# Nuclear Power -Greenhouse Gas Emissions & Risks A Comparative Life Cycle Analysis

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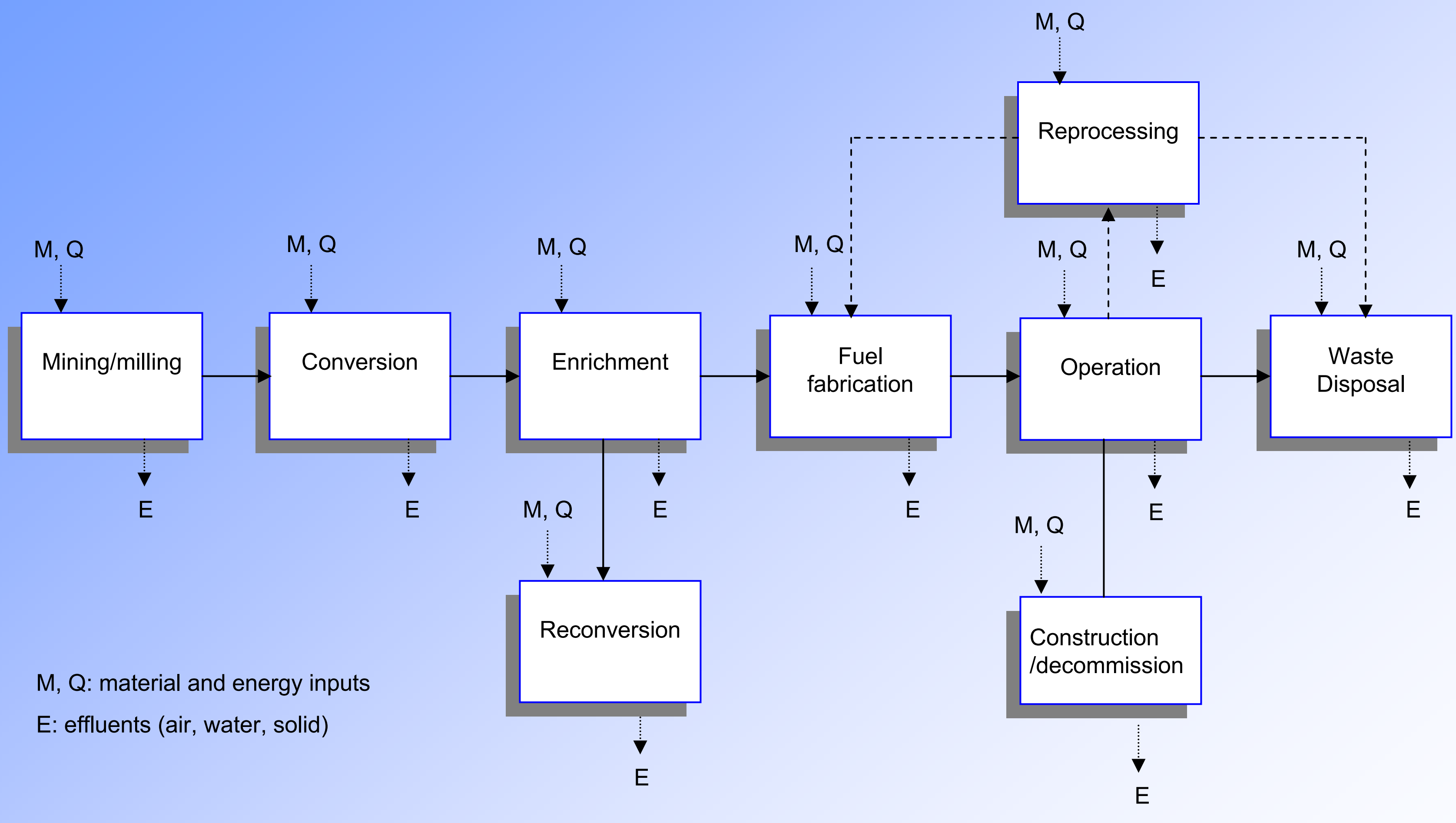
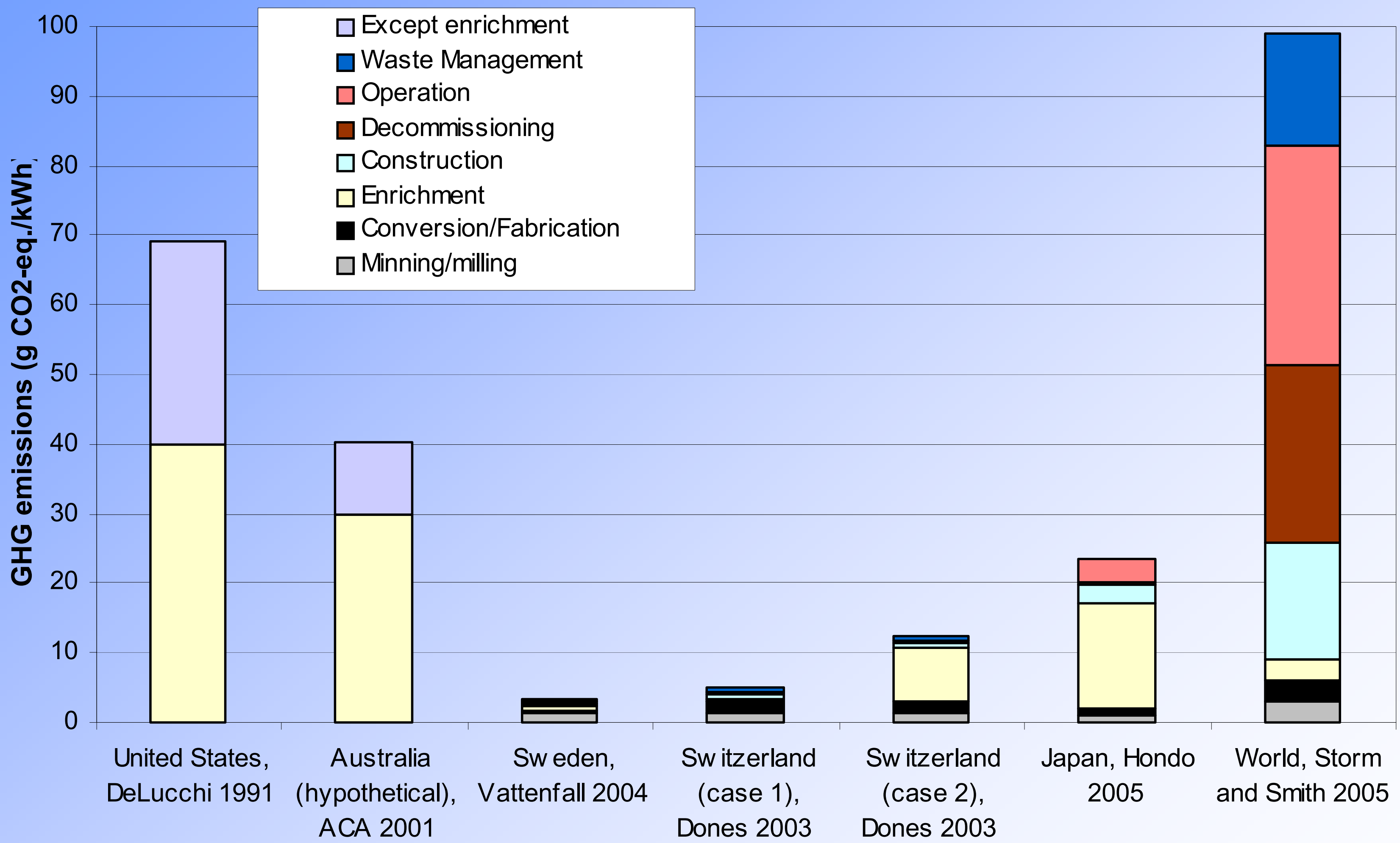
# The Nuclear Fuel Cycle



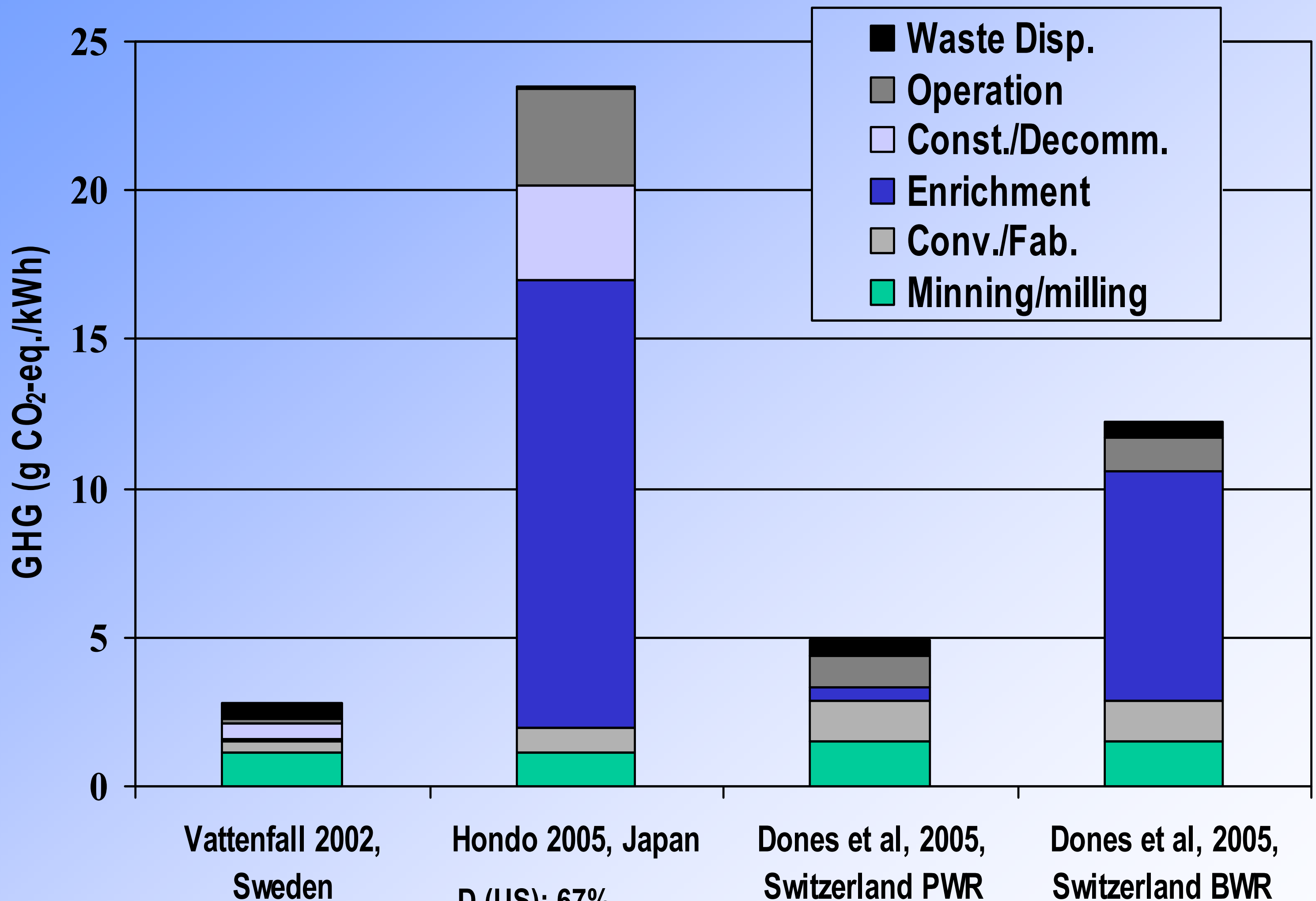

M, Q: material and energy inputs

E: effluents (air, water, solid)

# Review of GHG Emissions from Nuclear Fuel Cycle



# Breakdown of GHG Emissions from Nuclear Fuel Cycle




Vattenfall 2002, Sweden:
D (France): 20%
C: 80%

Hondo 2005, Japan:
D (US): 67%
D (France): 22%
C: 11%

Dones et al, 2005, Switzerland PWR:
D (France): 60%
C: 40%

Dones et al, 2005, Switzerland BWR:
D (US):13%
D (France): 55%
C: 32%

# BNL Reference Case -Conditions for US Nuclear Fuel Cycle

| | |
|---|---|
| Reactor lifetime (yrs) | 40 |
| Burn-up ($MWd_{th}/kgU$) | 42 |
| Enrichment mix (%)<br>EIA -1998-2002 | - Diffusion (US)-34%<br>(France)-11%<br>- Centrifuge (mix)-19%<br>- dilution highly enriched uranium (Russia)-36% |
| Upstream Electricity Mix for enrichment | 20% coal<br>80% Tennessee Valley Authority grid |
| Ore grade (% U3O8) | 0.2 |
| Capacity factor (%) | 85 |
| Thermal efficiency (%) | 35 |
| Product/tail assay (% $U^{235}$) | 3.8/ 0.25 |

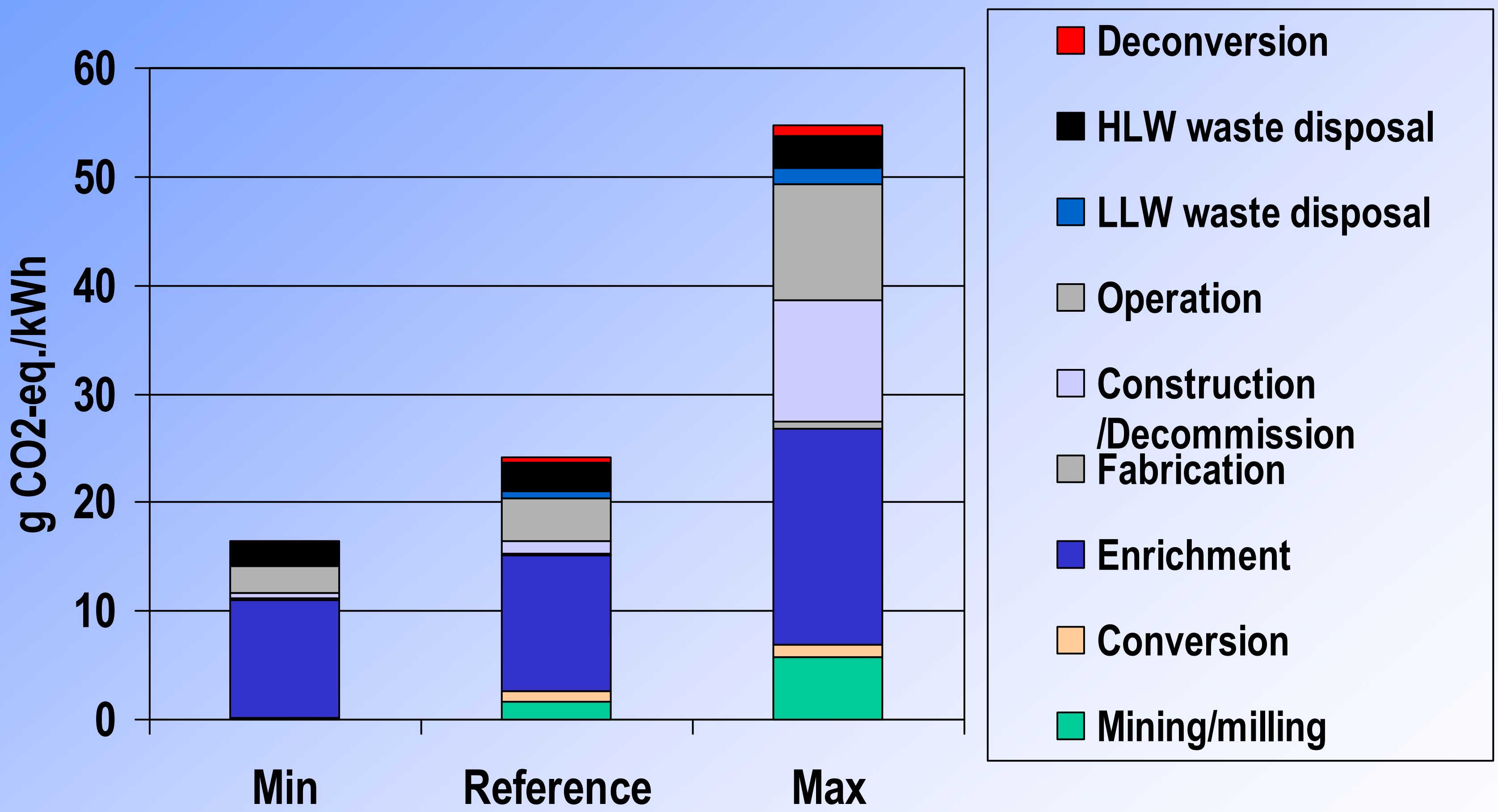
# BNL Study -Scenarios for GHG Estimation of US Nuclear Fuel Cycle

| Parameters | Min. | Reference | Max. |
|---|---|---|---|
| Energy for diffusion enrichment | 2400 kWh/SWU[a] | 2600 kWh/SWU | 3000 kWh/SWU |
| Electricity source for enrichment | 100% from US avg. | 80% from TVA[b], 20% from coal | 100% from coal |
| Ore concentration (% U) | 12.7 (Canada) | 0.2 | 0.05 (Australia) |
| LCA method: Construction stage | Process-based | Process-based | Economic Input/Output |

a: Separative Work Unit

b: Tennessee Valley Authority

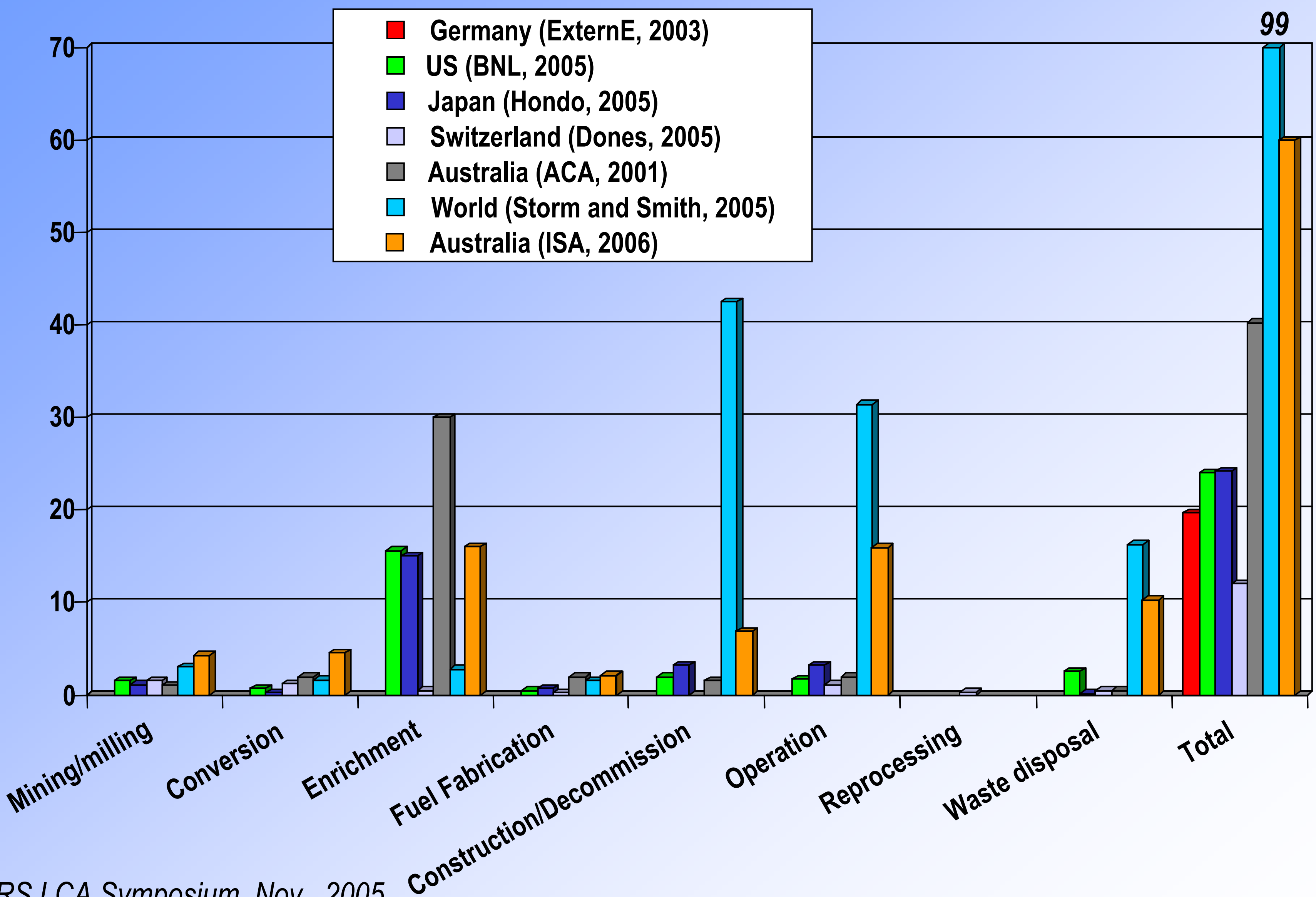
# BNL Study -US Nuclear Fuel Cycle: GHG Emissions




*MRS LCA Symposium, Nov. 2005*

*Energy Policy 35 (2007) 2549-2557*

# GHG Emissions from the Nuclear Fuel Cycle: Comparisons of different studies




*MRS LCA Symposium, Nov. 2005*

# Process Based vs. Economic Input/Output LCA Example: Construction –1 GW NPP-

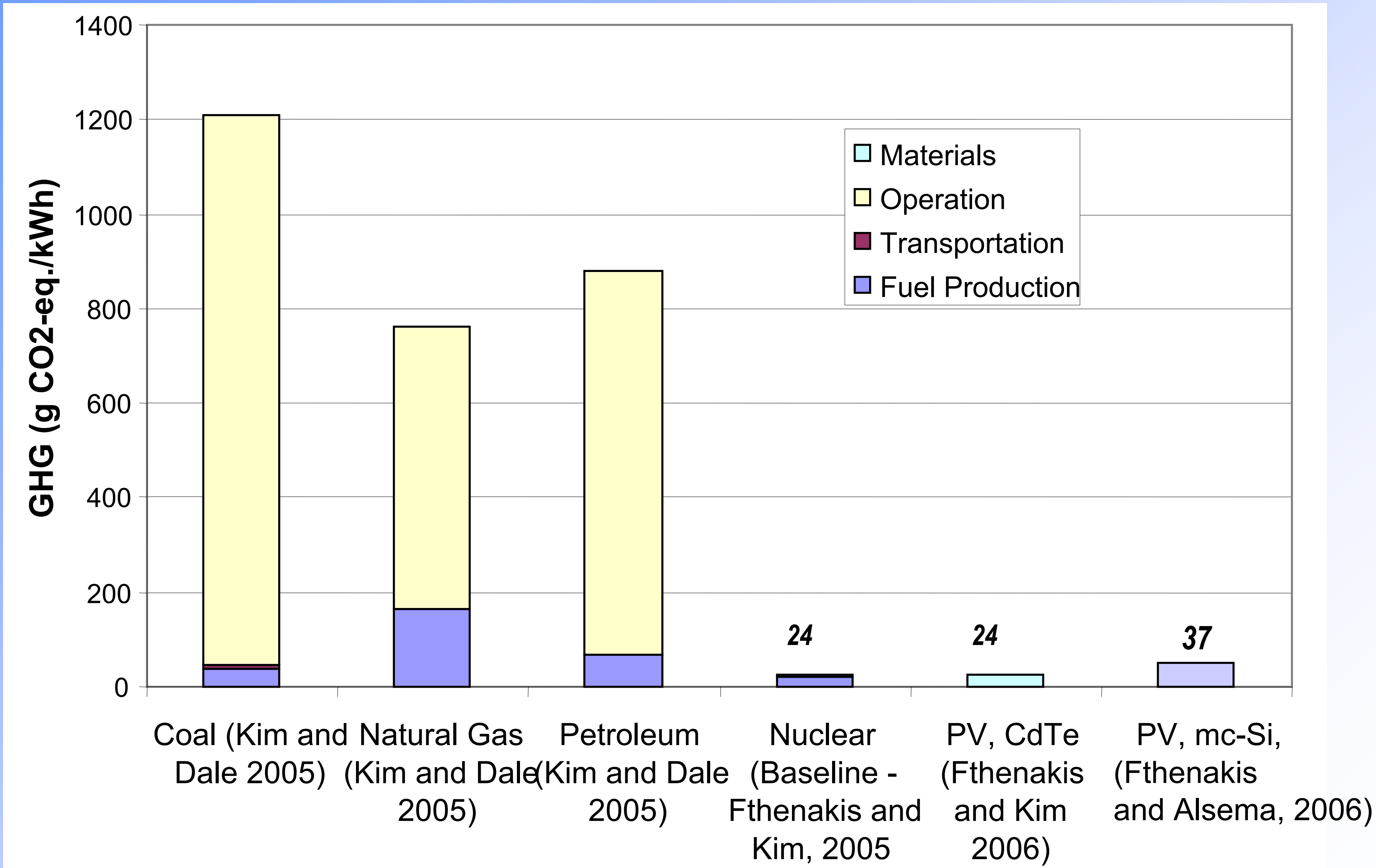
| | | Construction Cost ($2000) | $CO_2$ emission (g/ kWh) |
|---|---|---|---|
| BNL ref case | Process-Based (Steel, concrete, copper) | | 1 |
| BNL worst case | EI/O | 4.5 billion | 11 |
| Storm 2005, baseline | EI/O | 7.5 billion | 17 |
| ISA 2006 baseline | EI/O | 1.3 billion | 5 |

**EI/O LCA may overestimate GHG emissions**

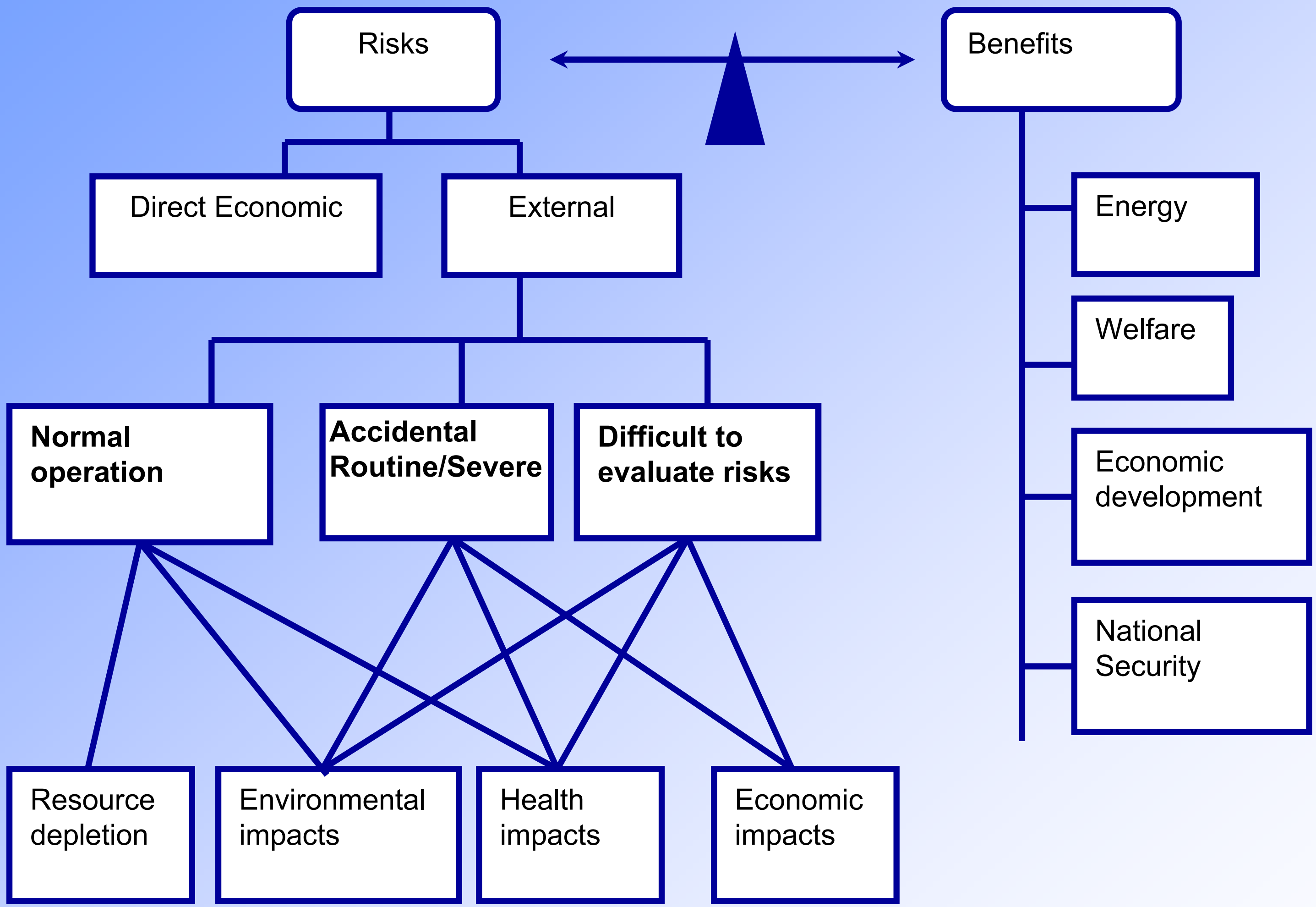
**Process-based LCA may slightly underestimate GHG emissions**

***Degree of overestimate of underestimate depends on the detail of material and energy inventories***

# Life Cycle GHG Emissions
# -A process-based LCA comparison-



# Framework for Evaluation of Life-Cycle Risks in Electricity Production

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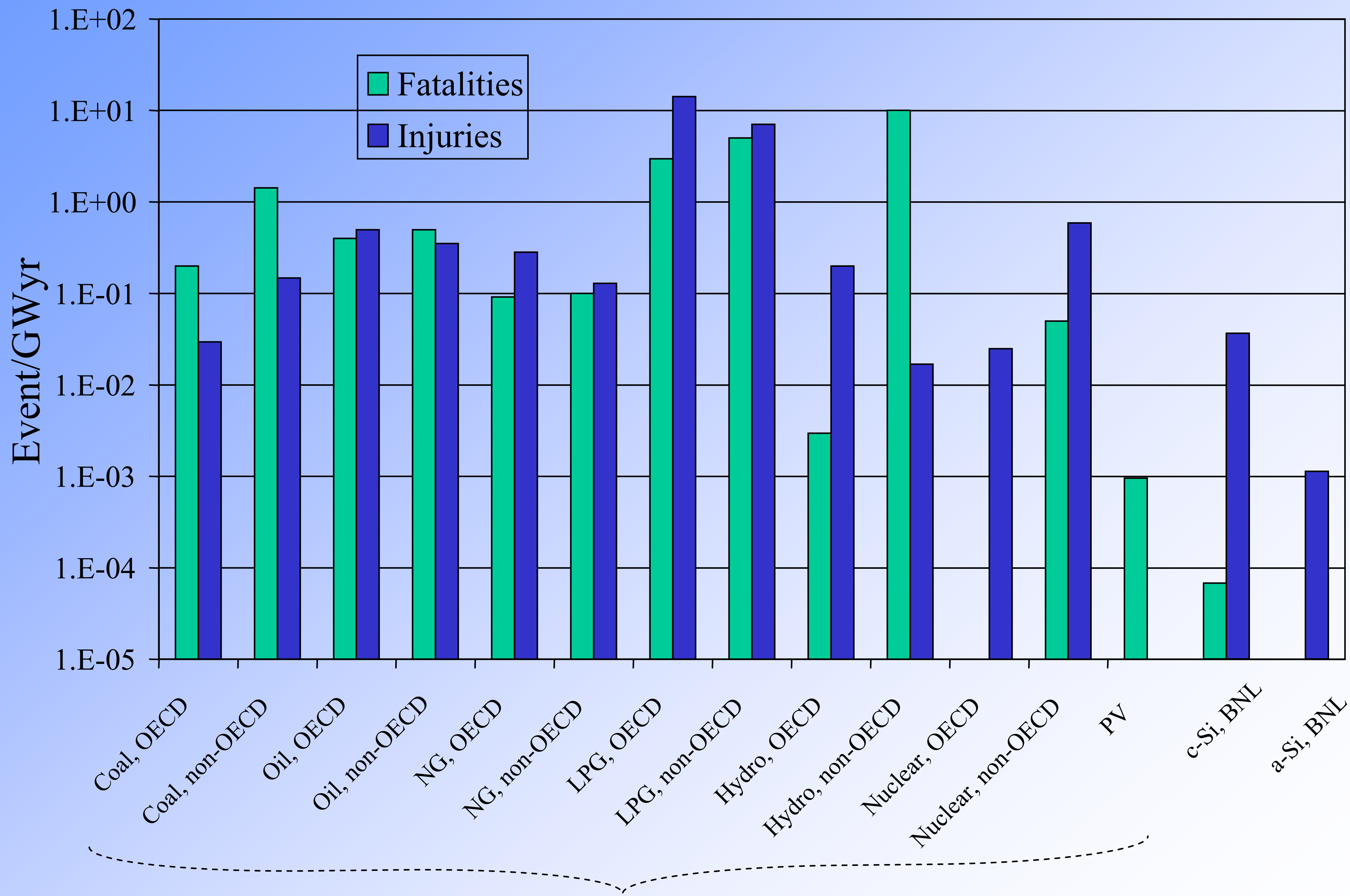
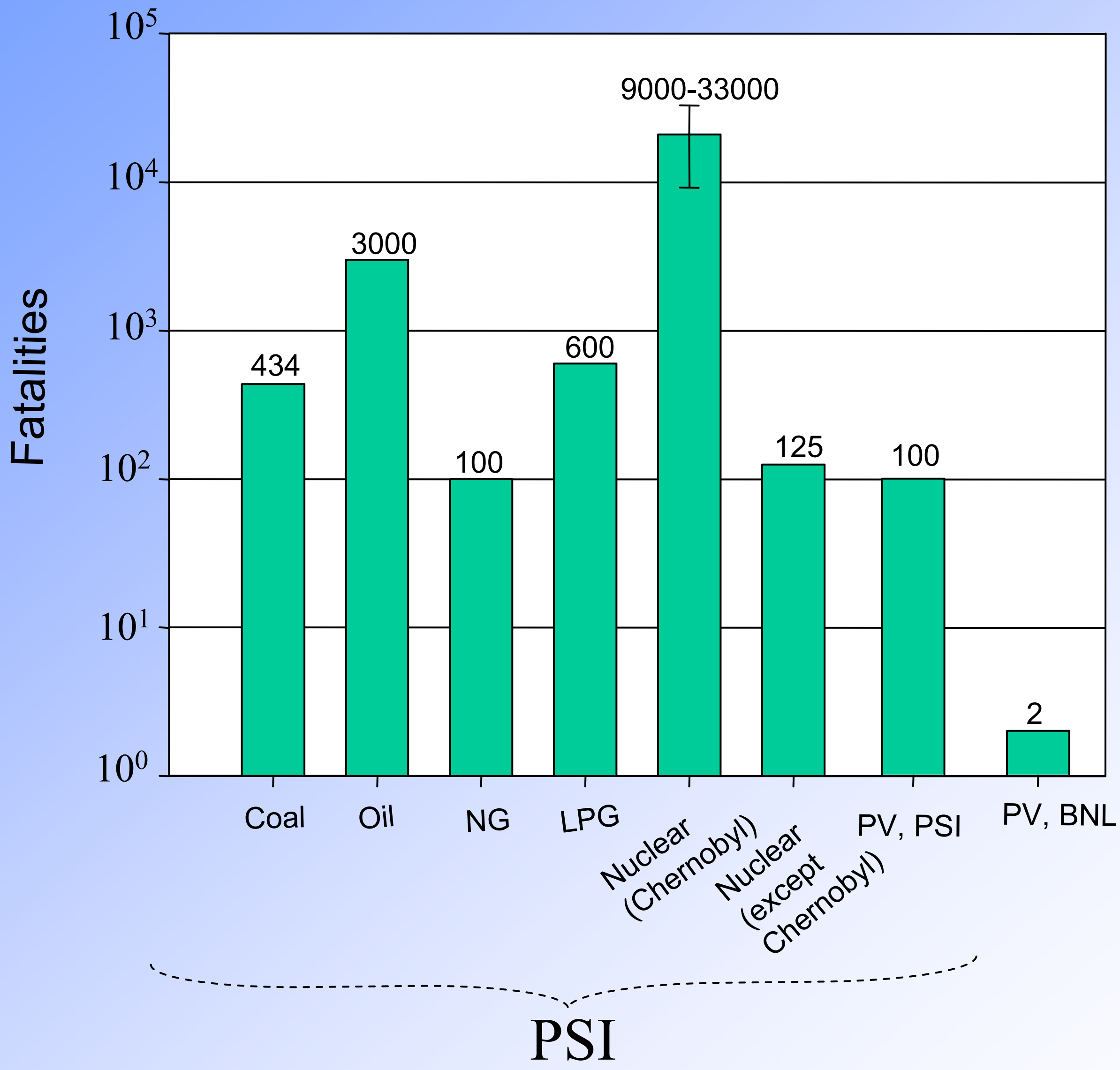
# Accidental Risks in Electricity Production




GaBE project, Paul Scherrer Institute (PSI), ENSAD 1969-2000

# Maximum Consequences per Accident



# Climate Change and Fossil Fuel Depletion Risks
# -Is there a tenable solution ?

- Nuclear Energy
  - Spent fuel management
  - Proliferation risks
- Coal with C sequestration
  - Reliability/Cost
  - Residual pollution
- Wind
  - Resource limits
  - Intermittency
- Solar
  - Cost
  - Intermittency

# The President's *Advanced Energy Initiative*

Initiated significant new investments and policies in:

- Clean Coal technology
- Nuclear Power
  - Global Nuclear Energy Partnership (GNEP) to address spent nuclear fuel, eliminate proliferation risks, and expand the promise of clean, reliable, and affordable nuclear energy
- Renewable Solar and Wind energy
  - Reduce the cost of solar PV technologies so that they become cost-effective by 2015 and expand access to wind energy.

# The President's *Advanced Energy Initiative*

"To safeguard our future economic health as well as national security, we must move aggressively to diversify our energy sources."

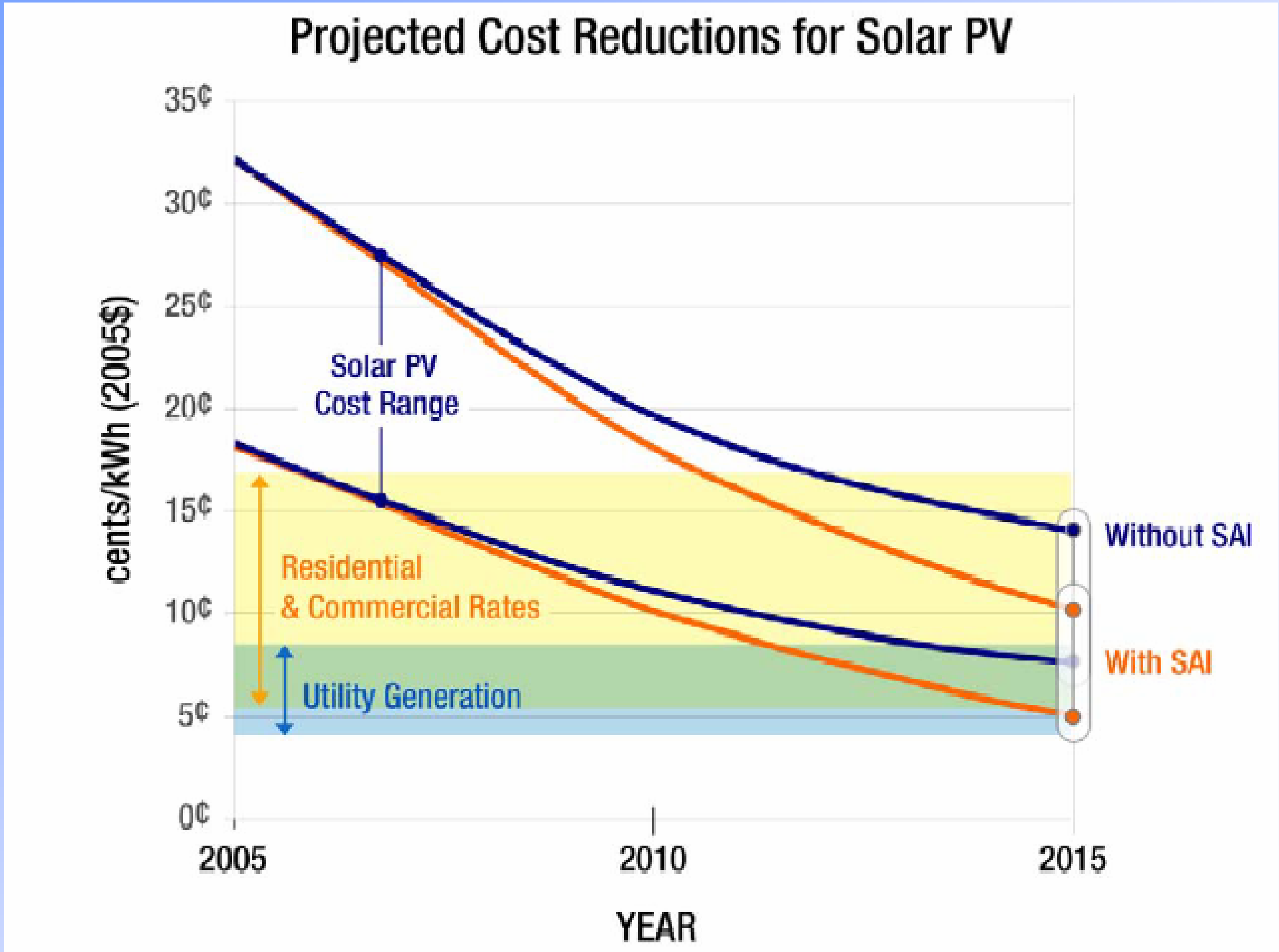
-*DOE Secretary Samuel Bodman*
*Golden, CO, July 7, 2006*

"I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait till oil and coal run out before we tackle that."

-*Thomas Edison*

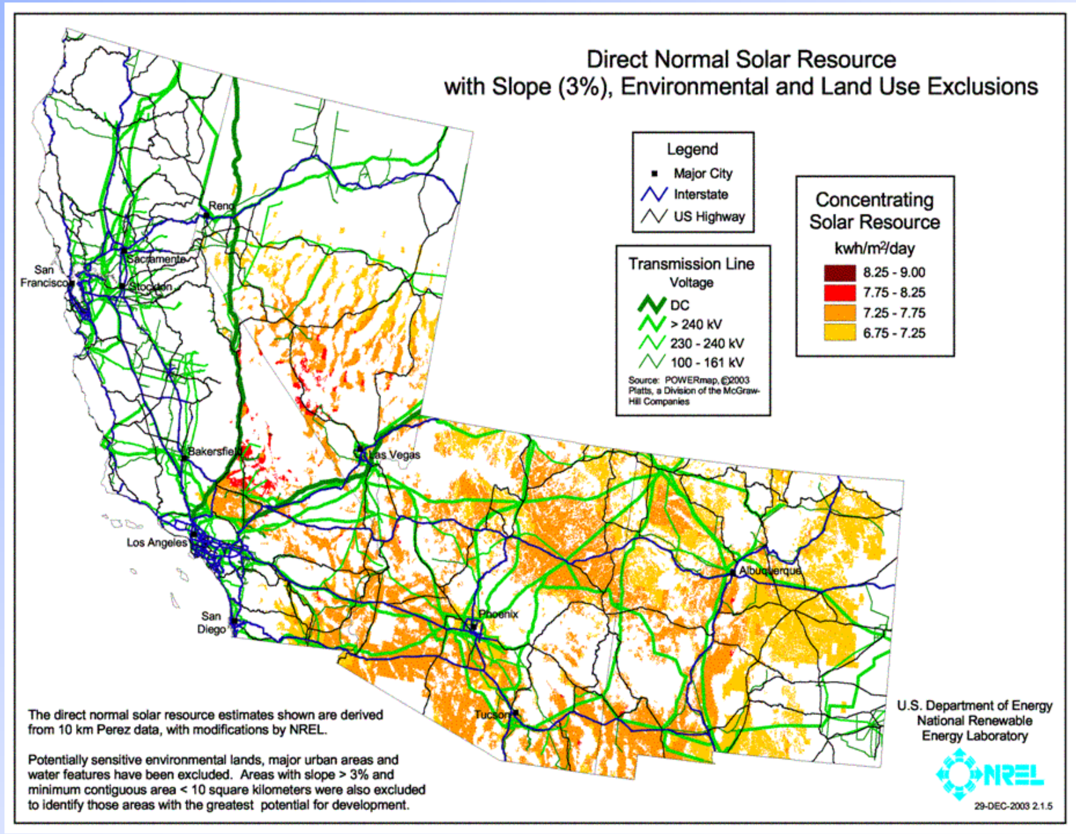
# The Solar America Initiative (SAI)

## SAI Goal: Achieve Grid Parity Nationwide by 2015



# Solar Solutions to Climate Change and Energy Self-Reliance*

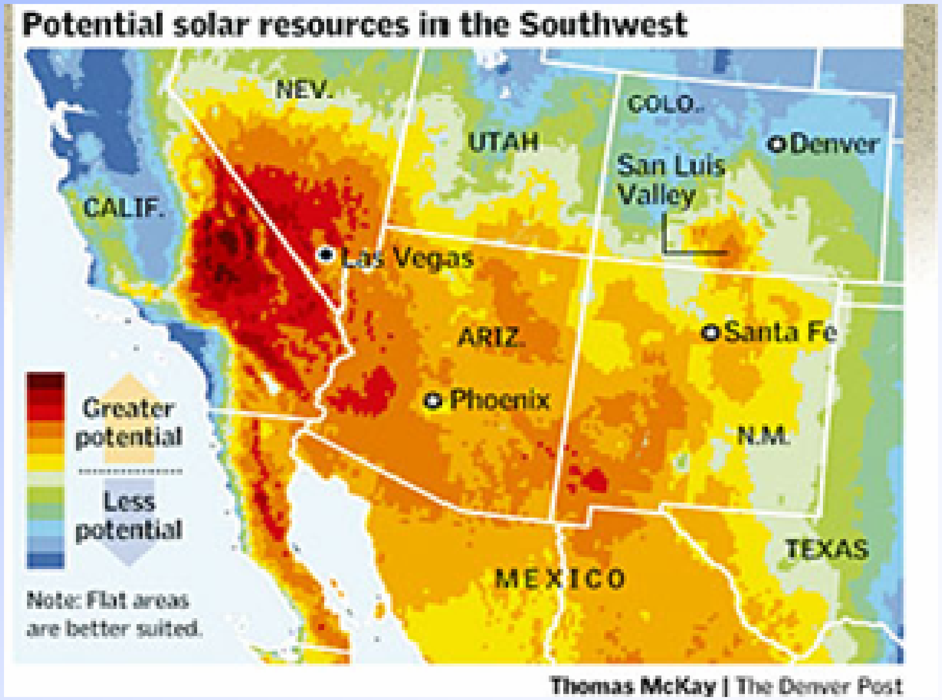
- 200,000 square miles of desert land in the SW is suitable for constructing solar power plants
- This area receives 3,600 quadrillion Btu of solar irradiation per year.
- If just 3% of this energy is converted to electricity, we satisfy the total US annual energy consumption.
- Throughout the rest of the country, sunlight can be used for distributed (rooftop) PV systems.




**From Zweibel, Mason, Fthenakis.*
*"An Imminent Solar Solution to Climate Change and Energy Security for the US", in press*

# Solar Solutions to Climate Change and Energy Self-Reliance*

- PV and compressed air energy storage (CAES) for 24-hour electricity
- Concentrating Solar Power with heat storage, also dispatchable
- Plug-in hybrids powered by solar electric (80%) and biofuels (20%)
- Wind as complement and nighttime backup to solar
- **Low-cost solar, an essential, enabling technology**
- **US SW solar enough to provide US energy self-sufficiency**

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# Conclusions

- A Life Cycle Framework is necessary for a complete description of the sustainability of energy technologies
- It enables a holistic approach encompassing resource availability and costs, potential risks and benefits to the US economy and the environment for current and future generations

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# Contributors

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