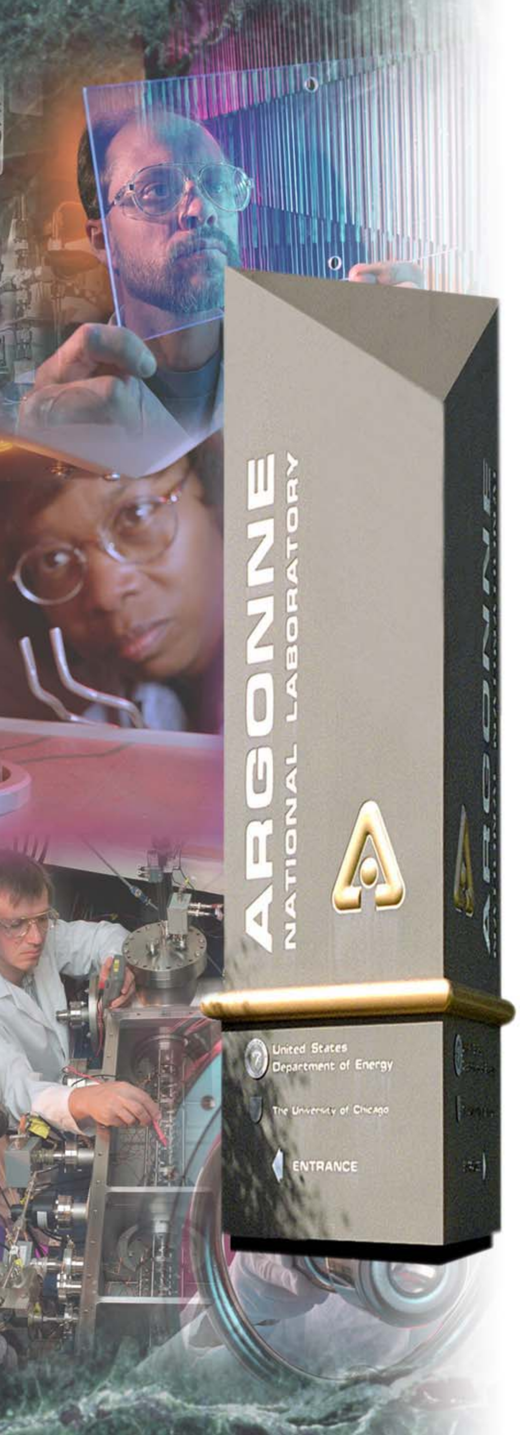

Might Canadian Oil Sands Promote Hydrogen Production Technologies for Transportation?

Greenhouse Gas Emission Implications of Oil Sands Recovery and Upgrading

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Argonne National Laboratory

Office of Science
U.S. Department of Energy

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The Pathway for Hydrogen In Transportation is a Difficult One

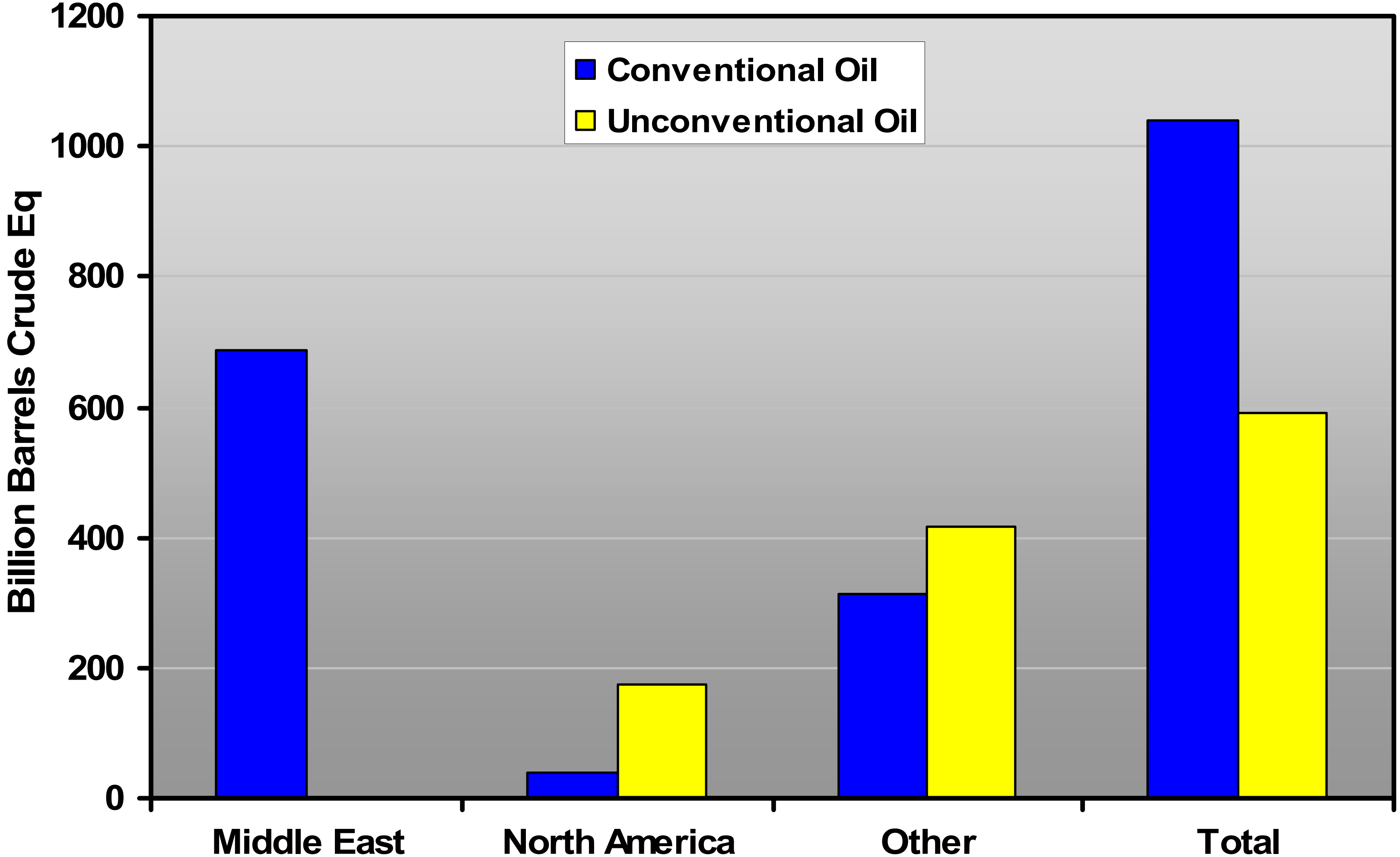
Challenges facing H_2 for Transportation

- Utilization (good progress)
- Storage (working hard)
- Distribution (good understanding of needs, cost)
- Production (very tough)

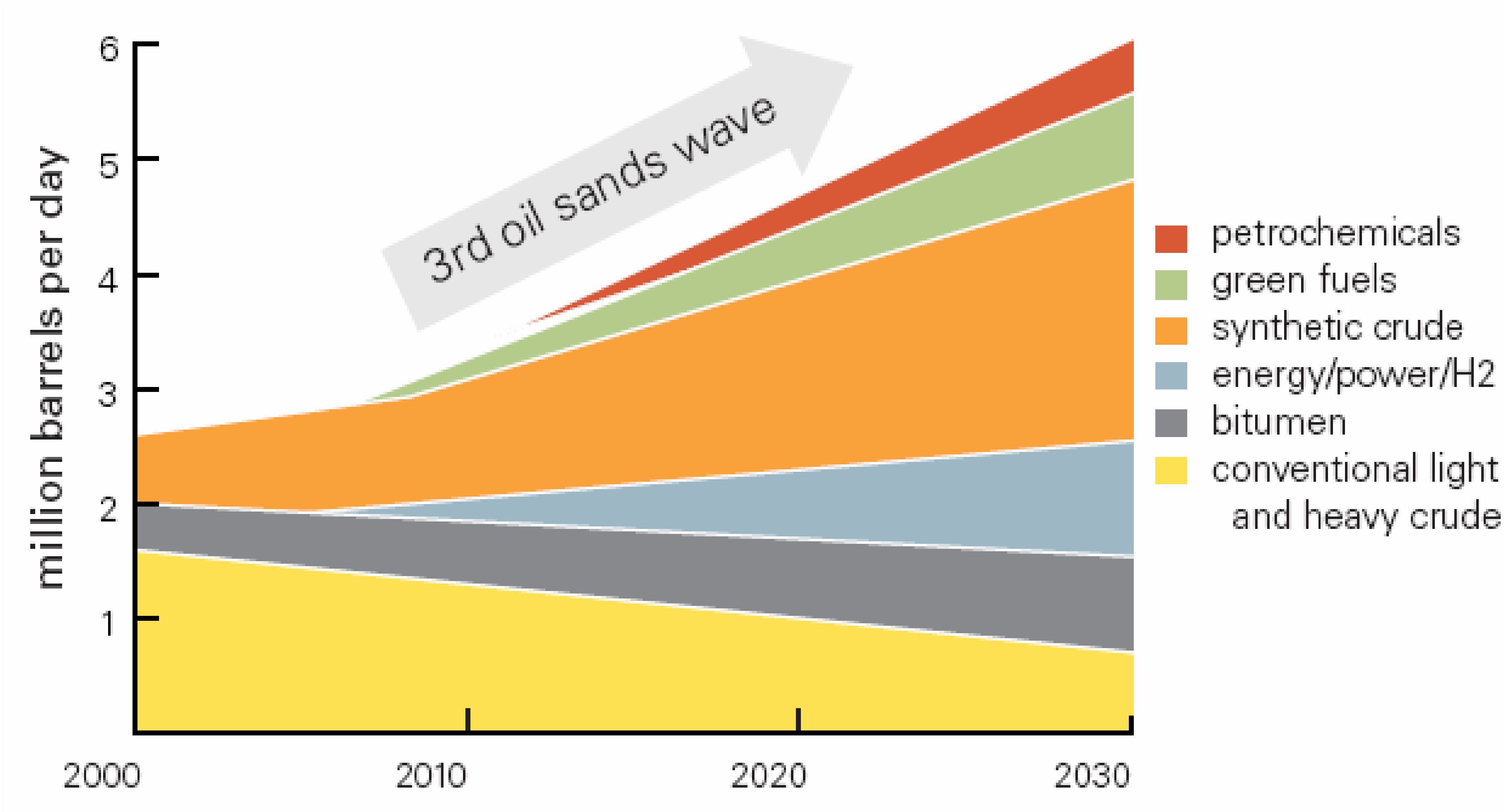
and

- Cost (not close yet)

North America Has Relatively Little Conventional Oil But 30% of Unconventional Oil Reserves



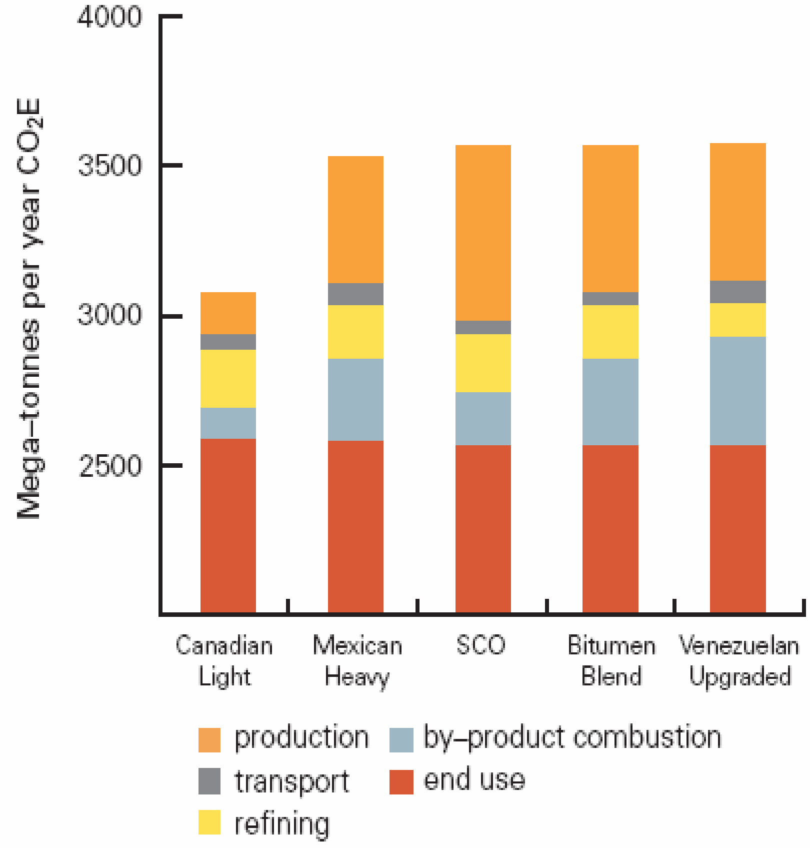
Canadian Oil Sands Production Is Expected to More Than Quadruple by 2030



Source: Alberta Chamber of Resources, Jan. 2004

Rising Heavy Crude and Non-Conventional Oil Production Increases Energy Use and CO2 Emissions

- Current production of synthetic crude oil (SCO) from Canadian oil sands is approaching 1 million b/d, mostly from surface mining
- US midwest refineries have already reached their current limits for SCO from bitumen
- By 2030, 5 million b/d of bitumen and synthetic crude oil may be produced in Alberta
- Most of it will be exported to US refineries in the Midwest, the Gulf Coast, and the West Coast

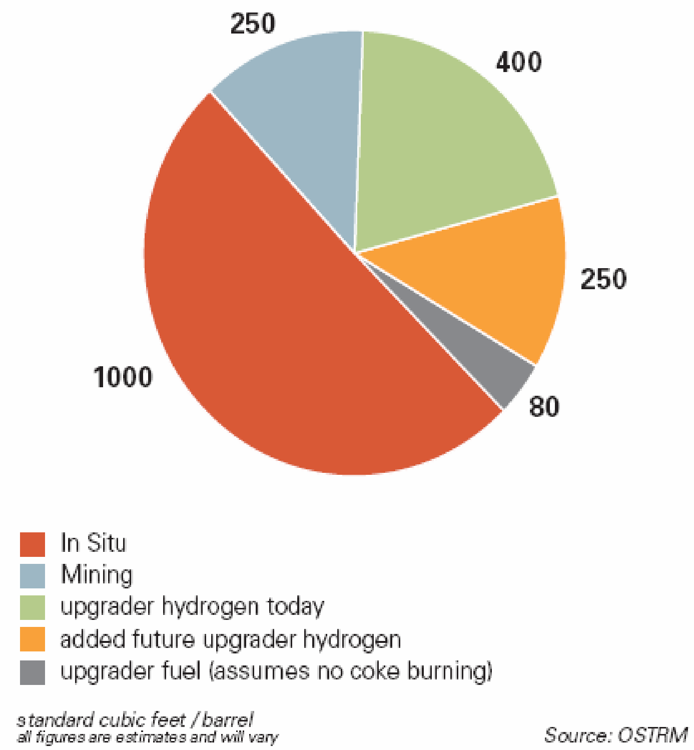


Source: T.J. McCann & Associates

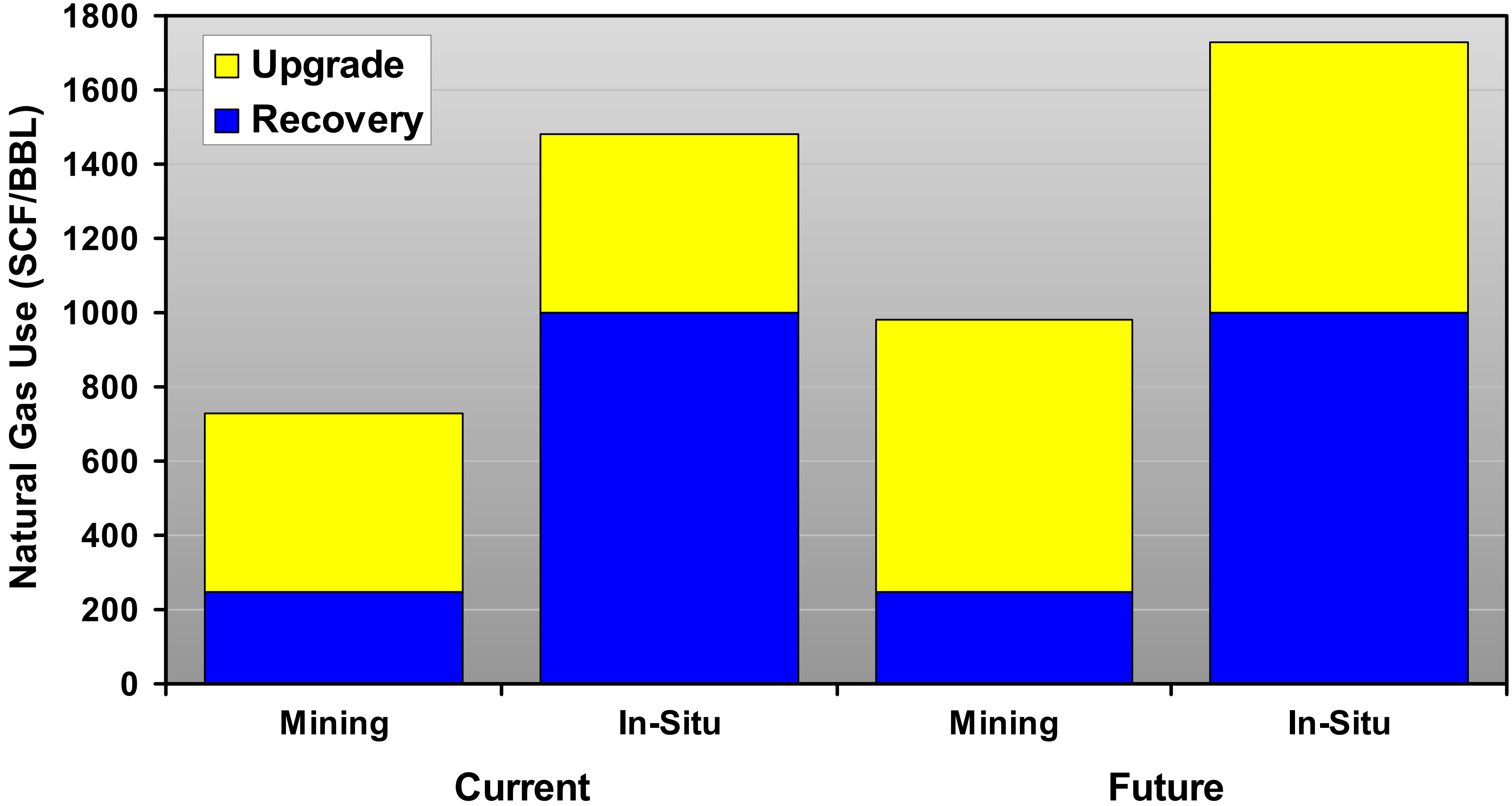
Oil Sands Recovery and Upgrading Uses a Significant Amount of Natural Gas

- **Surface mining operation produces low-quality bitumen that requires upgrading to produce synthetic crude oil (SCO)**
- **In-situ recovery, requiring large amounts of steam, produces bitumen that needs upgrading**
- **If steam and hydrogen are generated with natural gas (for now)**
  - 390 billion SCF of NG in 2003 (for 1.1 million B/D production)
  - 907 billion SCF of NG 2012 (for 2 million B/D production)
  - 2.5 trillion SCF of NG in 2030 (for 5 million B/D production)
  - Current Canadian NG use is >2.5 trillion SCF
  - Current U.S. NG use is 22 trillion SCF and will be about 32 trillion SCF in 2030

Natural Gas Use for Oil Sands Processing in SCF/BBL



NG Use Will Rise With Shift to In-Situ Production and More Upgrading to High Quality SCO

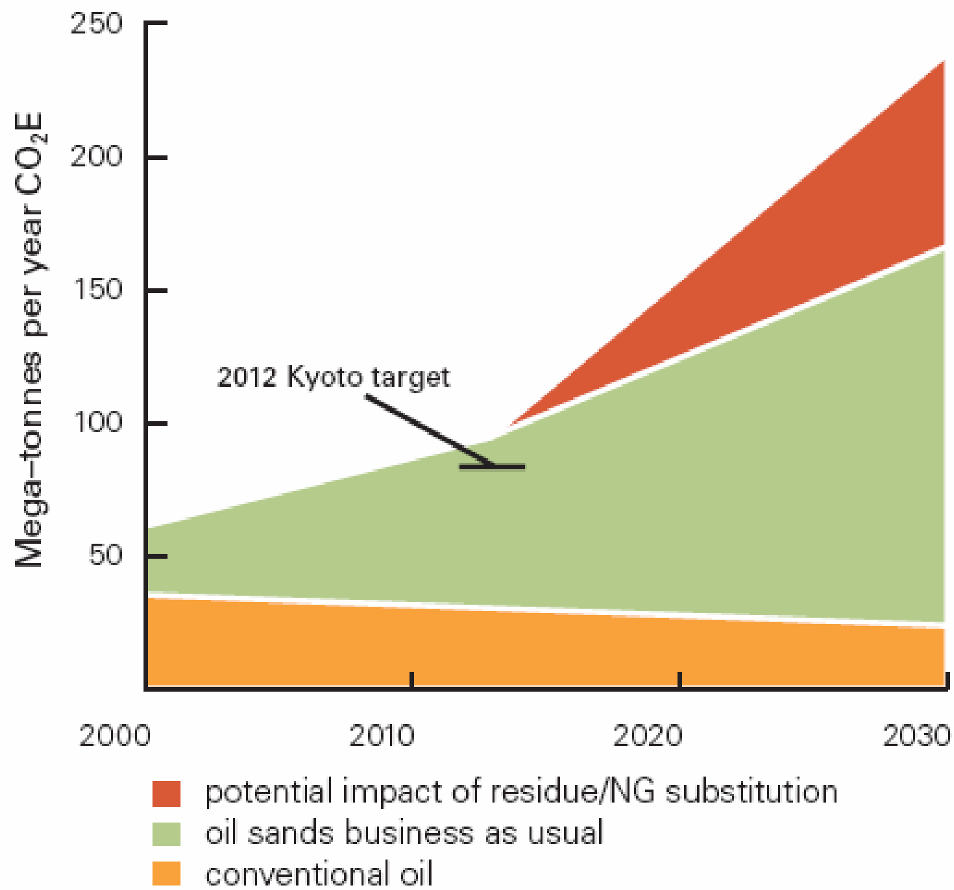


Sustainable Oil Sands Operations Will Require Alternative Energy Sources

- **Natural gas price in Alberta has risen to US$3.7/mmBtu; the U.S. NG price has risen to above US$5/mmBtu**
- **Gas supply in Alberta and Western Canada will be tight in the next 30 years**
- **Alternative energy sources need to be sought for sustainable oil sands operations**
  - Coal gasification to produce H_2 and steam: Alberta has large coal reserves
  - Nuclear plants to produce H_2 and steam are increasingly attractive: R&D efforts in Canada and U.S. are intensifying
  - **H_2 production pathways for oil sands operation could provide the needed incentive to develop large-scale, low-cost H_2 production technologies**

Canadian Challenges to Meet Kyoto GHG Treaty with Oil Sands Development are Significant

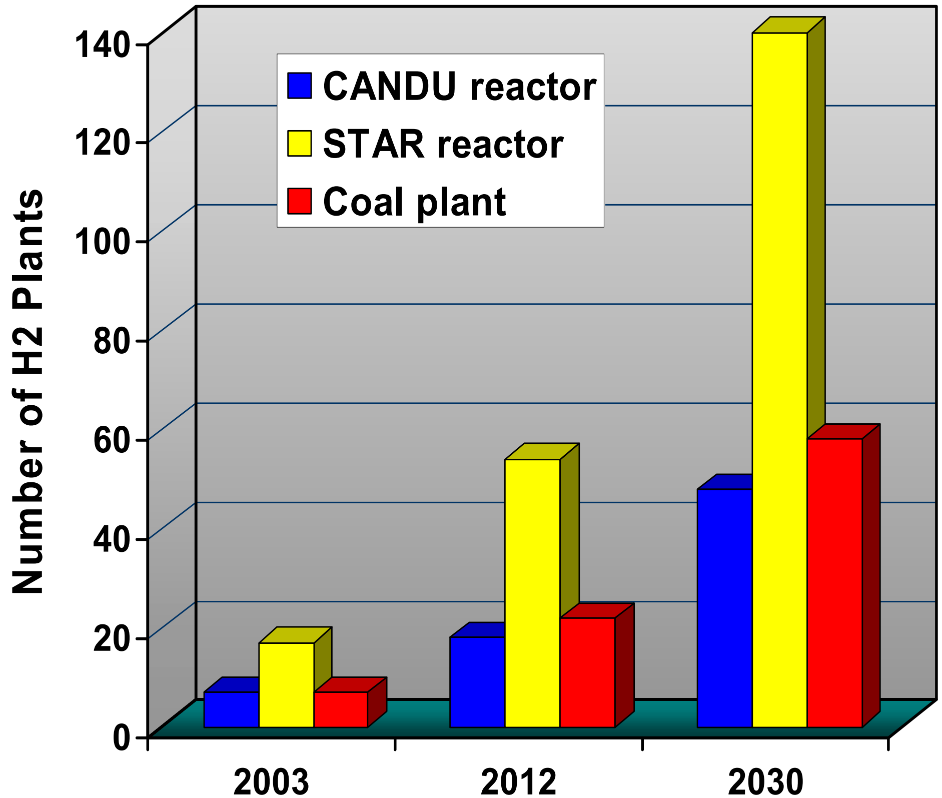
- **It is clear that "business as usual" using natural gas poses a great problem**
- **Switching to coal/coke will create more GHG problems without massive CO_2 sequestering**
- **Clearly a new source of H_2 with a much smaller GHG impact is needed**



Sources: LENEF/T.J. McCann

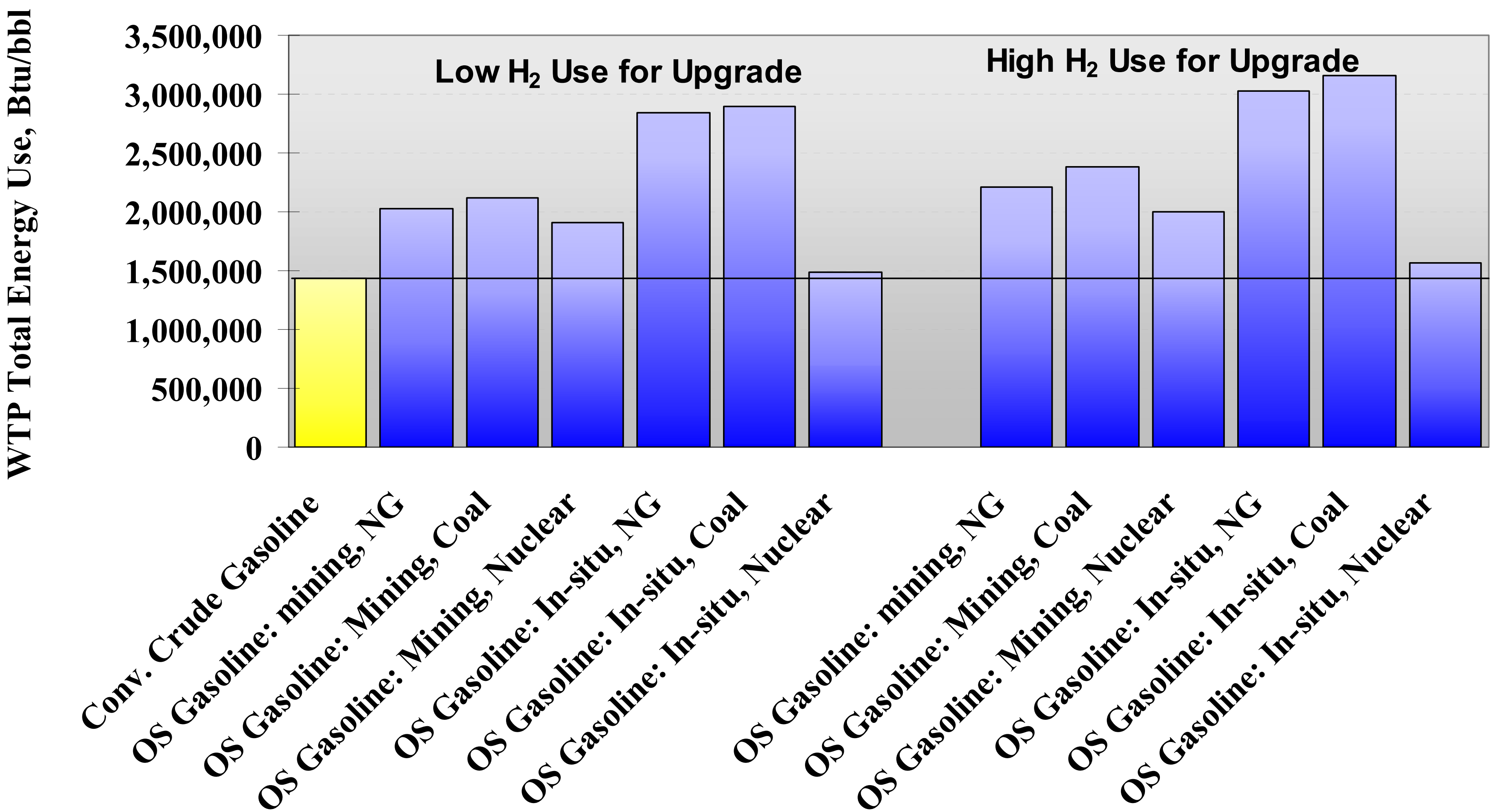
Large Demand for H_2 for Oil Sands Operations Creates Need for New Ways to Produce H_2

- Based on oil sands production and upgrading H_2 needs, we estimate:
  - 1 million MT of H_2 in 2003
  - 3.1 million MT of H_2 in 2012
  - 7.7 million MT of H_2 in 2030
  - In 1999, the U.S. consumed 7.913 million metric tons of H_2, of which 37% was used by refineries
- Proposed nuclear reactors for H_2 production
  - CANDU LW reactors of 690 MWe produce 132,000 MT/yr H_2 via electrolysis
  - Argonne HTGC STAR reactors of 180 MWe produce 43,000 MT/yr H_2 via H_2O split
- Coal gasification H_2 plants produce 108,000 MT/yr H_2

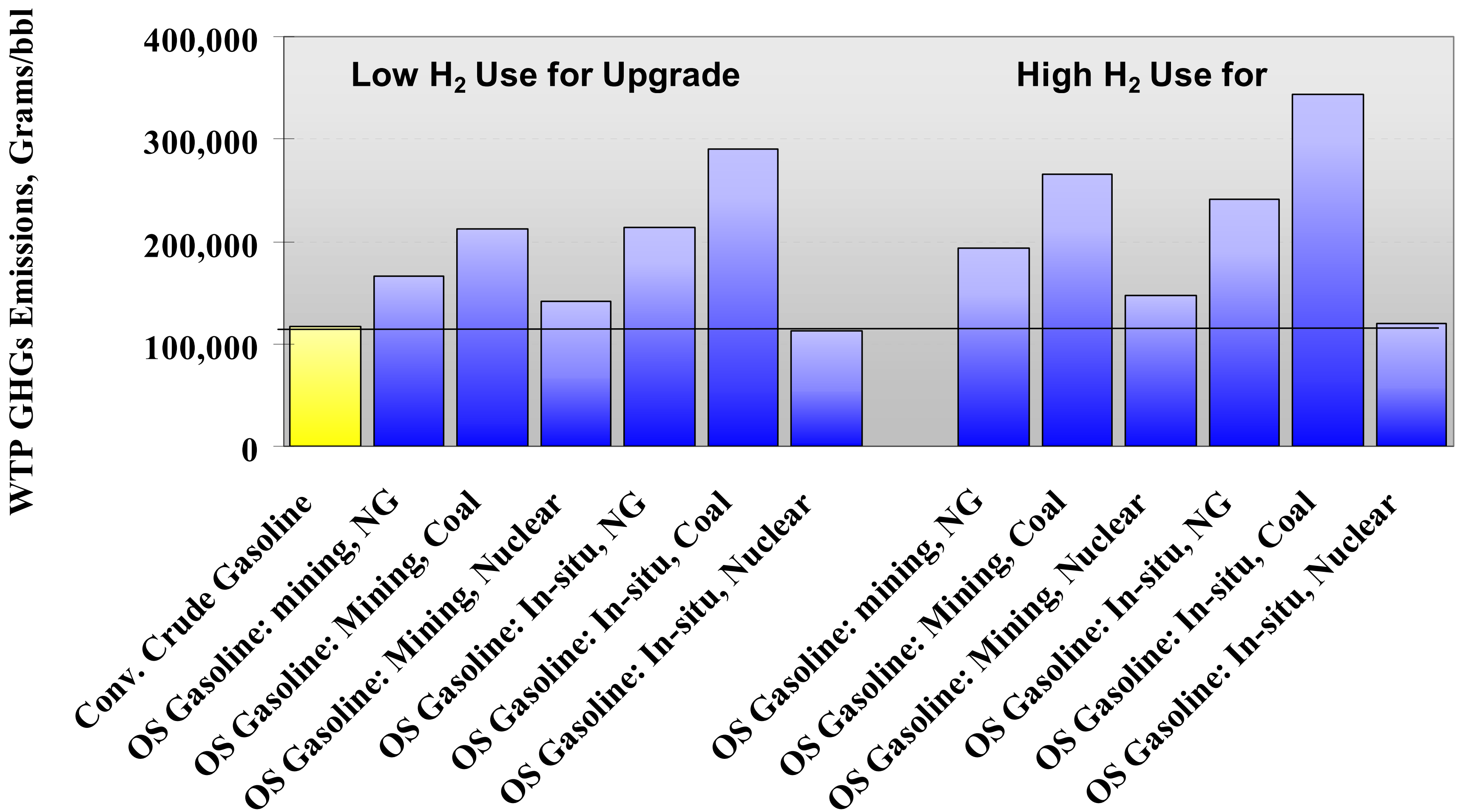


Reactors and plants are for H2 production only; if producing both steam and H2, more will be required.

Well to Pump (WTP) Total Energy for Producing a Barrel of Fuel Product



WTP Greenhouse Gas Emissions Per Barrel of Fuel Product

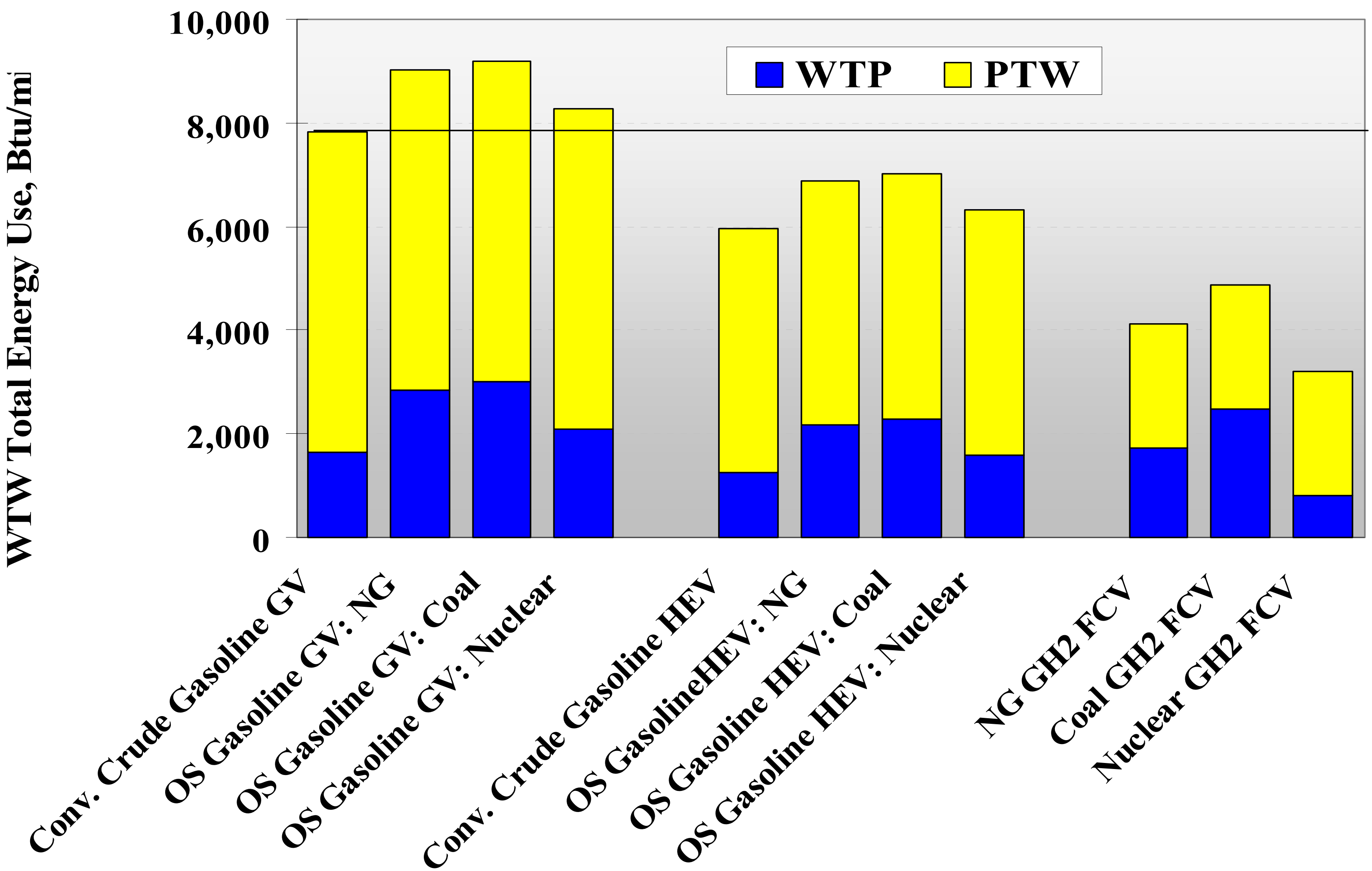


Illustrating the GHG Implications for Transportation Fuels and Technologies

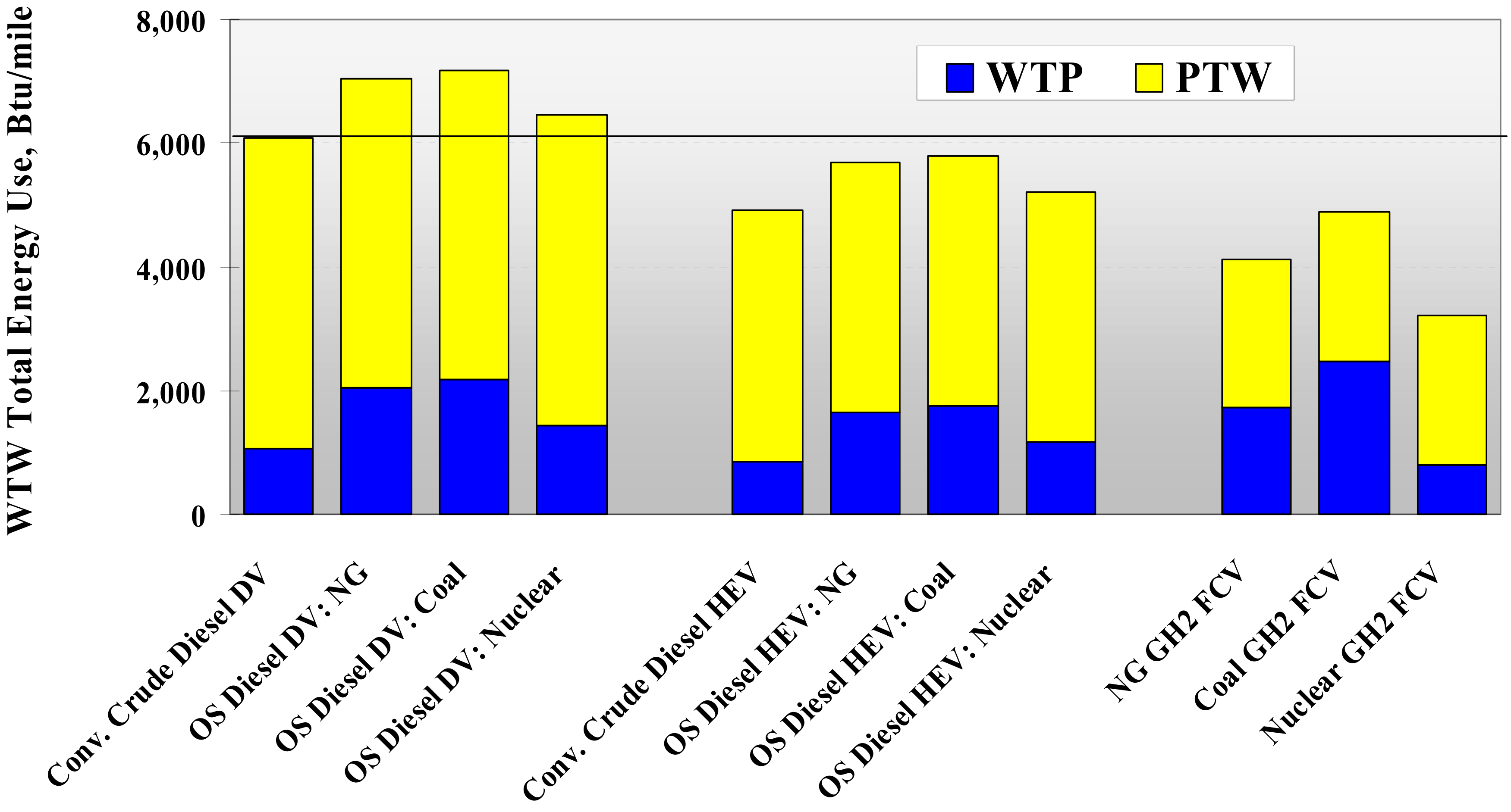
- **To show the GHG implications of future transportation fuel use and various advanced vehicle technologies, ANL/CTR performed a series of analyses using the GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) and the PSAT (Powertrain Systems Analysis Toolkit) models**

- **Energy use and total GHG emissions were calculated using a mid-sized Sport Utility Vehicle with the following configurations as measured on the combined city/highway US test cycles:**
  - Conventional gasoline and hybrid electric gasoline
  - Direct-Injection diesel and hybrid electric diesel
  - PEM fuel cell hybrid vehicle

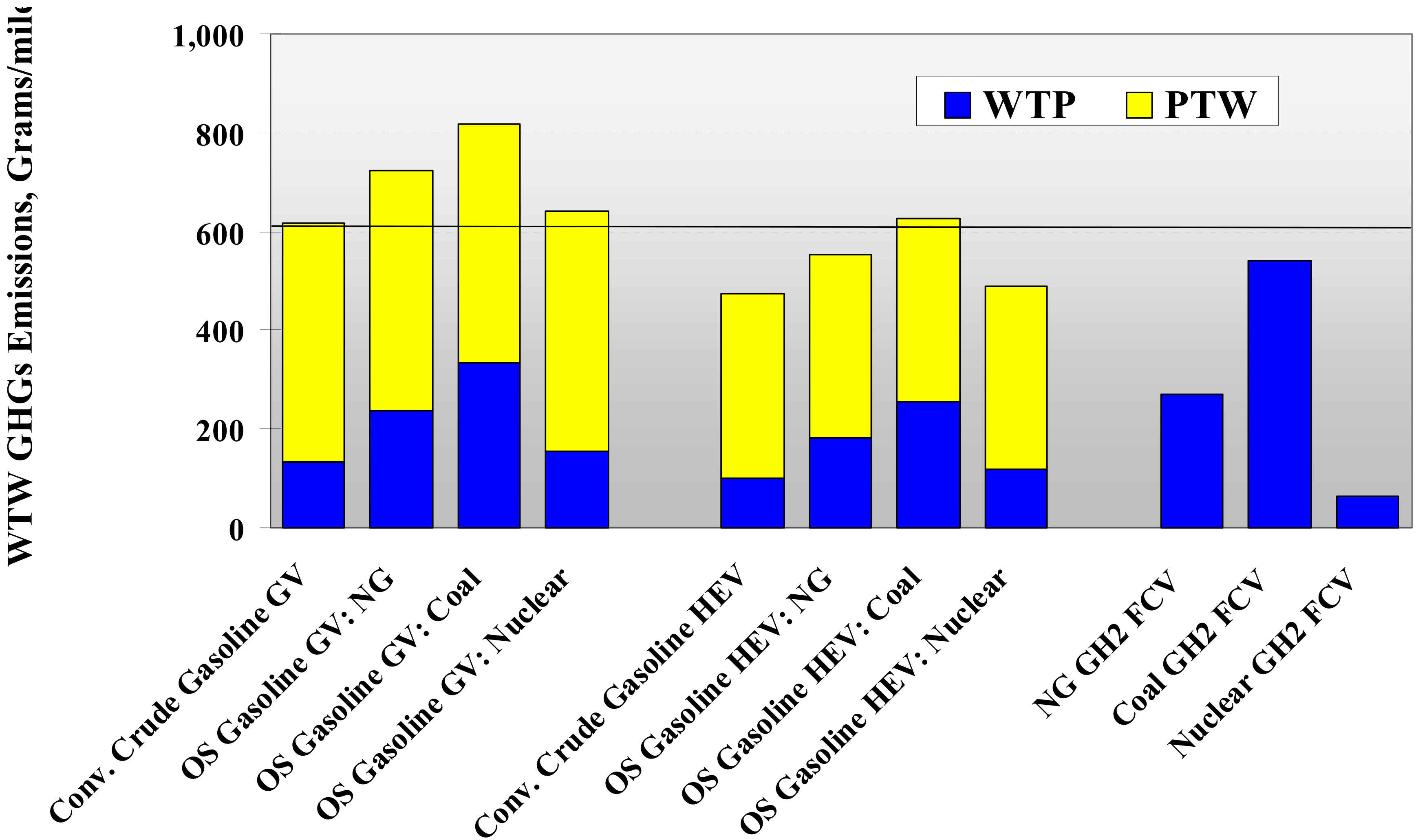
Well to Wheel (WTW) Total Energy Use for A Gasoline SUV, HEV and H2 FC SUV



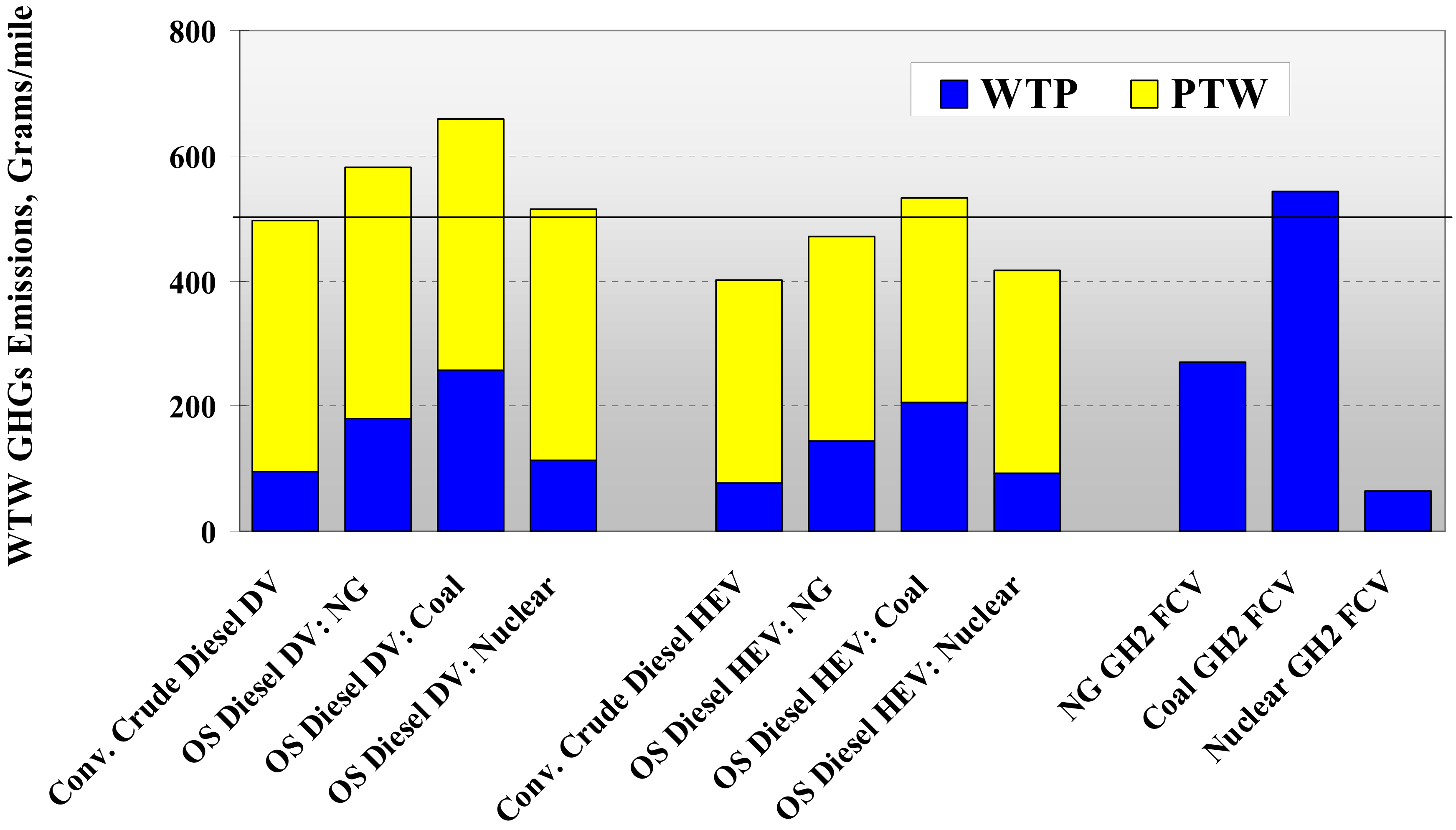
WTW Total Energy Use for A Diesel SUV, HEV, and H2 FC SUV



WTW GHG Emissions for A Gasoline SUV, HEV, and H2 FC SUV



WTW GHG Emissions for A Diesel SUV, HEV, and H2 FC SUV



Uncertainties and Mitigating Factors

- Price of oil, and thus the demand for SCO, depends on many factors, including world-wide demand, geo-political situation, economic growth rates, etc., but it is likely to produce fuel at less than half the price of H_2 at the pump in the U.S. for several decades
- Future actions by governments to regulate GHG emissions and/or encourage hydrogen development could change these projections
- Advances in carbon sequestration could delay the transition to nuclear hydrogen production and enable other energy sources such as coke from oil sands upgrading for H_2 production
- Calculations for coal to H_2 in this presentation did not assume CO_2 capture and sequestration
- Balanced production of H_2, steam, and electricity in a single plant could best serve oil sands operation (WTP and WTW calculations here are for H2 and steam co-production)
- Lower quality SCO and bitumen-diluent mixtures could be shipped to US refiners, shifting part of burden for hydrogen addition down the supply chain

The Need for Large Quantities of H_2 for Oil Sands Production Can Build a Bridge to the H_2 Economy and the Use of H_2 for Transportation

- The availability of oil at low cost will prevent the transition to a H_2 use in transportation in the near term
- Canadian oil sands production is likely to quadruple over the next 25 years, straining supplies of natural gas, the main source of steam for recovery and hydrogen for upgrading, and increasing GHG emissions
- Replacement of natural gas with non-fossil sources of hydrogen will be necessary to meet Canadian Kyoto treaty obligations
- Hydrogen production via nuclear heat sources shows particular promise for reducing GHG emissions and producing low-cost H_2
- The development of small, modular Generation IV nuclear reactors to meet the need for low-GHG and low-cost H_2 will accelerate the development of the hydrogen economy outside of oil sand production
- Once the cost of providing of H_2 approaches that of oil-based fuels, the large-scale transition to H_2 for transportation can begin