The Energy Sustainability Dilemma: 
*Powering the Future in a Finite World*

*PHEV2007 Conference*
*“Where the Grid Meets the Road”*
*Winnipeg, Manitoba*
*November 1, 2007*

*J. David Hughes*
*Geological Survey of Canada*
*Canadian Gas Potential Committee*

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**Foreword**

The interpretations and views in the following analysis are those of the author drawn from the best and most current data available to him and are solely his responsibility. The source of all data incorporated is cited wherever possible.
**Points to be covered:**

- The “ENERGY SUSTAINABILITY DILEMMA” defined:
  - **History** - where have we been
  - **Forecasts** - where are we going and how likely is it that we’ll get there

- Availability and deliverability of the nonrenewable fuels (OIL, GAS, COAL, URANIUM) that are the energy-dense elixers of our modern society

- **ELECTRICITY** – some issues in keeping the lights on

- Implications of **POPULATION GROWTH** and **ASPIRATIONS** of future energy consumption

- Going forward in a Finite World

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**World Primary Energy Consumption: 1965-2006**

- **By Region**
  - Asia Pacific
  - Africa
  - Middle East
  - Former Soviet Union
  - Europe
  - S. & Cent. America
  - North America

- **By Fuel**
  - Oil: 154%
  - Gas: 331%
  - Coal: 109%
  - Nuclear: 202%
  - Hydro: 176%

_Highest growth in 2006 = Asia Pacific 4.9%; Coal 4.5% (data from BP Statistical Review of World Energy, 2007)_


World Per Capita Annual Primary Energy Consumption by Fuel 1850-2006

World Population, Per Capita and Primary Energy Consumption, 1850-2006, as a Percentage of 2006 Levels

Cumulative OIL Consumption by the Human Race as a Percentage of Total Consumption through Yearend 2006

World Oil Reserve to Production Ratio in Years Including Oil Sands* and Possibly Spurious post-1984 OPEC Reserves


World Oil Production and Consumption 1965-2006

(data from BP Statistical Review of World Energy, 2007)
Published Estimates of Conventional World Oil Ultimate Recovery

Source: USGS and Colin Campbell

Consensus Estimate
~2000 Gigabarrels

The Growing Gap between Production and Discovery of Regular Conventional Oil (1930-2050)

World Discoveries Peak in 1965

Production has Exceeded Discoveries since 1984

Past discoveries have been backdated with revisions from ExxonMobil (2002) to reflect “Reserve Growth”
Campell's 2006 Hydrocarbon Liquids Production and Forecast 1930-2050

- Combined Liquids Peak 2010 (89 MMbbls/day)
- Ultimate Recoverable = 2.5 Trillion Barrels

EIA Projections (Oct 2005):
- 2004 – 82.5 MMbbls/day
- 2005 – 83.6 MMbbls/day
- 2006 – 85.4 MMbbls/day

Ultimate Recoverable = 2.5 Trillion Barrels

Most Recent Estimates of the Time of Peak World Oil Production

(Data Source Hirsch 2007 except for EIA; EIA estimate from EIA IEO, 2007, reference case demand growth of 1.4%/year and USGS 2000 P50 estimate with peaking at World R/P of 10 years)
World Oil Supply – March 2001 to April 2007
Can Investment Get Us to 120 Million barrels per Day?

(5-Month Moving Average including data to June 2007) (data from Energy Information Administration, September, 2007)
EIA World Oil Production and Consumption Forecast 2004-2030
(Reference Economic Case)

Production
- Unconventional +280%
- Non-OECD +37%
- OECD -17%
- OPEC +62%

Consumption
- Non-OECD +81%
  (82% of 2007 Population)
- OECD +16%
  (18% of 2007 Population)
- Non-OECD +81%
- OECD +49%
- Unconventional +289%

Range of Peak Production estimates of Duncan, Laherrere, Campbell, Bakhtiari, Ivanhoe, Deffeyes and others
- 42% increase
- 1.4% per year

North American Oil Consumption and Movements: 1965-2006

U.S.A.
- Consumption up 79%
- Net Imports (67% of 2005 consumption)
- Production (down 39% from Peak)
- Peak 1970

Canada
- Net Exports up 99%
- Production (up 242%)

Mexico
- Net Exports up 55%
- Production (up 917%)
- Peak 2004

(data from BP Statistical Review of World Energy, 2007)
Canada Scenarios of Oil Production Including Oil Sands (NEB, 2003)

Supply Push Scenario

- In Situ +285%
- Mining +503%

Techno-Vert Scenario

- In Situ +252%
- Mining +400%

(data from National Energy Board, July, 2003)

EIA World Unconventional Liquids Production Forecast 2004-2030
(Reference Economic Case, 2007)

- Gas-to-Liquids (mainly Qatar) +300%
- Coal-to-Liquids +2300%
- Ultra-Heavy Oil (mainly Venezuela) +183%
- Canadian Oil Sands/Bitumen +227%
- Biofuels +467%

8.9% of forecast 2030 World Oil Consumption

Energy Profit Ratio for Liquid Hydrocarbons

Energy Source (EROEI > 1)

Energy Sink (EROEI < 1)

Source

University of Minnesota

Pimentel and Patzek

Increasing Energy Input

Energy Return on Energy Invested

"Old" Conventional Oil
"New" Conventional Oil
Heavy Oil
Extra Heavy Oil
Gas to Liquids
Tar Sands
Coal Liquefaction
Biodiesel
Ethanol
Shale Oil
Biodiesel
Ethanol

Cumulative GAS consumption by the Human Race as a Percentage of Total Consumption through Yearend 2006

533 Billion barrels Oil Equivalent Consumed

90% of the GAS Consumed by the Human Race Used Since 1988

50% of the GAS Consumed by the Human Race Used Since 1963

Start 1885

1% 1930 5% 1954


Year

Forecast World Gas Consumption 2004-2030 in Three Economic Cases (EIA, 2007)

High Economic Case
Reference Economic Case
Low Economic Case

Projections

Year

Quadrillion Btu
0 20 40 60 80 100 120 140 160 180 200

(data from Energy Information Administration International Energy Outlook, May, 2007)

World Gas Reserves: 1980-2006

Middle East
Former Soviet Union
Asia Pacific
Africa
Europe
S. & C. America
North America

Percentage of Remaining Reserves
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

Trillion Cubic Feet
0 1000 2000 3000 4000 5000 6000 7000

Year

(data from BP Statistical Review of World Energy, 2007)
World Natural Gas Reserve to Production Ratio in Years 1990-2006

Years of Production at Current Rates

North America  Europe  Rest of World  Total World

(data from BP Statistical Review of World Energy, 2007)

Campell's 2006 Gas Production and Forecast 1930-2050

Peak/Plateau
Conventional Gas
2025

Peak of All Gas
2045

(C.J. Campbell, personal communication, September, 2006)
Campell's 2006 Total Hydrocarbon Production and Forecast 1930-2050


Canada: 122% increase in Production 1985-2006

(data from BP Statistical Review of World Energy, 2007)
North America Natural Gas Reserve to Production Ratio in Years 1990-2006

Years of Production at Current Rates.

U.S.A. Canada Mexico North America

North America Natural Gas Reserve to Production Ratio in Years 1990-2006


Discovered Resources

Remaining Discovered and Undiscovered Resources

Canada’s Exploration Treadmill – more and more drilling to find less and less gas

(Wells drilled from Canadian Association of Petroleum Producers (CAPP), 2007, and Canadian Association of Oil Well Drilling Contractors; Production from Statistics Canada, 2007; Reserves from CAPP, 2007)

Annual Canadian Marketable Natural Gas Production
by Month January 1991 - May 2007
(12 month centered moving average)

(Source of data Statistics Canada, August, 2007)
The WCSB Treadmill:
Gas Rate Added per Foot Drilled down 12%/year

Down 53% 1999-2005

Source: Forward Energy Group
(modified from Flint, 2007)

The WCSB Treadmill:
Drilling Cost per Foot Drilled up 100% - 1999-2006

1999-2006

Source: Forward Energy, CAPP
(modified from Flint, 2007)
The WCSB Treadmill: Finding and Developing Cost up 21%/year

F&D Costs Up >200% 1999-2005

2005 gas at $4.40 per Mcf F&D requires a $6.16 cash netback from the 2005 sales price of $8.41 per Mcf to provide a 10% return

21%/year

F&D Costs Up >200% 1999-2005

Source: Forward Energy, CAPP

Canadian Active Drilling Rig Count and Marketable Gas Production 2000-2007
(2005 Canadian Overall Decline Rate was 21%)

Active Rigs 2000-2007
(52-week moving average)

Marketable Gas Production
(12-month moving average)

(data from Baker-Hughes, 2007; Statistics Canada, August, 2007)

Declines by 2009:
- Low Case = 1.2 bcfd = 8%
- Reference Case = 2.1 bcfd = 12%
- High Case = 2.6 bcfd = 15%

NEB, 2003, Canadian Domestic Natural Gas Demand Scenarios by Sector, 2002-2025

Supply Push Scenario

Techno-Vert Scenario
U.S. Gas Consumption by Sector, 1997-2006

Overall Decline -4.1% 1997-2006
Peak Consumption 2000
+53.7%
Due to Major Capacity Expansion
-12.6%
-10.9%
-12.5%
-22.2%
Demand Destruction
Due to Price

Year

Trillion Cubic Feet/Year
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30

(1) Demand Destruction Due to Price

U.S. Natural Gas Supply Forecast by Source 2005-2030
(Energy Information Administration)

19% Total Growth from 2005-2030
Supply Peaks at 26.2 Tcf
25.5 Tcf
Liquefied Natural Gas +700%
Canada Imports
Alaska
Lower 48 Offshore

Peak
Lower 48 Production
In 2017
Up 9.6%
2005-2017

Lower 48 Onshore
Lower 48 Production Declines 5.7% 2017-2030

Year
2005 2010 2015 2020 2025 2030

Trillion cubic feet/year.
0 5 10 15 20 25 30

(2) (data from Energy Information Administration, 2007)

(3) (data from Energy Information Administration Annual Energy Outlook, 2007)
The U.S. Gas Exploration Treadmill
U.S. Gas Wells Drilled 1993-2006
U.S. Dry Gas Production 1993-2006

Year
1993 1995 1997 1999 2001 2003 2005

Trillion Cubic Feet per Year

Number of Successful Gas Wells Drilled

Year
1993 1995 1997 1999 2001 2003 2005

2017 EIA Forecast
Production Peak July 2001

(data from U.S. Energy Information Administration, June, 2007)

U.S. Annual Dry Gas Production Rate by Month January 1993 - May 2007 (centered 12 month moving average)

Month
Jan-93 Jan-94 Jan-95 Jan-96 Jan-97 Jan-98 Jan-99 Jan-00 Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06

Trillion cubic feet/Year
17.5 18 18.5 19 19.5 20

EIA 2017 Forecast
Peak July 2001
Katrina

Growth 1.1%/Year
Decline 0.9%/Year
Down 4.7%

Lowest Level Since October 1995

(Data from Energy Information Administration, August, 2007; Forecast from EIA Annual Energy Outlook, 2007)
U.S. Supply with Canadian Imports and Shortfalls Given NEB, 2003, Supply Scenarios and EIA (2007) Reference Case Supply Scenario with 1.5% Yearly Decline in Lower 48 Production

Supply Push Scenario
Techno-Vert Scenario

LNG Producers and Consumers in 2006

(data from Energy Information Administration

(data from BP Statistical Review of World Energy, 2007)
**Existing and Proposed North American LNG Terminals**

**Cancelled Terminals - 26**

- Cheniere LNG, Brownsville, TX
- Cheniere LNG, Pinto Island, AL
- Fairwinds LNG, Harpswell, ME
- Hope Island LNG, ME
- Humbolt Bay LNG, Eureka, CA
- Mare Island LNG, Vallejo, CA
- Navy Homeport LNG, Mobile, AL
- NJ Energy Bridge, Belmar, NJ
- Ormond Beach LNG, CA
- Radio Island LNG, NC
- Tampa LNG, Tampa, FL
- Tijuana Energy Center, Tijuana, MX
- Offshore Shell Gulf Landing, LA
- Pearl Crossing ExxonMobil, GOM
- Southern Offshore Crystal Energy, CA
- Bahamas, Seafarer/El Paso
- Offshore Louisiana, Main Pass/McRoran
- Long Beach, Mitsubishi/ConocoPhillips, CA
- Point Tupper, Anadarko, NS
- Baja California Offshore, Chevron, MX
- Pascagoula, MS, Gulf LNG
- Pascagoula, MS, Chevron/Texaco
- Offshore Boston, MA, Neptune LNG
- Offshore Boston, MA, Excelerate LNG
- Gulf of Mexico, ConocoPhillips
- Offshore California, BHP Billiton

**Construction**

- *As of August 6, 2007*
- **Construction suspended**

**Office of Energy Projects**

**LNG Imports and Surplus Capacity 2000-2006**

- **Lake Charles and Elba Island Terminals**
- **Gulf of Mexico Expansions Complete**
- **Excelerate Energy Comes on Line**

**Data from Energy Information Administration September, 2007**
Energy Profit Ratio for Natural Gas and Alternatives

- **High** Energy Source (EROEI > 1)
- **Low** Energy Sink (EROEI < 1)

**Energy Return on Energy Invested**

**Increasing Energy Input**

- Old Conventional Gas
- New Conventional Gas
- Imported LNG
- Tight Gas
- Coal Gasification
- Shale Gas
- Gas Hydrates (so far)
- Compressed Hydrogen
- Liquid Hydrogen

Cumulative COAL Consumption by the Human Race as a Percentage of Total Consumption through Year-end 2006

- 50% of the COAL Consumed by the Human Race Used Since 1970
- 90% of the COAL Consumed by the Human Race Used Since 1909

1116 Billion barrels Oil Equivalent Consumed

Forecast World Coal Consumption 2004-2030 in Three Economic Cases (EIA, 2007)

(data from Energy Information Administration International Energy Outlook, May, 2007)

World Remaining Recoverable Hydrocarbon Reserves by Energy Content (2006)

(data from BP Statistical Review of World Energy, 2007)
One Forecast of Future World Coal Production (EWG, 2007)

Future Fossil-Fuels Production

Caltech Remaining Recoverable Fossil Fuels: $OIL$ and $GAS = 3.1$ Tboe; $COAL = 1.6$ Tboe; Total = 4.7 Tboe. IPCC Remaining Recoverable Fossil Fuels: $OIL$ and $GAS = 10-15$ Tboe; $COAL = 18$ Tboe; Total = 28-33 Tboe – OVERSTATED BY 6-7 TIMES.

(from Rutledge, Caltech, 2007)
Comparing with the UN IPCC Scenarios

- Caltech’s production constrained projection has lower emissions than any of the 40 IPCC scenarios
- This is still true even with full coal reserves
- Jean Laherrere has been pointing out that something is wrong for years

(from Rutledge, Caltech, 2007)

Simulated Carbon-Dioxide Levels

- Simulations from the program MAGICC from Tom Wigley at the National Center for Atmospheric Research in Boulder. This program was used in the earlier UN IPCC Assessment Reports.
- Caltech’s projection gives a peak CO₂ concentration of 460ppm

(from Rutledge, Caltech, 2007)
Forecast World Electricity Generation by Fuel 2004-2030 (Reference Case EIA 2007)

Market Share

85% Growth 2004-2030

Hydro/Renewables +56%
Nuclear +38%
Coal +103%
Natural Gas +130%

(data from Energy Information Administration International Energy Outlook, May, 2007)


Market Share

46% Growth 2004-2030

Hydro/Renewables +41.1%
Nuclear +13.6%
Coal +68.3%
Natural Gas +31.7%

(data from Energy Information Administration International Energy Outlook, May, 2007)
Forecast Canadian Electricity Generation by Fuel 2004-2030 (Reference Case EIA 2007)

- Hydro/Renewables +39.8%
- Nuclear +46.5%
- Coal +55.1%
- Natural Gas +103%

Year
- Terawatt Hours
- Market Share

0 100 200 300 400 500 600 700 800 900


60%
5.8%
5.8%
5.8%
8%
15.1%
17.1%
18.2%
57.5%
15.1%


1998-2005 – 236 Gwatts
- Gas
- Coal
- Nuclear
- Wind
- Other

Total Expansion 331 Gwatts or ~30%

2006-2015 – 95 Gwatts
- Gas
- Coal
- Nuclear
- Wind
- Other

(data from Energy Information Administration International Energy Outlook, May, 2007)

(data from National Electricity Reliability Council, October, 2006)
WHAT ABOUT “NUCLEAR”? Generation Capacity at Current Construction Levels and Levels Required to Maintain and/or Increase Nuclear Capacity by 2025

WHAT ABOUT “NUCLEAR”? The FUEL SUPPLY Issue:

WHAT ABOUT “NUCLEAR”? 
The FUEL SUPPLY Issue:

![Worldwide Uranium Resource Utilization](image)

(From Busby, September 2007, Sanders Research, based on Nuclear Energy Agency “Redbook” (2006) - <$130/kg/U)

There is a Great Inequity in Energy Consumption Worldwide

Primary Per Capita Energy Consumption of Selected Countries in 2001

![Energy Consumption Chart](image)

Population Growth – History and Forecast (1965-2030)

(United States Bureau of Census, October, 2007)

Per Capita Consumption – History and Forecast (1965-2030)

**Total Consumption – History and Forecast (1965-2030)**

*Industrialized* - United States, Canada, OECD-Europe
*Developing* - China, India
*Other Non-OECD Asia*

Million Tons Oil Equivalent


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**World Population Increase 1950-2050**


*Percentage Increase* (70 million new Vehicles built in 2006)

*Net Increase/Year* (60 million new Vehicles built in 2006)
Trends in Energy Investment for Food Production
(The Hydrocarbons We Eat)

Energy Input per Unit of Food Energy Output

Loss  Profit

Industialized  Developing

Consumption by Source

World Population, Per Capita and Primary Energy Consumption, 1850-2006, as a Percentage of 2006 Levels

Population

Per Capita Consumption

Consumption by Source

World Population, Per Capita and Primary Energy Consumption, 1850-2030, as a Percentage of 2030 Levels


“The term ‘SUSTAINABLE GROWTH’ is an Oxymoron”

(Albert A. Bartlett, 2000)
Summary

• The five-fold expansion of global population since 1850 has been made possible by non-renewable fuels, the consumption of which pervades all aspects of society – food, transportation, communication etc.

• The eight-fold expansion of global per capita energy consumption since 1850 has been entirely a result of consumption of non-renewable energy

• North America consumes a disproportionate amount of energy (5 times the global per capita average). The Developing World understandably aspires to North American energy consumption levels, however, finite non-renewable resources are unlikely to be sufficient to allow this to happen, setting the stage for global conflict over energy

• The realities of the finite nature of non-renewable energy resources are now becoming evident – peak oil in many producing countries, peak North American natural gas, ten-fold increase in uranium prices since 2000, imports of coal into the US after centuries of self-sufficiency

• Despite the hype, renewable energy technologies are **EXTREMELY UNLIKELY** to be able to replace non-renewable energy in existing energy demand forecasts – a sustainable future lies in radically reducing and rethinking energy consumption

Summary

• The US (and later Canada) will become increasingly more vulnerable to the vagaries of imported supplies, not just for oil and natural gas, but for the products produced from them - petrochemicals, fertilizers etc.

• Even maintaining nuclear’s contribution to North America’s electricity generation implies a major program of repowering, decommissioning and replacing the aging nuclear fleet

• The first step is to recognize the problem, and begin making the changes and creating the infrastructure that will be required for transit to a more sustainable energy future

• The most cost-effective long-term approach is energy conservation and much greater efficiency - reduce consumption on all levels

• A sustainable energy future is not out of reach but will be hugely challenging – we have to be thinking in the 10-20+ year timeframe to develop the infrastructure for alternatives as well as technologies and incentives to reduce consumption
Despite the Proponents of Infinite Growth and the Ability of the Markets and Technology to Overcome all Obstacles there is One Supreme Overriding Principle:

**ENERGY CONSUMPTION CANNOT EXCEED ENERGY SUPPLY**

Therefore the reality of **FINITE** nonrenewable energy resources will force a transition to a sustainable energy future.

The Only Question Is:

**HOW WILL THIS TRANSITION OCCUR?**

“...a Lower-Impact Society is the Most Impossible Scenario for Our Future...

...Except for all other Conceivable Scenarios”

*Jared Diamond (2005) from his best-seller “Collapse”*
Thank you

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