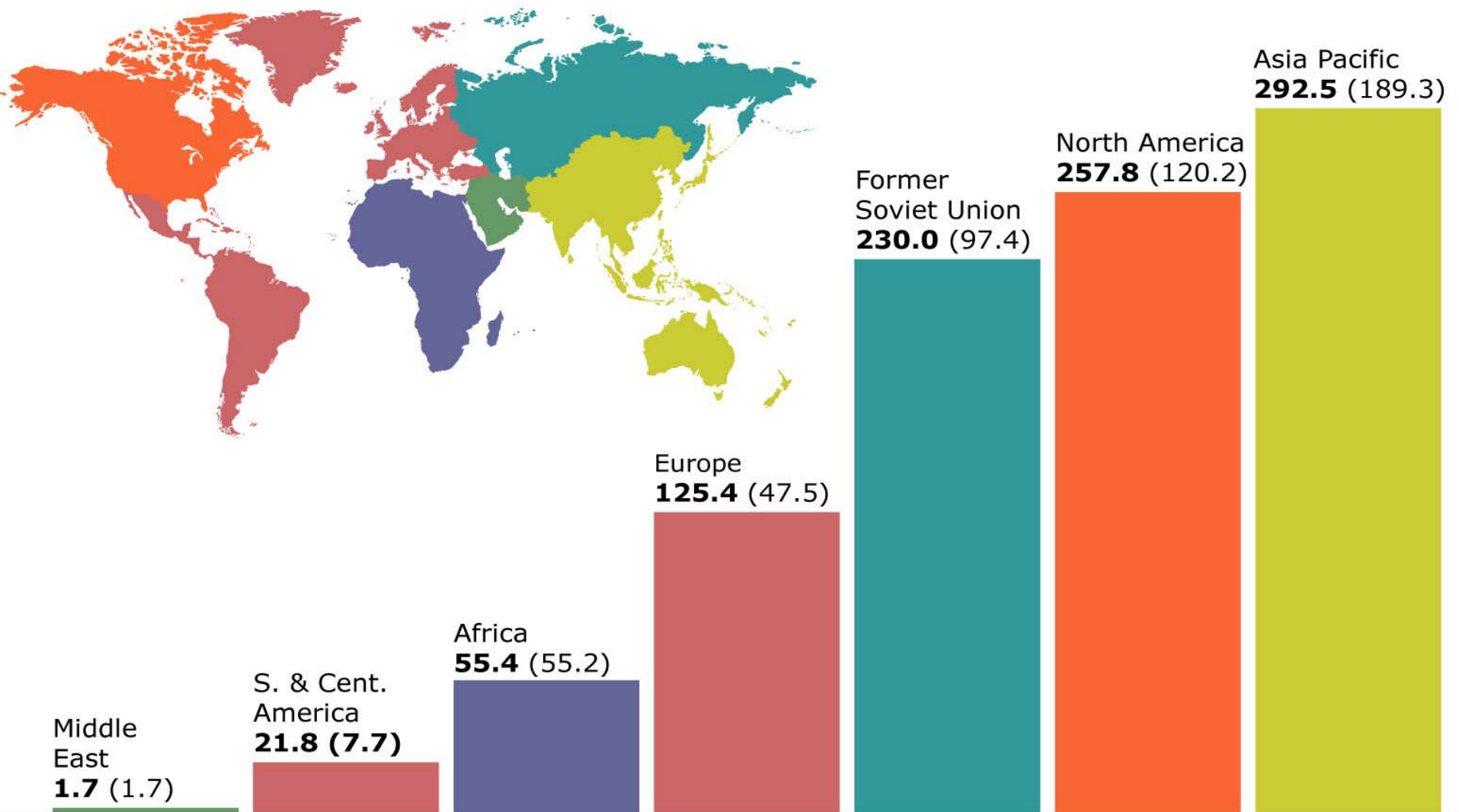
# map of proved oil reserves at end 2001

Thousand million barrels



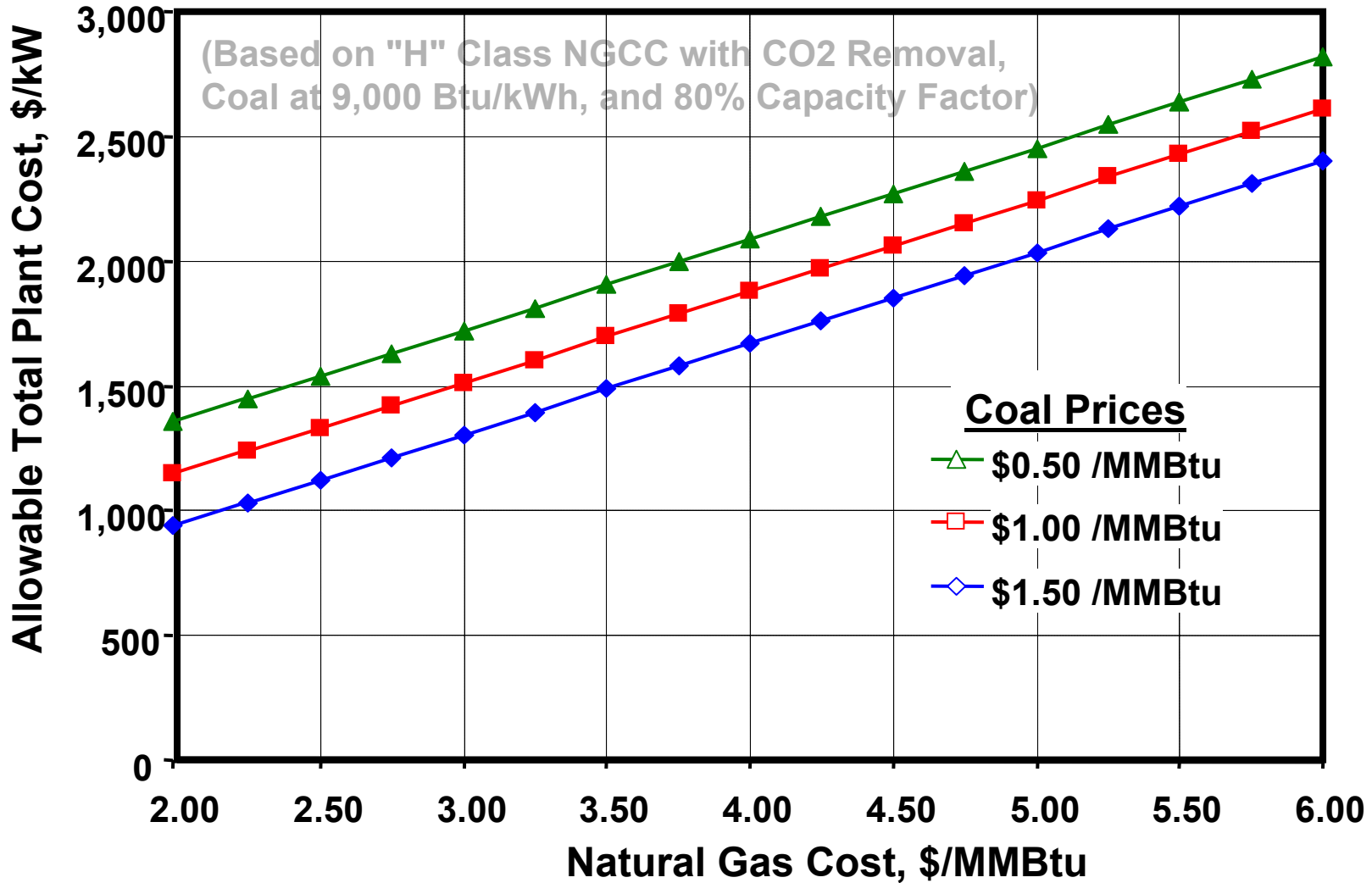
# map of proved coal reserves at end 2001

Thousand million tonnes (share of anthracite and bituminous coal is shown in brackets)



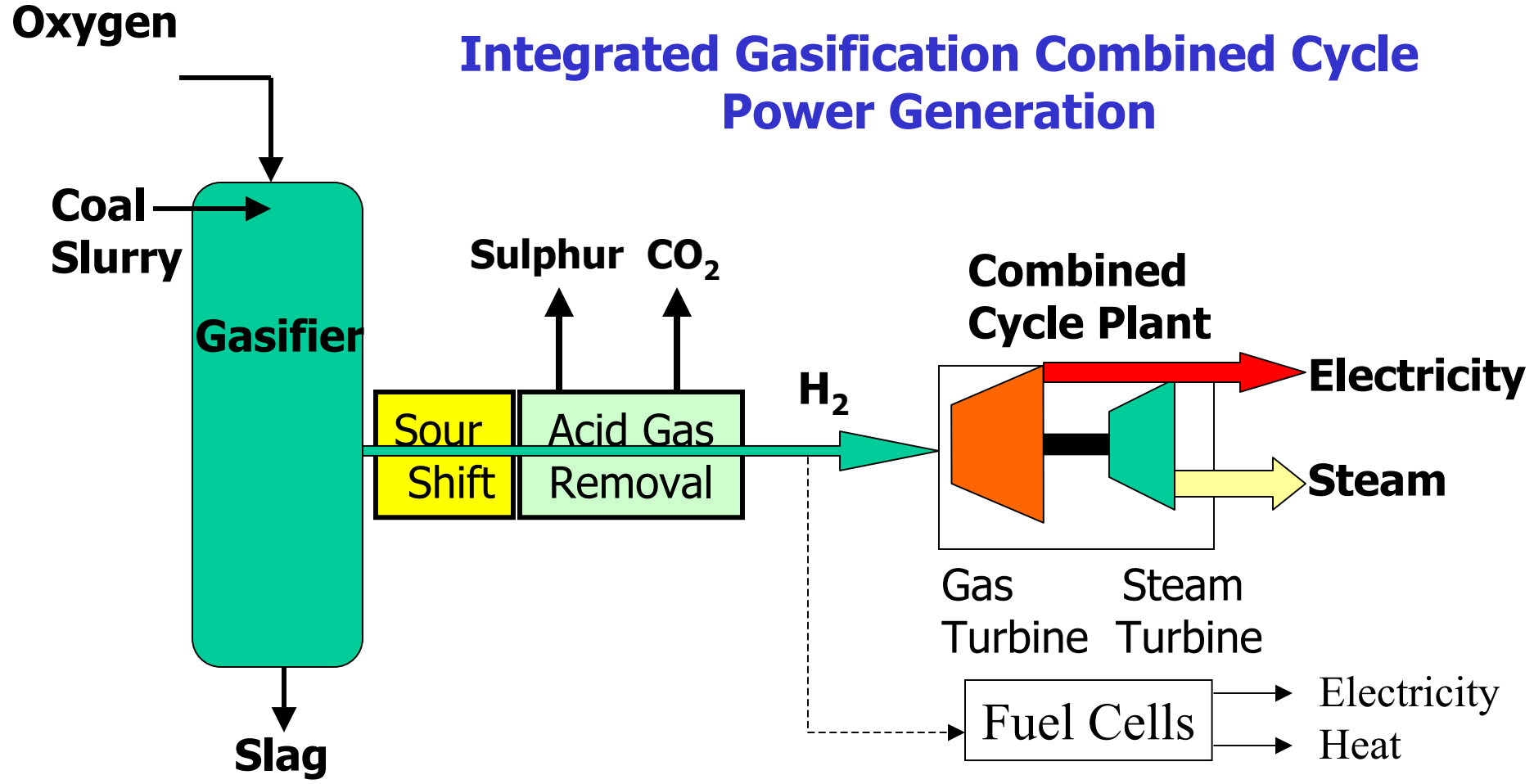


# Allowable Coal Plant Capital Costs





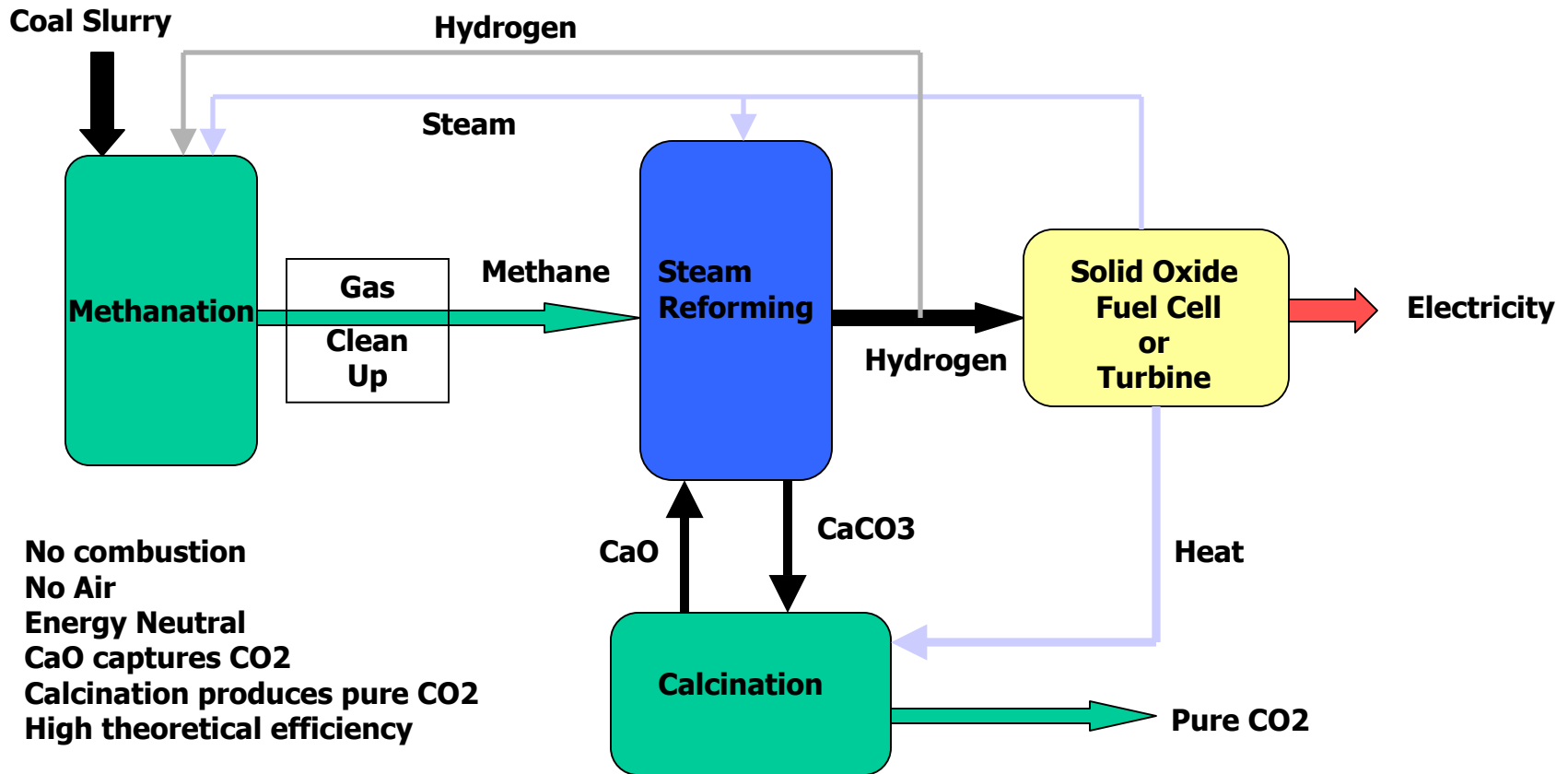
# Integrated Gasification Combined Cycle Power Generation



*IGCC has the best potential for commercial production of clean power  
With near zero emissions within the next 5 to 10 years*



# Zero Emission Anaerobic Hydrogen/Electricity Production

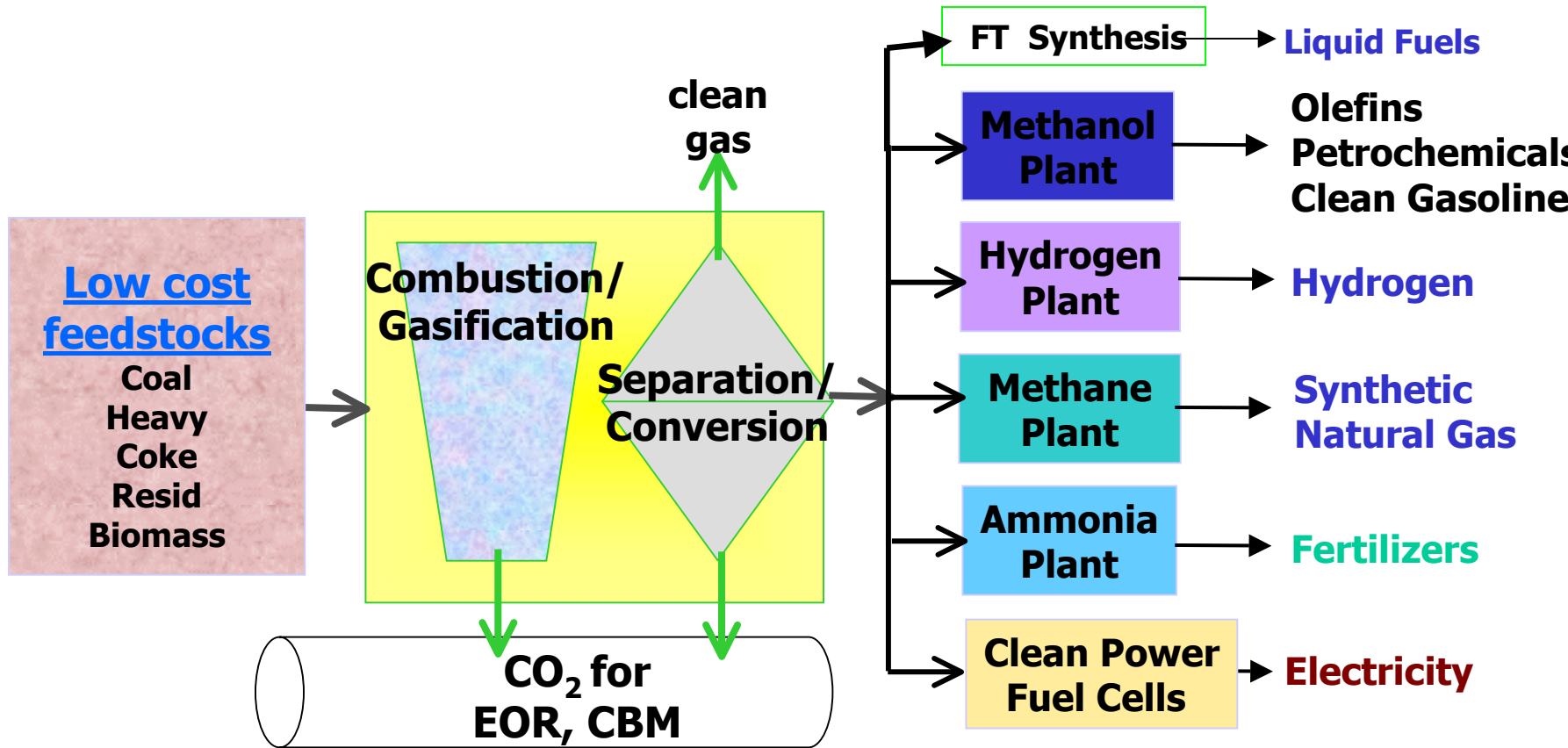


At the laboratory & pilot stage of development



# Alberta Energy Research Institute (AERI)

*Vision: Add Value to Alberta's Hydrocarbon Resources*





## Some Key Messages

- The problems with Kyoto for Canada
  - ❑ Canada has major challenges to meet Kyoto targets
  - ❑ Impact of technology longer than the timeframe
- Technology the solution?
  - ❑ Only if combined with progressive policy, conservation, public education etc.
  - ❑ Need for realistic stretch targets for transportation, industry and domestic sectors
- Fuel cell industry not likely to have impact in the first Kyoto period
  - ❑ Potential is high to reduce GHG's and other emissions
  - ❑ Need for major incentives to accelerate commercial applications
- Private-public partnership to focus research & technology on clean energy



“ . . .the cost of producing [gasoline] is far beyond the financial capacity of private industry... In addition the development of this new power may displace the use of horses, which would wreck our agriculture.”

- U.S. Congressional Record 1875