# HIS 2129

Technology, Society and Environment since 1800

(Winter 2014)

# Biotechnology, Old and New

- In the form of agriculture, biotechnology is humanity's oldest technological system (excluding our commensal relationships with other life forms, the only older technologies were, arguably, simple tools—and fire)
- The environmental consequences may have been profound; it has recently been argued that agriculture forestalled a new ice age
- Through selective breeding, humans have done more than simply hijack biological processes; they have changed them in ways beneficial to them (and often detrimental to those life forms)
- Genetic engineering is a new tool for doing the same, not only to plants and commensals, but to ourselves

# The Final Frontier...

- The final frontier of technology is the body
- In this course, we have seen technology shaping the *production and movement of goods*, the *communication and processing of information*, *daily work*, *life at home*, *everyday mobility*, the *artificial environment* (from clothing outward to cities), and even the *food* we eat
- In this class, we turn to the most intimate of technologies, those we make a part of ourselves

# Topics: Biotechnology and Risk

- WWII production of penicillin in Canada
- The risks of the contraceptive pill
- The evolution of technological risks, from Sudbury to Chernobyl
  - steam accidents
  - chemical accidents
  - nuclear accidents
- The risks of the contraceptive pill
- The assessment and perception of risks
- The case for prudence: global warming

# Biotechnology as Technoscience

- During WWII, governments invested heavily in applied research
- This meant that scientists, engineers, and technicians were called upon to cooperate
- The more ambitious the goals, the more complex the organization, and the more resources were needed to proceed
- This melding where science relies on advanced technologies, and technology relies on cutting edge scientific research has been called “technoscience”; above all, it is goal-oriented

# Penicillin Production at the Connaught Laboratories (Toronto, May 1944)

Harry Rowed, National Film Board, Library and Archives Canada

Step 1: A worker tends the broth prepared by mixing a red corn-steeping liquor with milk sugar (lactose)

Surface culture of the penicillin spore in bottles was later superseded by a large-scale deep fermentation method using sterile pipes and tanks.

# Penicillin Production at the Connaught Laboratories (Toronto, May 1944)

Step 2: A worker by the name of Ben Martin samples (for quality control) the broth prepared by mixing a red corn-steeping liquor with milk sugar (lactose)

Harry Rowed, National Film Board, Library and Archives Canada

# Penicillin Production in Canada (1)

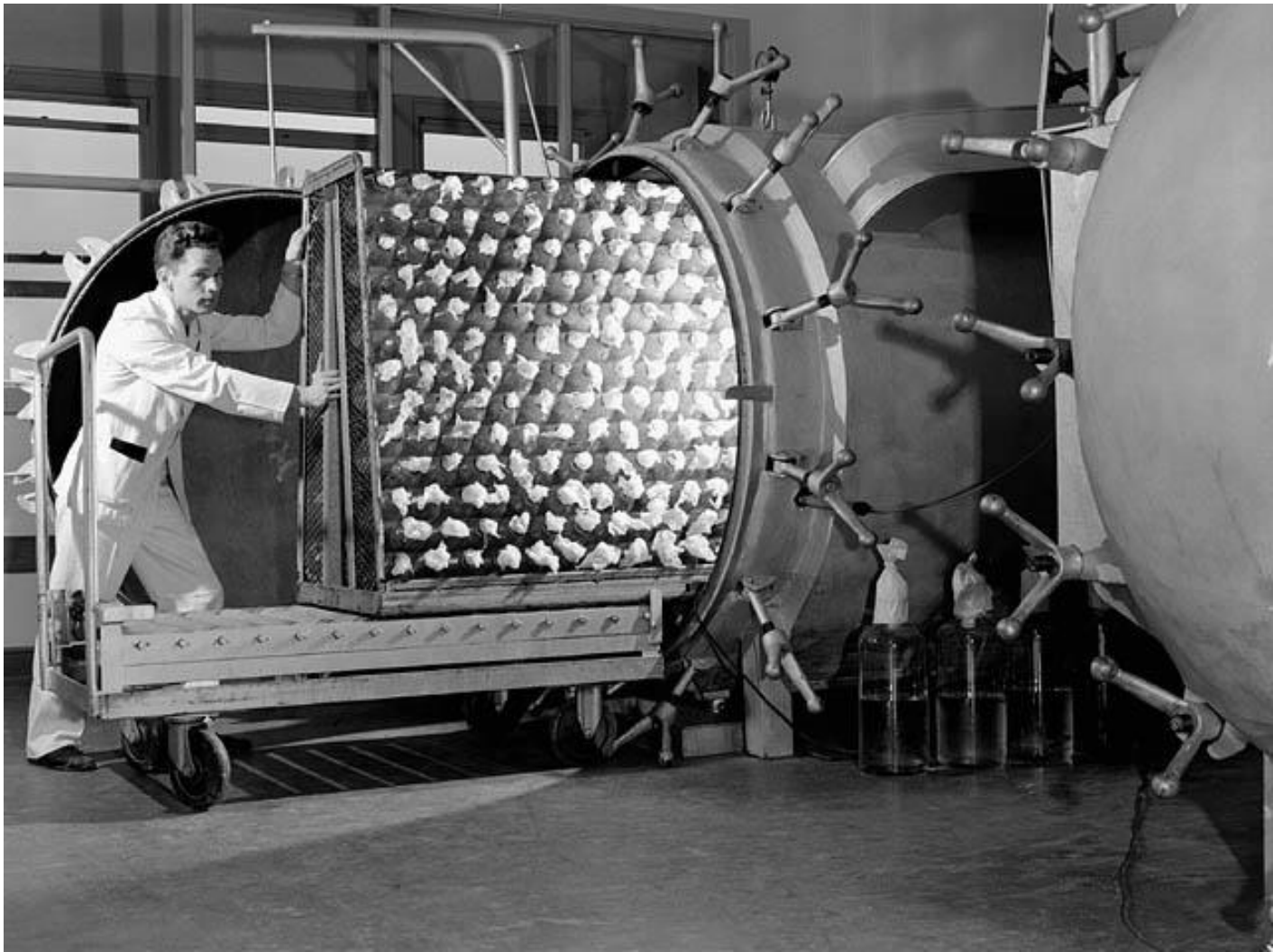
A worker inserts cotton plugs into sterile bottles in order to prevent contamination while allowing for aeration. (Connaught Laboratories, Toronto, May 1944)

Harry Rowed, National Film Board, Library and Archives Canada

# Penicillin Production at the Merck Laboratories (Montréal, May 1944)

A worker pushes broth-filled bottles into an autoclave for sterilization before inoculation.

Harry Rowed, National Film Board, Library and Archives Canada



# Wartime Penicillin Production in Canada

A worker pulls out from the autoclave a tray of sterilized bottles at the Connaught Laboratories in Toronto (May 1944)

Harry Rowed, National Film Board, Library and Archives Canada

# Penicillin Production in Canada (2)

The worker, dressed in sterile clothing, inoculates the bottles of broth with the *Penicillium notatum* mold using a spray gun. (Connaught Laboratories, Toronto, May 1944)

Harry Rowed, National Film Board, Library and Archives Canada

# Penicillin Production in Canada (3)

Close-up at Merck: The worker is dressed in sterile clothing, though her face mask is rather primitive. She is inoculating the bottles of broth with the *Penicillium notatum* mold. The spray gun uses sterile air.
(Merck Laboratories, Montréal, May 1944)

Harry Rowed, National Film Board, Library and Archives Canada

# Penicillin Production in Canada (4)

Esther Fox checks on a batch of broth-filled bottles in the “culture room”, where the mold forms during a ten-day growing process inside the bottles. (Connaught Laboratories, Toronto, June 1944)

Harry Rowed, National Film Board, Library and Archives Canada

# Penicillin Production in Canada (5)

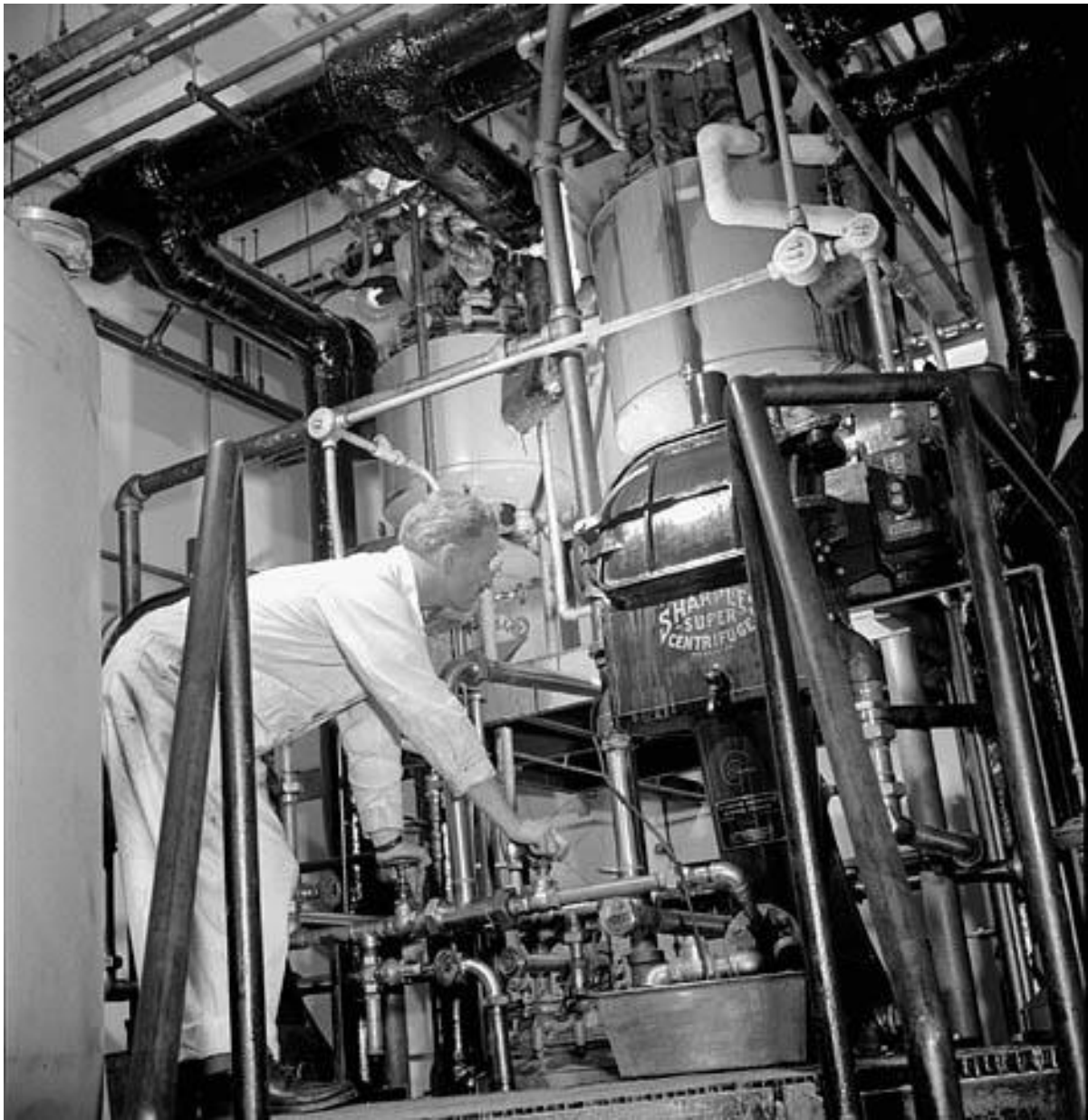
## Getting the mould out

(Connaught Laboratories, Toronto, May 1944)

All three pictures by Harry Rowed, National Film Board, Library and Archives Canada

# Penicillin Production in Canada (6)

## Extracting the penicillin




Part of the purification process: A chemist watches the level of the liquid in a centrifugal tank.
(Connaught Laboratories, Toronto, June 1944)

Harry Rowed, National Film Board, Library and Archives Canada

# Penicillin Production in Canada (7)

## Extracting the penicillin

Part of the purification process: A worker filter funnels amberlite solution into the final sodium salt solution of penicillin to remove excess sodium. (Connaught Laboratories, Toronto, May 1944)

Harry Rowed, National Film Board, Library and Archives Canada

# Penicillin Production in Canada (8)

## Penicillin for the troops

Women workers with surgical face masks and sterile clothing fill 20-cc vials with the sodium salt solution of penicillin. (Connaught Laboratories, Toronto, May 1944)

Harry Rowed, National Film Board, Library and Archives Canada

# Penicillin Production in Canada (9)

## Penicillin ready to go

A workman operates a vial-capping machine (Connaught Laboratories, Toronto, May 1944)

Harry Rowed, National Film Board, Library and Archives Canada

# Penicillin:  The Final Product

A close-up view of penicillin vials.  (Connaught Laboratories, Toronto, May 1944)


Harry Rowed, National Film Board, Library and Archives Canada

# Penicillin: The Last Step

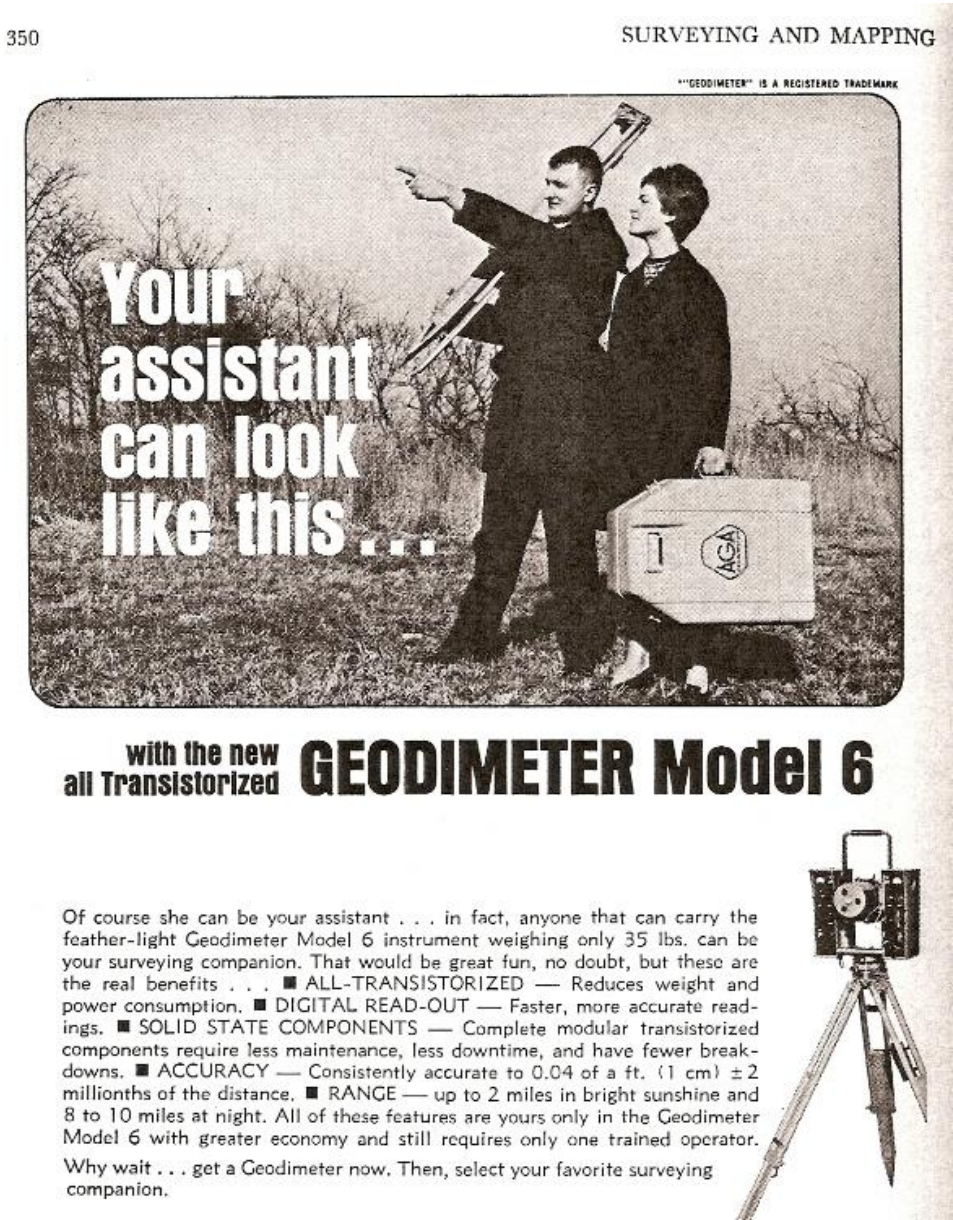
**Labeling and packaging the penicillin**

(Connaught Laboratories, Toronto, May 1944)

Harry Rowed, National Film Board, Library and Archives Canada

# The birth control pill: a new era?

- As recently as the middle of the 1960s, it was inconceivable that women might enter certain technological professions and fields as anything but a (comely) assistant
- The number of U.S. engineering doctoral degrees granted to women was essentially nil before 1970, but it started to rise soon afterwards



# The birth control pill: overview

- Tens of millions of women worldwide have taken oral contraceptives since 1956
- The original pill was marketed in 1957 as a treatment for gynaecological disorders, but as an official oral contraceptive in 1960 only
- To avoid pregnancy, the early pill used high doses of its active ingredients
- In the wake of the Thalidomide disaster (1961-1962), food and drug safety legislation was reinforced in the U.S. and required post-marketing reports
- The first cases of fatal thromboses caused by the Pill emerged quickly (1961), but they weren't confirmed until 1967 by a British epidemiological study

**Statistic:** 41% of pregnancies worldwide were unintended in 2008 (the number is declining)

Source: Singh, Susheela, Gilda Sedgh, and Rubina Hussain, "Unintended pregnancy", *Studies in Family Planning*, **41**, Number 4 (December 2010): 241-250.

# Safety and efficacy assessment

- Since 1938, the Food and Drug Administration in the U.S. required evidence of a new product's safety; it then had 60 days to review the evidence and grant approval
- In 1958, it had 5 full-time-equivalent reviewers to process an average of 400 new drug applications a year, as well as 3,000 supplemental applications
- The "new drug application" for the Pill was approved in 1957 for therapeutic purposes; in 1959, a supplemental application asked to expand its use to contraceptive purposes (both before Thalidomide)
- Aware of side effects noticed in the company's trials and in pre-1960 use of the Pill, the 1960 FDA approval was conditional on no more than two-years' continual use

A 2007 law has funded the FDA's hiring of 400 new employees for drug review.

See: Suzanne White Junod and Lara Marks, "Women's Trials", *Journal of the History of Medicine*, 57 (April 2002), pp. 117-160.

# Epidemiology and causation (1)

- The Pill was approved because the known side effects seemed less significant than the known risks of pregnancy and childbirth (in fact, many effects mimicked symptoms of early pregnancy)
- In the U.S., the low-dose pill required a separate approval from the high-dose one, delaying its introduction

| *Investigators cited in 1959* | *No. patients* | *Woman-years* | *Cycles* | *Women+cycles* |
|---|---|---|---|---|
| Rock, Garcia, Pincus, and Paniagua | 364 | 421.7 | 5,483 | 66 patients, 24-38 cycles |
| Laraque and Nicola | 121 | 77.4 | 1,007 | 64 patients, 9-12 cycles |
| Pendelton | 181 | 151.5 | 1,970 | 80 patients, 12-21 cycles |
| Morris | 47 | 15.0 | 196 | 47 patients, 1-10 cycles |
| Banks, Rutherford, and Coburn | 20 | 9.0 | 120 | 20 patients, 6 cycles |
| Tyler | 164 | 127.0 | 1,651 | 70 patients, 12-22 cycles |

# Epidemiology and causation (2)

- Given that by 1959, 100,000-500,000 women had used the Pill without serious consequences, the trials cited by Searle were comparable, or even superior, to those used to solicit approval for other drugs at the time
- When thromboses were first reported, the normal risk for young women was unclear (lack of autopsies)
- By 1969, journalists Morton Mintz and Barbara Seaman, unaware of confidential FDA records, averred that FDA approval had turned on the study of only 132 women
- The Nelson hearings then applied the stricter standards of 1969 to the issue of the safety of oral contraceptives, leading to new guarantees of informed consent

The change in testing practices during the 1960s may be gauged from the American Cancer Society's decision to initiate by 1965 a seven-year study comparing 5,000 contraceptive pill users with 5,000 non users. (Compare to the Searle trials.)

# Epidemiology and causation (3)

- In 1963, the FDA determined that thrombotic deaths occurred at a rate of 12.1 per million Pill users versus 8.4 per million for the general population
  (which was judged a statistically insignificant increase)

By 1967, however, the work of British scientists yields a more worrisome assessment of the risk of embolism or thrombosis. Later work confirmed the increase and a link with estrogen doses.

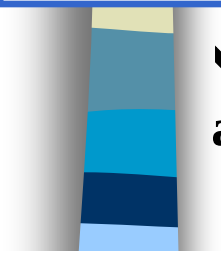
Estimates of risk of death from pulmonary embolism or cerebral thrombosis in users and non-users of oral contraceptives compared with risk of death from certain other causes (Inman and Vessey, 1968)

| | Age in years | |
|---|---|---|
| | 20–34 | 35–44 |
| Estimated death rate per 100,000 healthy married non-pregnant women from pulmonary cerebral thromboembolism | | |
| Users of OCs | 1.5 | 3.9 |
| Non-users of OCs | 0.2 | 0.5 |
| Annual death rate per 100,000 total female population from: | | |
| Cancer | 13.7 | 70.1 |
| Motor accidents | 4.9 | 3.9 |
| All causes | 60.1 | 170.5 |
| Death rate per 100,000 maternities from: | | |
| Complications of pregnancy | 7.5 | 13.8 |
| Abortion | 5.6 | 10.4 |
| Complications of delivery | 7.1 | 26.5 |
| Complications of the puerperium: | | |
| Phlebitis, thrombosis and embolism | 1.3 | 2.3 |
| Other complications | 1.3 | 4.6 |
| All risks of pregnancy, delivery and puerperium | 22.8 | 57.6 |

- In 1995, it's discovered a gene mutation puts some women using the Pill at increased risk of venous thrombosis

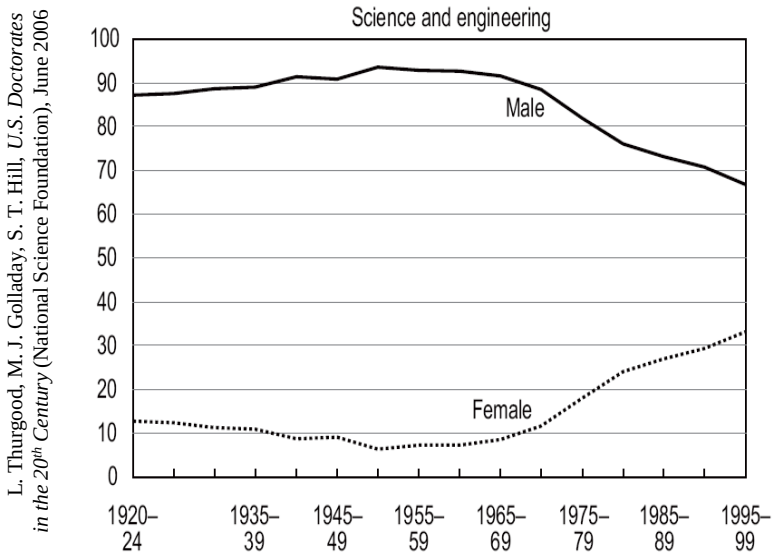
Lara Marks, "'Not just a statistic'", *Social Science & Medicine* **49** (1999), pp. 1139-1155,

# The birth control pill: consequences?

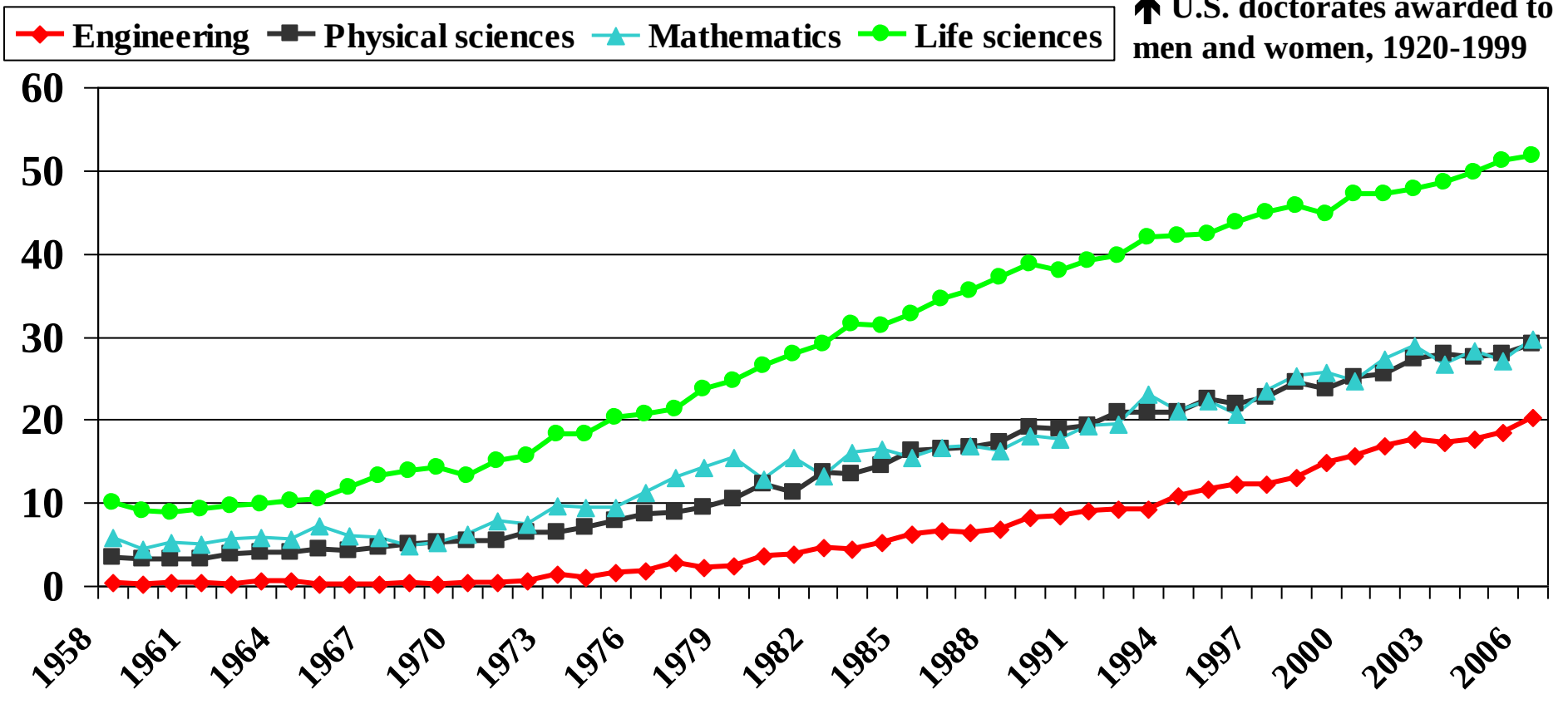


**⬇ Percentage of U.S. doctoral degrees awarded to women, 1958-2006, by field**

Joan Burrelli, "Thirty-Three Years of Women in S&E Faculty Positions", *InfoBrief* (National Science Foundation, NSF 08-308), July 2008




**⬆ U.S. doctorates awarded to men and women, 1920-1999**



# *To recapitulate (1)*

- What would be humanity's oldest technological system?
- Why is the invention and production of penicillin an example of technoscience in action?
- Identify five (5) characteristics of technoscience.
- Was the number of science and engineering doctorates awarded to U.S. women higher in the 1920s than in the 1950s?
- When was the oral contraceptive pill approved for contraceptive use?
- Why did the FDA approve the pill for contraceptive use?

# A World at Risk

- Risks and externalities
- The evolution of risks
- Consequences and the control of risks
- The assessment and perception of risks
- Weighing the evidence:  global warming
  - consuming carbon fuels
  - watching greenhouse gases rise
  - watching temperatures rise
  - doing something about it

# Risks and Externalities

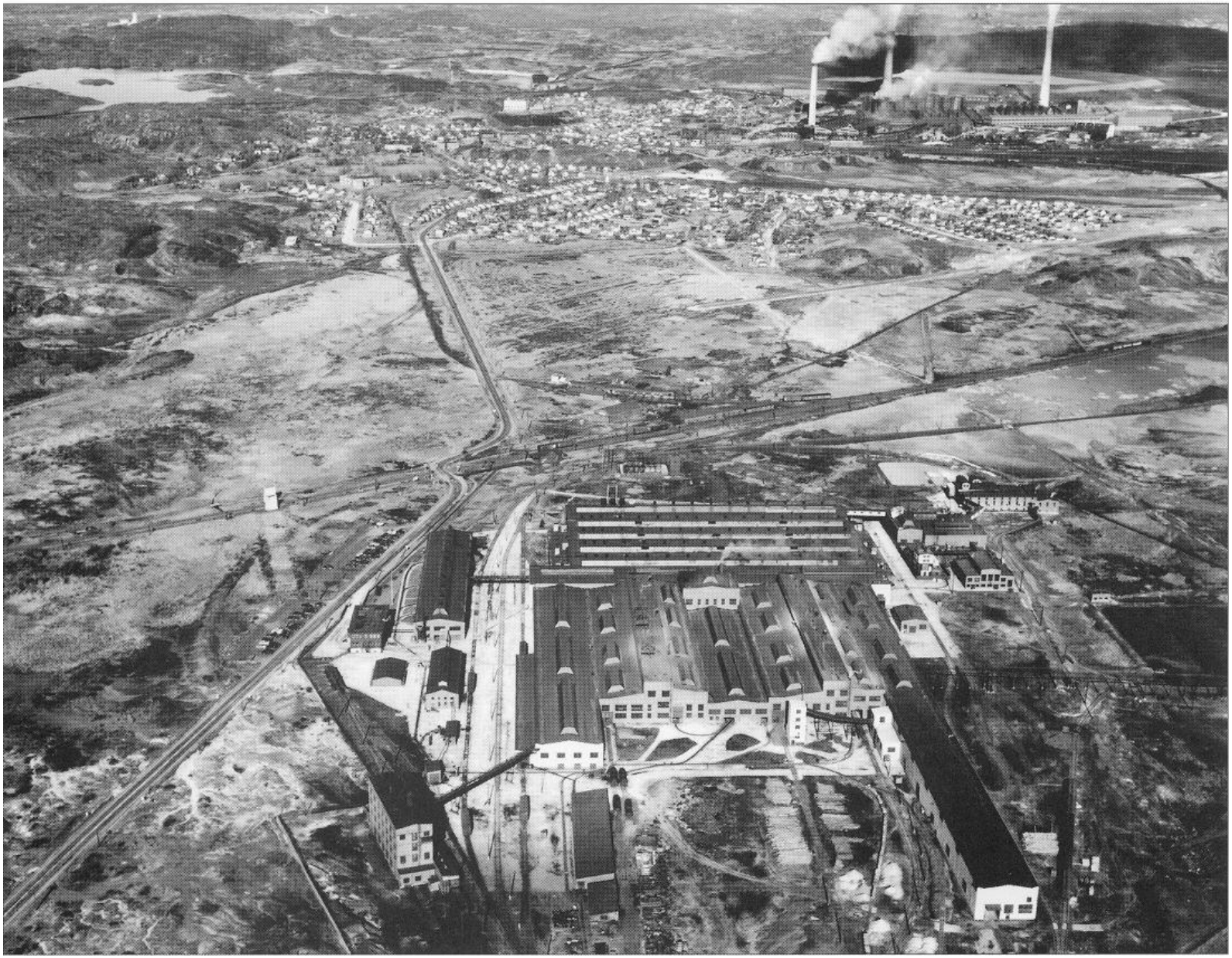
- Technologies create new risks and benefits as a matter of course
- More crucially, in liberal societies, these risks are often *externalities* protected by various rights (in less liberal societies, they are shielded by the exercise of raw power)
- A cost that is not (entirely) borne by the user is a (negative) externality
- The risks associated with early steam engine use were, in a sense, externalities
- The environmental consequences of engines burning fossil fuels are also externalities

# The Evolution of Risks

- A technology may fail accidentally and cause injury, but some risks arise from technologies that function ***exactly*** as designed
- The environmental consequences of early technologies were often part and parcel of the very results sought for by users:  the replacement of a forest by fields, the rise in river level caused by a weir, animals killed by firearms…
- Side-effects could be a worry:  deforestation led to floods; pesticides killed species that were not actual pests; the contraceptive pill raised blood pressure; mining polluted the land, rivers and water table…
- However, it is now the effects of the by-products that become noticeable, from ozone depletion to global warming

# Sudbury (ON) in 1888

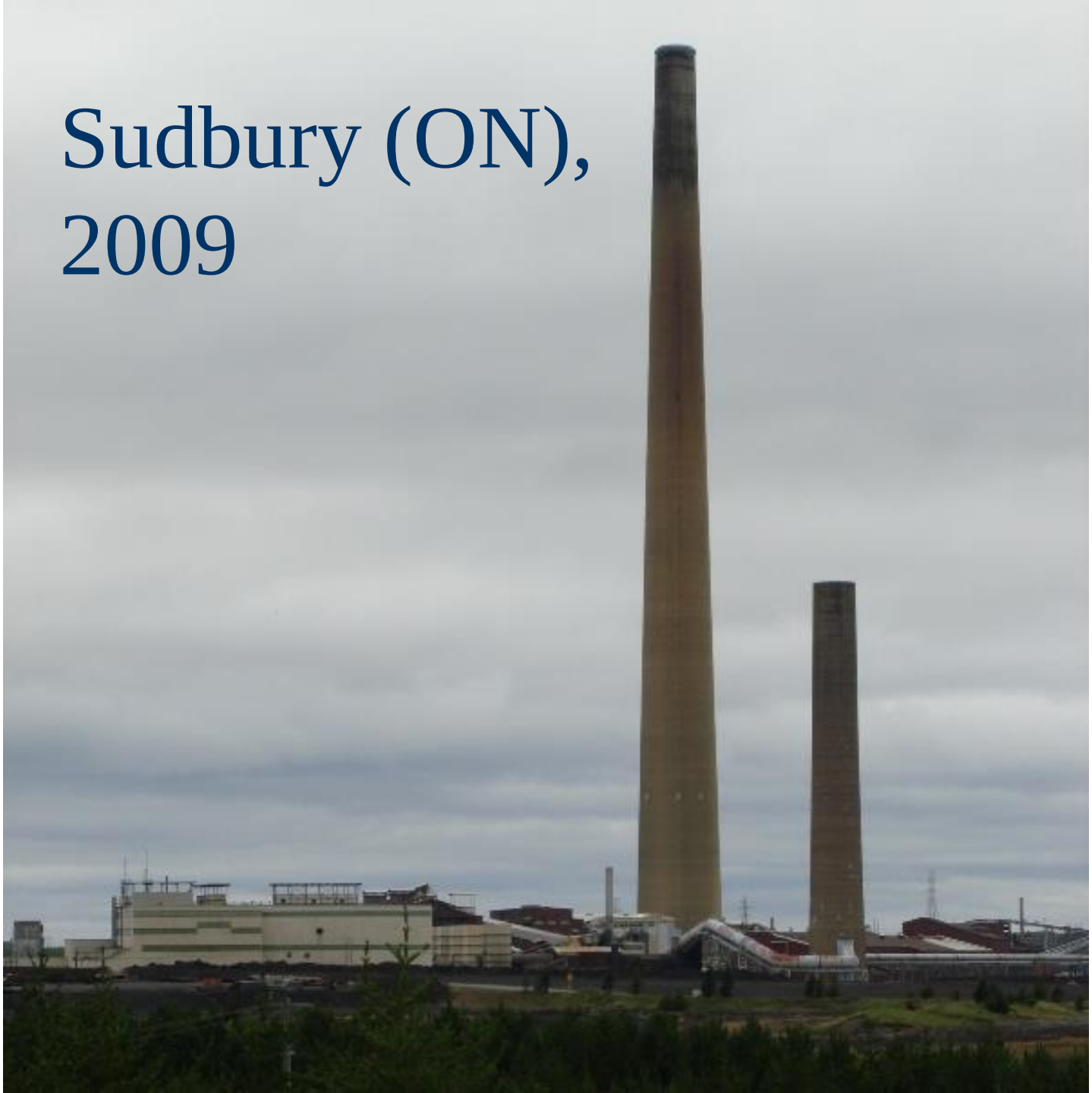
# Sudbury (ON), around 1950



# Sudbury (ON) in 1985 : Tailings from the INCO mine

© Jean-Louis Trudel, August 2009

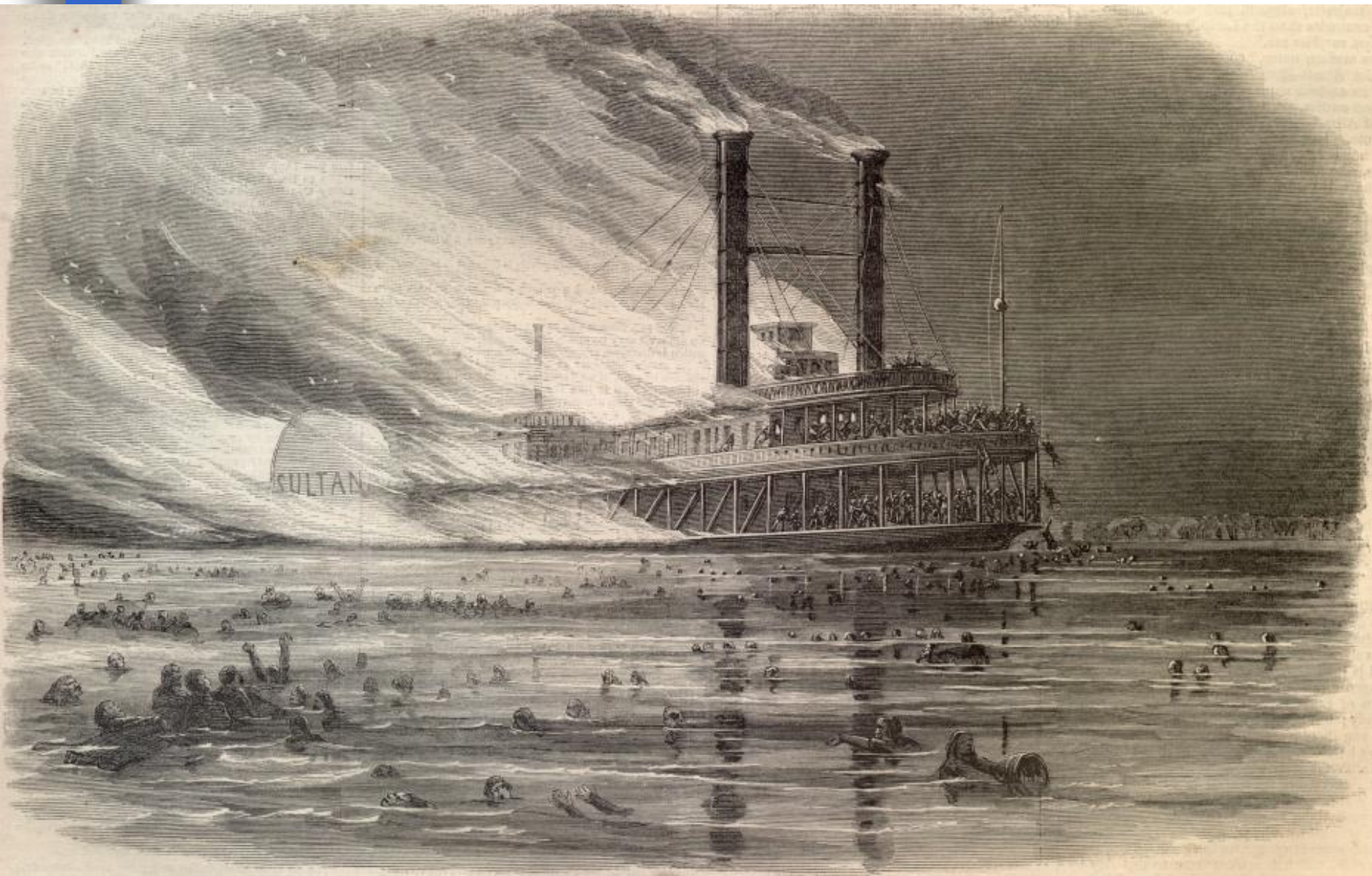
# Sudbury (ON), 2009



Harper's Weekly

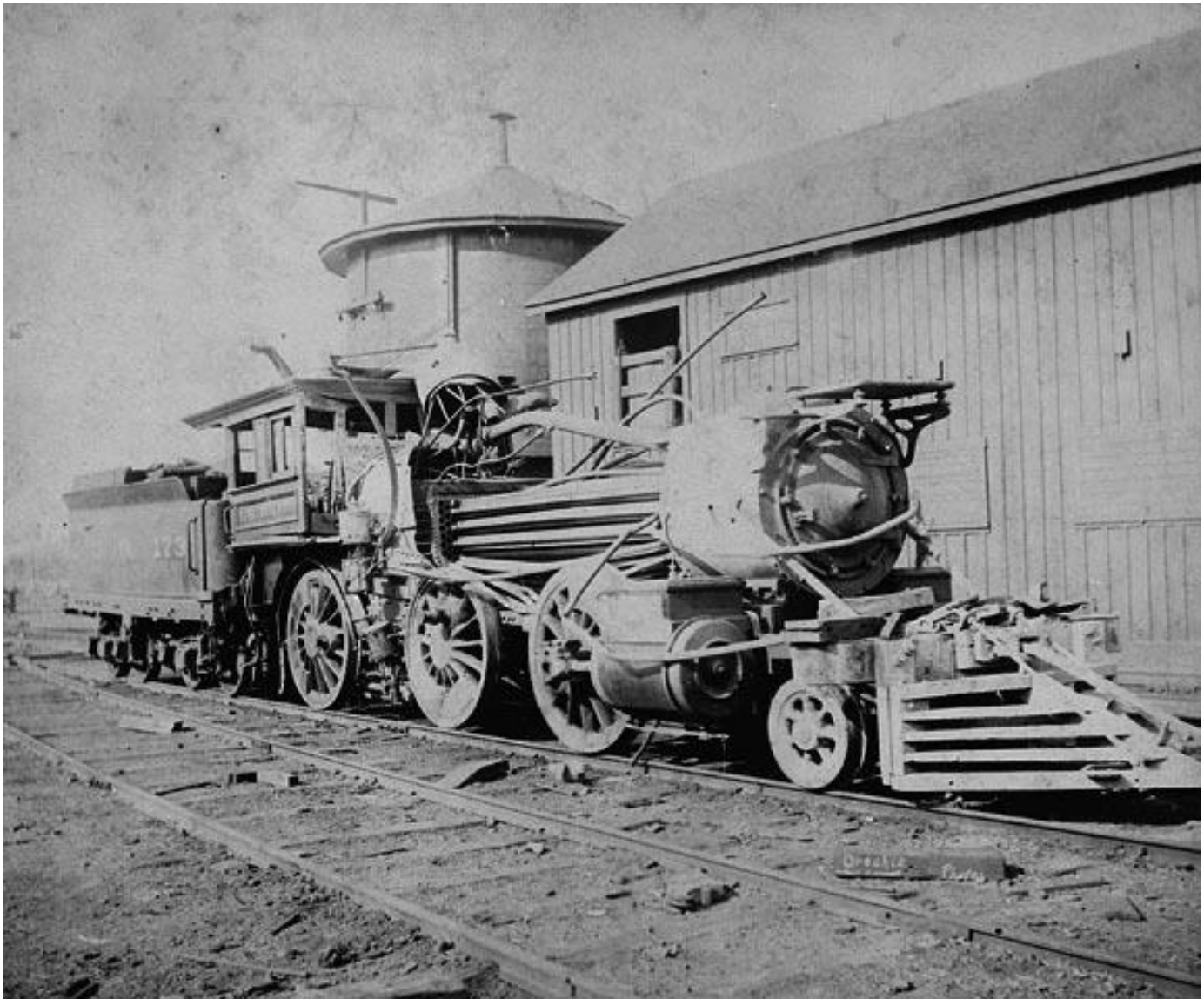
# Steam and Accidents (1)

The *Sultana* disaster: April 26-27, 1865, near Memphis (Ohio)



# Steam and Accidents (2)

Intercolonial Railway locomotive in Stellarton (NS) destroyed by a boiler explosion, on September 8th, 1892



J. B. Orechia, Library and Archives Canada

# Steam and Accidents (3)

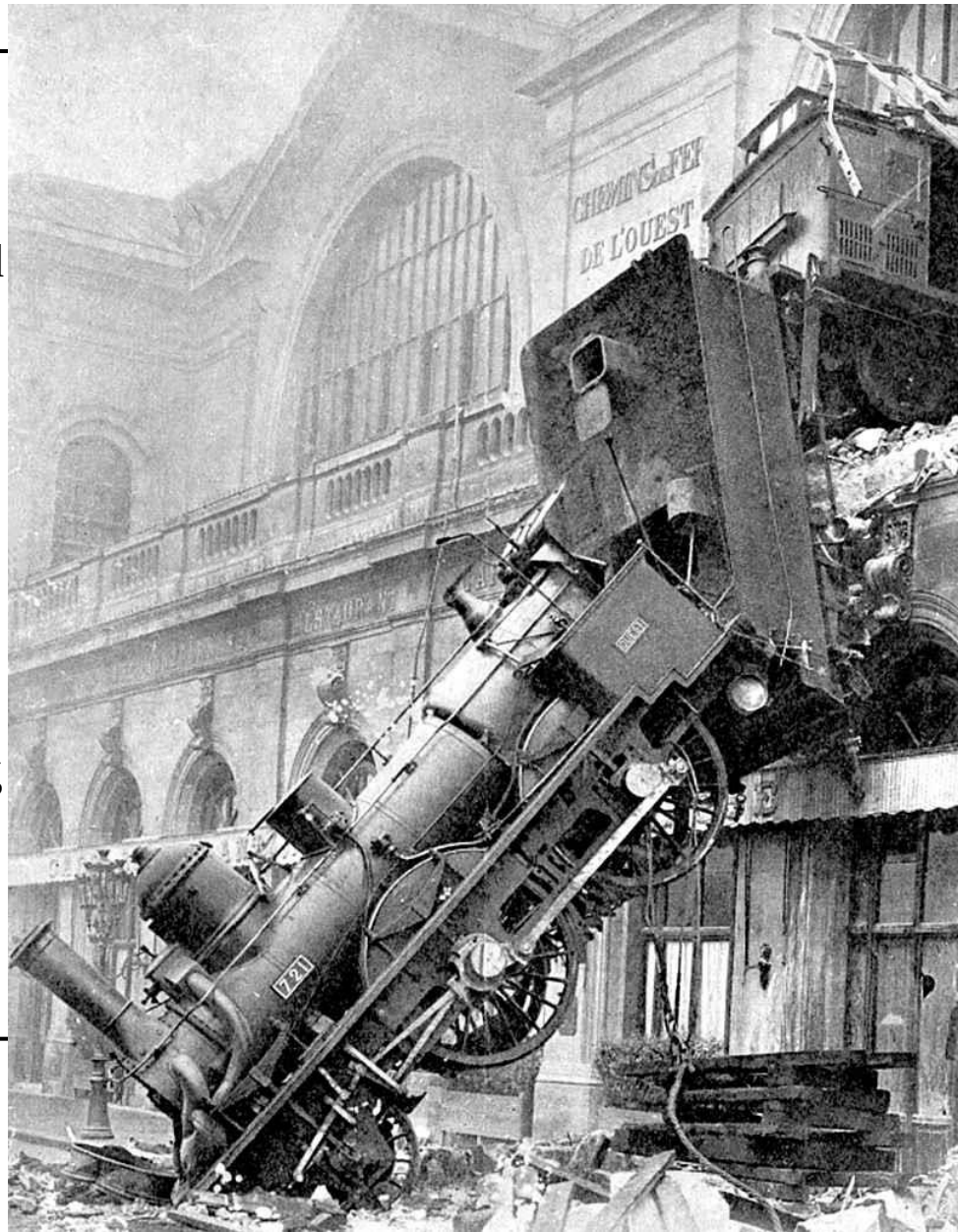
Milwaukee Journal-Sentinel

**Aftermath of a boiler explosion, Milwaukee, 1909**

# Accidents and their Impacts (1)

On October 22nd, 1895, the Granville to Paris express was running late, so driver Guillaume-Marie Pellerin, who boasted 19 years of experience, stayed at cruising speed a bit longer as the train approached the train station. However, the Westinghouse (air) brake failed and conductor Albert Mariette, distracted with paperwork, applied the locomotive brake too late. Five passengers and crewmen were seriously injured. A newsstand vendor was killed by a piece of falling masonry.

Pellerin was sentenced to two months in prison and a fine. Mariette was fined.




Paris, Gare Montparnasse, 22 October 1895

# Accidents and their Impacts (2)

Incidents of inadvertent poisoning either by the chemical industry (methylmercury in Minamata Bay, 1956) or by the pharmaceutical industry (Thalidomide, 1962) illuminated deficiencies in the management of technological risks, before and after.

Children with Congenital Minamata Disease due to intrauterine methylmercury poisoning (Harada 1986).


A French documentary on the “Thalidomide Babies” and their parents, who felt betrayed by the doctors had prescribed Thalidomide to mitigate nausea during pregnancy

# Accidents and their Impacts (3)

Seveso (Italy) was the scene of a major chemical accident in 1976. A dense cloud of TCDD (tetrachlorodibenzoparadioxin) was released from a reactor used for the production of trichlorofenol. Though there were no immediate fatalities, fifteen square kilometres were contaminated and 600 people were evacuated, while 2,000 were treated for dioxin poisoning. (In 1984, the citizens of Bhopal, in India, were not so lucky. A methyl isocyanate leak from a Union Carbide plant killed over 2,000.)


**Evacuazione della popolazione di Seveso**

Il 10 luglio 1976 presso la ditta ICMESA di Meda, in provincia di Milano, si verificò una fuoriuscita di gas tossico contenente diossina. Fu necessario ordinare la temporanea evacuazione della popolazione di Seveso, un centro situato nei pressi degli stabilimenti.

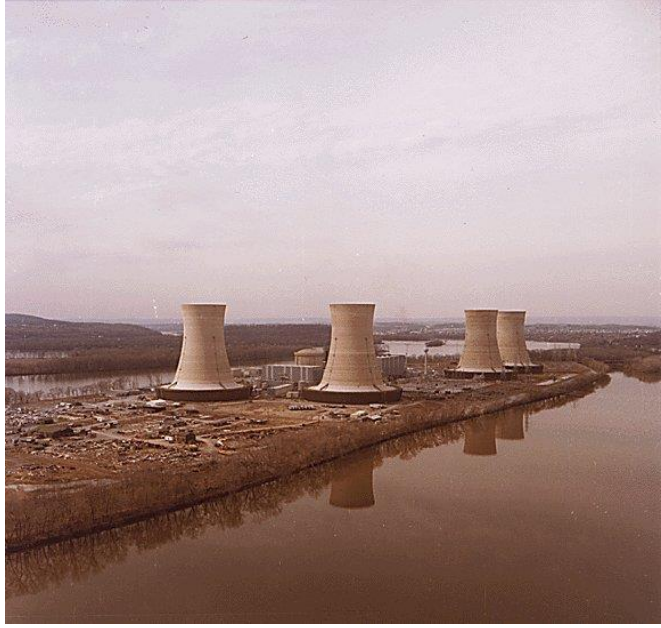
Seveso, Italia, 10 July 1976

# The “Seveso Directives”

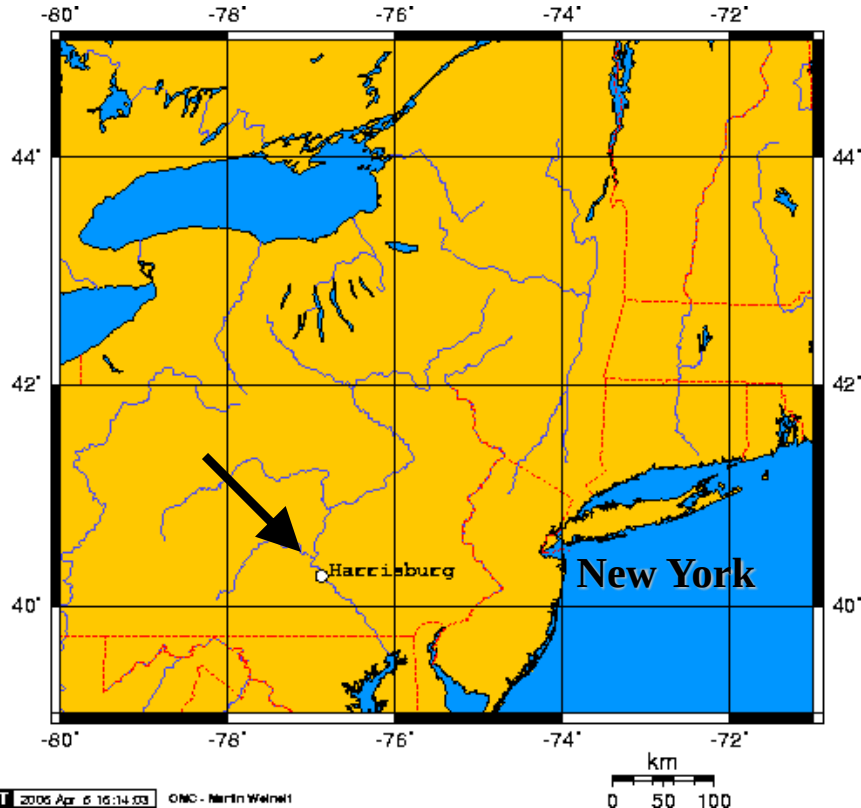
- The European Union adopted the “Seveso Directive” in 1982, superseded by the “Seveso II Directive” in 1996.
- The objectives of the “Seveso II Directive” are two-fold
- First, it aims to prevent major accidents or hazards involving dangerous substances
- Second, it aims to limit the consequences of such accidents not only for people (whose safety and health are paramount) but also for nature (thus protecting the common environment)
- The storage and use of dangerous substances are regulated; safety management, emergency plans, and land-use planning are mandated
- Accident reporting and the opening of a dialogue with the public are required

# Three Mile Island (1979)

- On March 28, 1979, a nuclear crisis erupted at the Three Mile Island nuclear power plant near Harrisburg, Pennsylvania
- By the end of it, the reactor core had suffered a partial meltdown and over 100,000 area residents left
- Public support for nuclear power dropped by a third



NARA



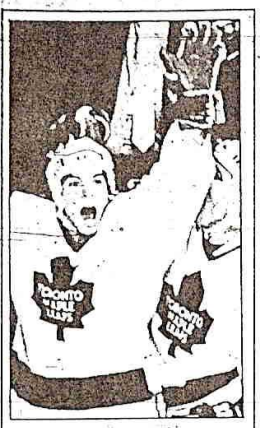
# The Chernobyl nuclear plant

The 1986 accident caused a relatively minor number of direct fatalities (at least 56), but the number of people adversely affected by the fall-out was much greater, and will probably never be known precisely (a few thousands at least will die early as a result).

# The Early News in Ottawa

**Scoreboard**

Leafs 5, Blues 3
Oilers 5, Flames 2
Cards 5, Giants 4



Leafs keep hopes alive D3

# High death toll feared in Soviet nuclear mishap

UPI and Citizen staff

MOSCOW — A nuclear accident damaged a reactor at a giant atomic power plant in Ukraine, the Soviet Union said Monday, sending a radioactive cloud more than 1,000 miles to Scandinavia.

Western diplomats feared a high death toll at the accident site.

Moscow said there were injuries in the accident at the restricted Chernobyl nuclear power plant, 80 miles north of the Ukrainian capital of Kiev, the nation's third most populous city with 2.3 million people, located in the western Soviet Union.

It was impossible to immediately assess the number of casualties independently.

An unprecedented statement acknowledging the accident was issued by the official Tass news agency after Sweden, Finland, Norway and Denmark reported higher than normal levels of radioactivity they believed to be from a nuclear accident in the Soviet Union.

Many Soviet nuclear plants do not have radiation containment walls as are required in the United States.

Scandinavian officials said the radiation levels carried by wind currents 1,000 miles from the site of the accident — believed to have occurred during the weekend — were low enough that they were not believed to pose any immediate threat to their citizens. The levels were expected to return to normal over the next few days, the officials said.

The cloud could reach the Canadian and U.S. west coasts within a week on a route over the North Polar region, the U.S. Environmental Protection Agency said.

In Canada, Atomic Energy of Canada spokesman Don Charlesworth said in a telephone interview Monday night that since the level of radiation in the cloud is reportedly weak, there is likely no real danger to Canadians.

"Nothing we have heard indicates we should have any concerns," he said.

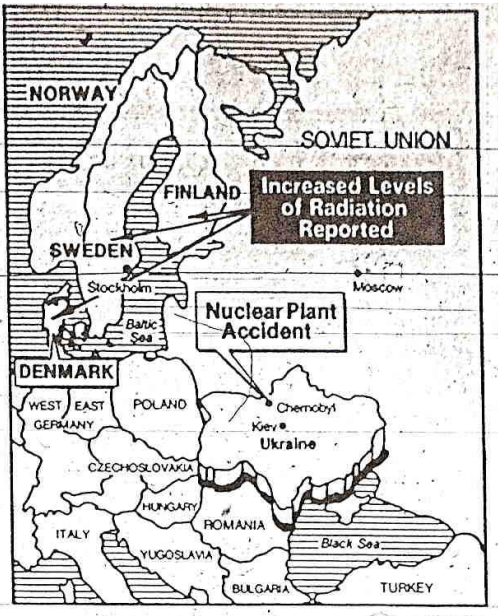
Charlesworth would not comment on whether the radioactive cloud would even reach Canada, citing weather patterns as the determining factor.

An Environment Canada spokesman said a group of governmental agencies and departments, including Health and Welfare and National Defence, would assess the magnitude of the accident today.

"Everyone will be looking into the situation," said Bob Beach, manager of the department's environmental emergency centre.

"It will likely take up to a week" to determine

(Nuclear, page A20)




— AP graphic

Cloud could reach Western Canada within a week

Tuesday
April 29, 1986
Ottawa

The Citizen

Capital Edition
$1.75 weekly
home delivered
35¢ per copy

## Today

**Sunny**

Afternoon cloudiness. High today 25. Low tonight 10. High Wednesday 17. A2

**Headlights**

On at 7:37 p.m. today, off at 6:23 a.m. Wednesday

**World**

A Soviet defector returns home, denouncing Radio Liberty as a front for U.S. spy operations A6

**Consumers**

Now that you've gone through the agony of filling in your tax return, spare a little sympathy

# Beatty defends decision to probe terrorism claims

By Stephen Bindman and Ian MacLeod
Citizen staff writers

Solicitor General Perrin Beatty has denied he's trying to intimidate terrorist experts by ordering an investigation into their weekend claims that Canada will soon become a prime target for attack.

Shoniker said a group known as Direct Action has become the biggest terrorist threat in Canada today.

He said the group is recruiting students at Carleton University, Simon Fraser University in British Columbia and York University, near Toronto, for overseas ter-

A Kiev resident, who has close contacts to hospital and rescue officials, told United Press International in a telephone interview that between 10,000 and 15,000 people had been evacuated from Pripyat, site of the Chernobyl nuclear reactor.
"Eighty people died immediately and some 2,000 people died on the way to hospitals," the Kiev resident said. "The whole October Hospital in Kiev is packed with people who suffer from radiation sickness."
"It was not possible to immediately confirm the Kiev woman's reports."

# Final Edition, April 29

Tuesday
April 29, 1986
Ottawa

The Citizen

Final Edition
$1.75 weekly
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## Up to 2,000 dead in reactor accident

UPI, AP and Citizen staff

The Soviet Union said today the nuclear accident at its giant power plant north of Kiev was a "disaster." One unconfirmed report from the area said the death toll may have reached 2,000.

A Kiev resident, who has close contacts to hospital and rescue officials, told United Press International in a telephone interview that between 10,000 and 15,000 people had been evacuated from Pripyat, site of the Chernobyl nuclear reactor.

"Eighty people died immediately and some 2,000 people died on the way to hospitals," the Kiev resident said. "The whole October Hospital in Kiev is packed with people who suffer from radiation sickness."

It was not possible to immediately confirm the Kiev woman's reports. The Soviet government has issued no statements on casualties except that "aid is being given to those affected."

"The people were not buried in ordinary cemeteries but in the village of Pirogov, where radioactive wastes are usually buried," the Kiev resident said. "It so horrible and sad, the whole city is discussing it. Everything possible is being done to help the people."

She said as many as 15,000 Pripyat residents had been evacuated by bus and military planes and helicopters to Kiev, the Soviet Union's third largest city with 2.3 million people.

Other Soviet sources said the report on Moscow radio indicated the accident at the Chernobyl plant, 120 kilometres north of Kiev, caused a catastrophic loss of life. A Soviet diplomat called it history's worst nuclear accident.

Soviet officials have asked the West for assistance in fighting the fire. But the Soviets are still keeping an official lid on information about the disaster, which many in the West say was a meltdown, the most serious type of reactor accident.

The official Soviet news agency Tass first reported the accident Monday in a four-sentence dispatch saying one of the plant's atomic reactors was damaged and measures were being taken to "eliminate the consequences."

It did not say how serious the accident was or when it occurred. Abnormally high radiation levels were first detected Sunday in Finland and also reported in Denmark and Sweden, more than 1,200 kilometres northwest of the plant.

In Ottawa, an Environment Canada spokesman said a group of government agencies and departments, including Health and Welfare Canada and National Defence would assess the possible effects on Canada today.

Twenty-eight Canadian weather stations, including one at Ottawa International Airport, have been put on "a surveillance position" in order to detect abnormal levels of radiation.

Normally, stations take radiation readings weekly, but that will now be done daily.

"When we have a nuclear emergency, and I think this does qualify, we switch to monitoring every 24 hours," said Bliss Tracey, a research scientist with the bureau of radiation at Health and Welfare.

It will likely take a week for the first results to come in, although those results won't be conclusive.

Atomic Energy of Canada spokesman Don Charlesworth said in a telephone interview Monday night that since the level of radiation in the cloud is reportedly weak, there is likely no real danger to Canadians.

"Nothing we have heard indicates we should have any concerns," he said.

Charlesworth would not comment on whether the radioactive cloud would even reach Canada, citing weather patterns as the determining factor.

Officials in both West Germany and Sweden say their countries have been asked for assistance.

The Canadian government has received no request from the Soviet Union to help with the nuclear accident in the Ukraine, an external affairs department official said today.

There also were reports that Britain was being asked to help because of its experience in putting out a fire at its Windscale nuclear plant in 1957. However, spokesmen for the British nuclear industry said they had received no such request.

An official of a West German atomic energy lobbying group said today the Soviet Embassy in Bonn

(Nuclear, page A20)

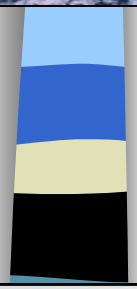

— AP graphic

Nuclear plant located near Chernobyl

Even though superior containment in Three Mile Island prevented the release of radiation seen at Chernobyl, the Catch-22 of the nuclear industry ever since has been that any argument in favour of a new and improved generation of reactors is rarely pressed lest it imply that existing reactors are unsafe.

# Fukushima (March 2011)

**after the overheating of a reactor (one of several) and a hydrogen explosion ↓**



**before the tsunami ↑**

**after the tsunami ↓**

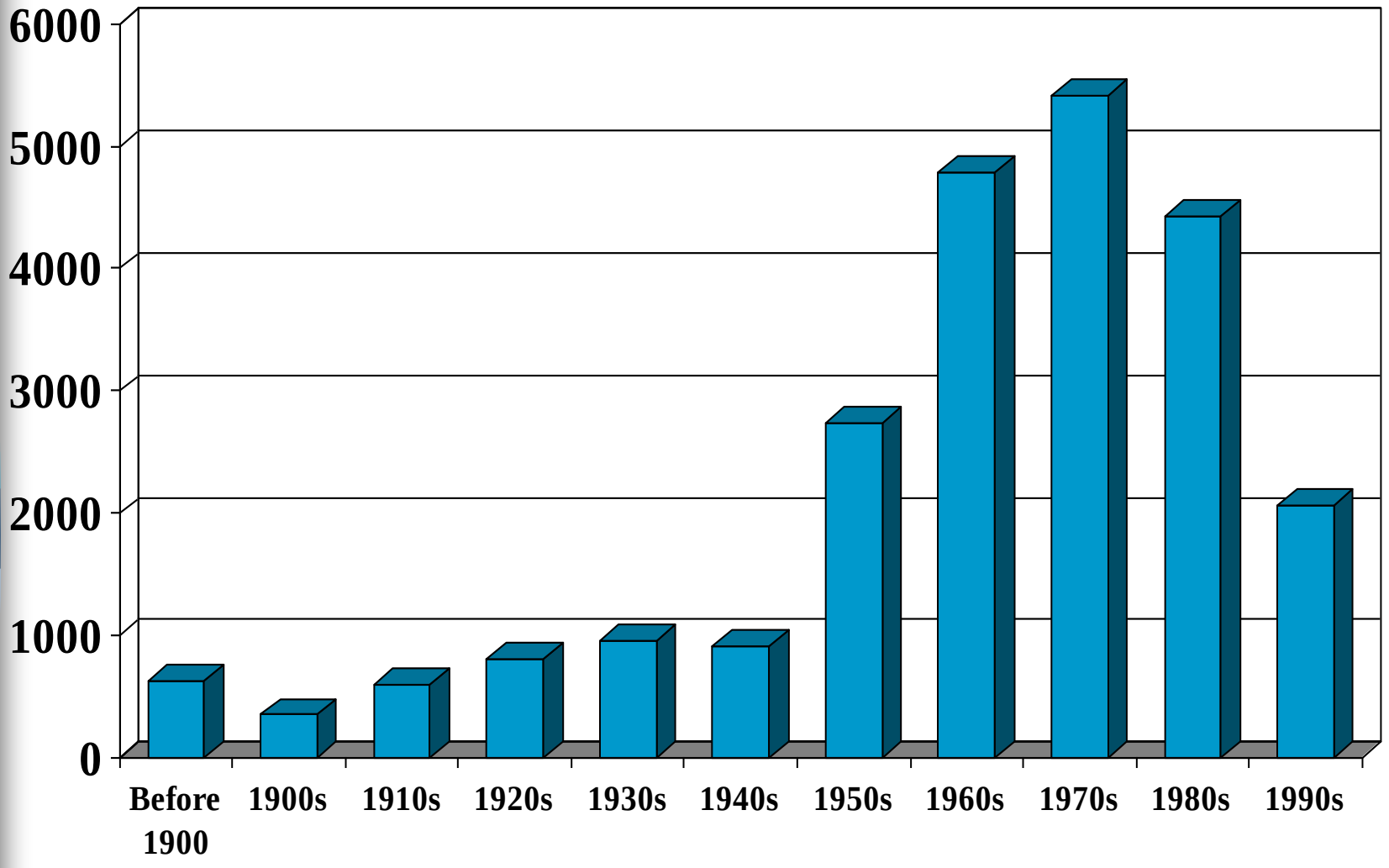
Cleanup and decontamination will likely take decades. While relatively few people were injured during the accident, most casualties will be recorded over the next decades and may well number in the thousands.

# The Disasters You've Never Heard Of: Dam (and dyke, levee…) failures

Note: This is a selection; dams are estimated to have a failure rate in excess of 2%.

- 1868, Irukaike (Japan): 1,000-1,200 dead
- 1889, Johnstown (U.S.A.): 2,200 dead
- 1923, Gleno (Italy): 356 dead
- 1928, St. Francis Dam (U.S.A.): 400-500 dead
- 1954, Malpasset (France): 423 dead
- 1959, Vega de Tera (Spain): 144 dead
- 1975, Banqiao Dam (China): 26,000 dead, officially (another 145,000-205,000 dead, in part from ensuing famine and epidemics)
- 1979, Machhu (India): about 2,000 dead
- 2005, New Orleans (U.S.A.): about 1,500 dead

# The Commissioning of the Largest Dams in the 20th Century (Total=23,711)




Pacific Institute (http://www.worldwater.org/data.html)

# The Importance and Impact of Dams

- Estimated number of dams in the world: **845,000**, including **48,000** large dams (about 10% of the former are in North America and as much as 16% of the latter)
- Worldwide, hydropower from dams accounts for about **19%** of electricity production
- Worldwide, dams obstruct about **65%** of ocean-bound freshwater flows (more than half of the world's 292 large river systems are adversely affected)
- Number of dam failures in the U.S. (**2002-2007**): **49**; about **85%** of all large U.S. dams will have exceeded their design life spans by 2020

# Chronological Milestones

- pre-1950
  - the *Titanic*, WWI, the *Hindenburg*, WWII
- 1960s
  - smog (London, Los Angeles), nuclear fall-out, Thalidomide, divided highways and expressways, pesticide use, the Pill, Minamata, *Torrey Canyon* oil spill
- 1970s
  - EPA, Asilomar Conference, Seveso, Three Mile Island, acid rain, ozone layer depletion by chlorofluorocarbons (CFCs), *Amoco Cadiz* oil spill
- 1980s
  - Chernobyl, Bhopal, the greenhouse effect, Montreal Protocol on CFCs, *Exxon Valdez* oil spill
- 1990s
  - BSE (“mad cow disease”, bovine spongiform encephalopathy), genetically modified organisms, Kyoto Protocol

# The Assessment and Perception of Technological Risk

- (1) The blurring of causation (from the direct to the statistical)
- (2) Levels of risks (to people, to their children, to the environment, to the legally liable corporation, to the corporation's profits, to society and the traditional social order)
- (3) The elusiveness of new risks (as technologies grow larger and more complex, evaluation requires more effort or greater scientific knowledge)
- (4) Overselling and the public backlash (hype sells, but unfulfilled promises generate skepticism)
- (5) The power of linkage (the Bomb and nuclear plants)
- (6) The credibility of technology's advocates

# *To recapitulate (2)*

- What new technology did the Asilomar Conference seek to regulate?
- During what decade was the greatest number of large dams commissioned?
- Identify three (3) nuclear accidents involving power plants and the year they happened.
- Could the statistically increased risk of death due to being exposed to radioactive fallout from Chernobyl be considered an externality? Explain.
- Identify three (3) accidental spills into the environment of toxic chemicals and their effects.
- Identify the tankers linked to three (3) oil spills.

The best lack all conviction, while the worst
Are full of passionate intensity.

*The Second Coming*, W. Butler Yeats, 1920

# The Case for Doubt

- The battle for public opinion is often fought over the middle ground occupied by those who doubt and who are willing to entertain new ideas
- In recent debates, most arguments have been designed to win over those who are naturally inclined to doubt, but some have simply aimed to raise doubts

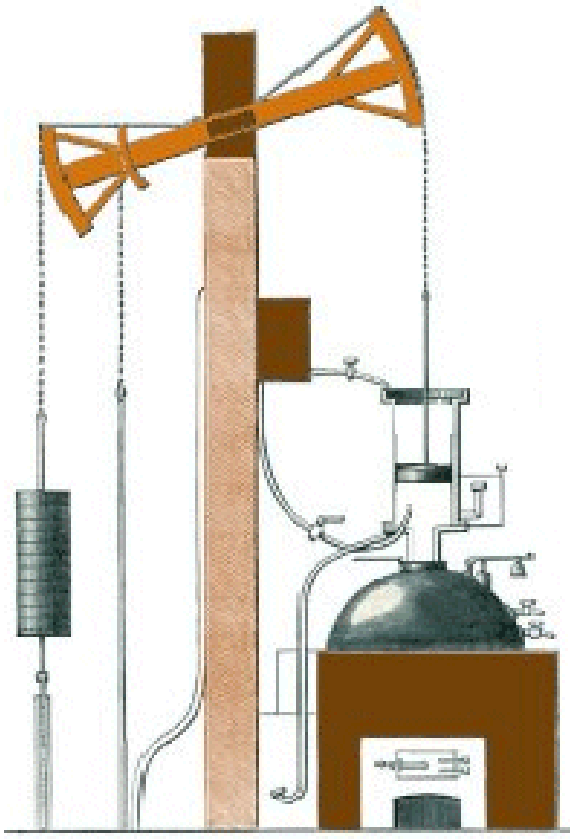
# The Case Against Doubt:
## Five Stages of Denial of Global Warming
(according to Richard C. J. Somerville)

- 1) Global warming is not occurring
- 2) If it is occurring, we don't know why
- 3) If it is real, it is not caused by humans
- 4) But if it is, it's not that bad
- 5) Even if it is that bad, it's too late: global warming can't be stopped

# The Argument for Prudence

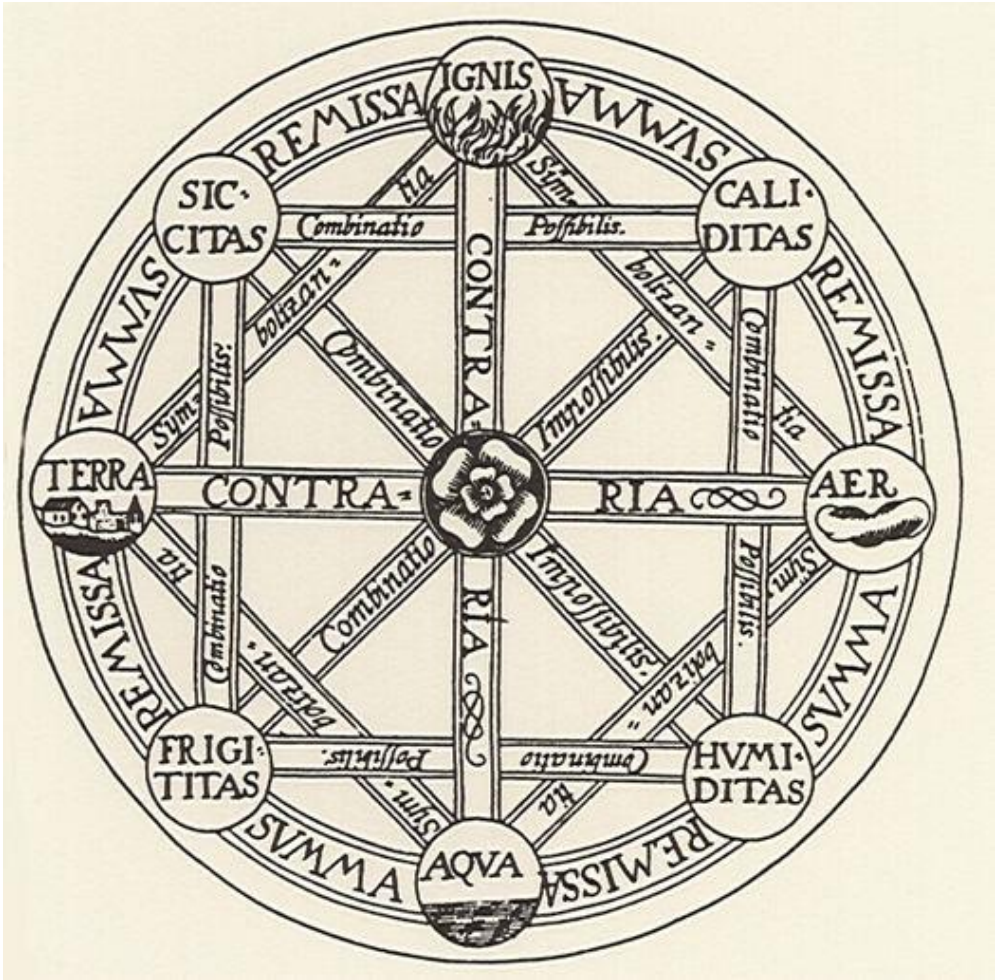
- When Thomas Newcomen was born in 1663, materials science was basically limited to the traditional list of elements and a more recent catalogue of substances that resisted chemical analysis
- His (atmospheric) steam engine required burning prodigious quantities of coal or wood

Newcomen engine (18th c.)

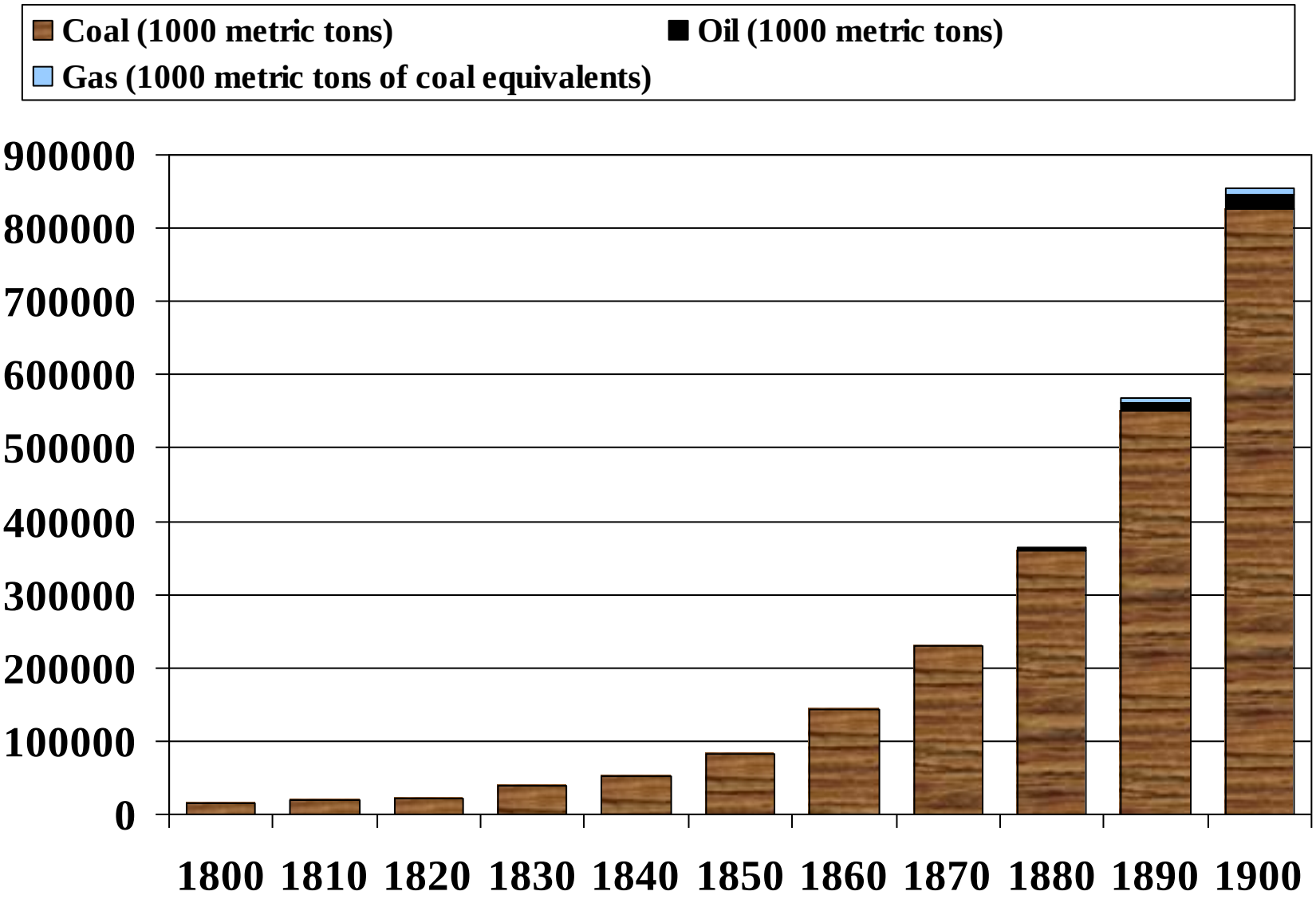


# Knowledge and Risk

- Leibniz charts here the classical elements known in 1666:
- Fire (*Ignis*)
- Air (*Aer*)
- Water (*Aqua*)
- Earth (*Terra*) (clockwise)
- … not $CO_2$

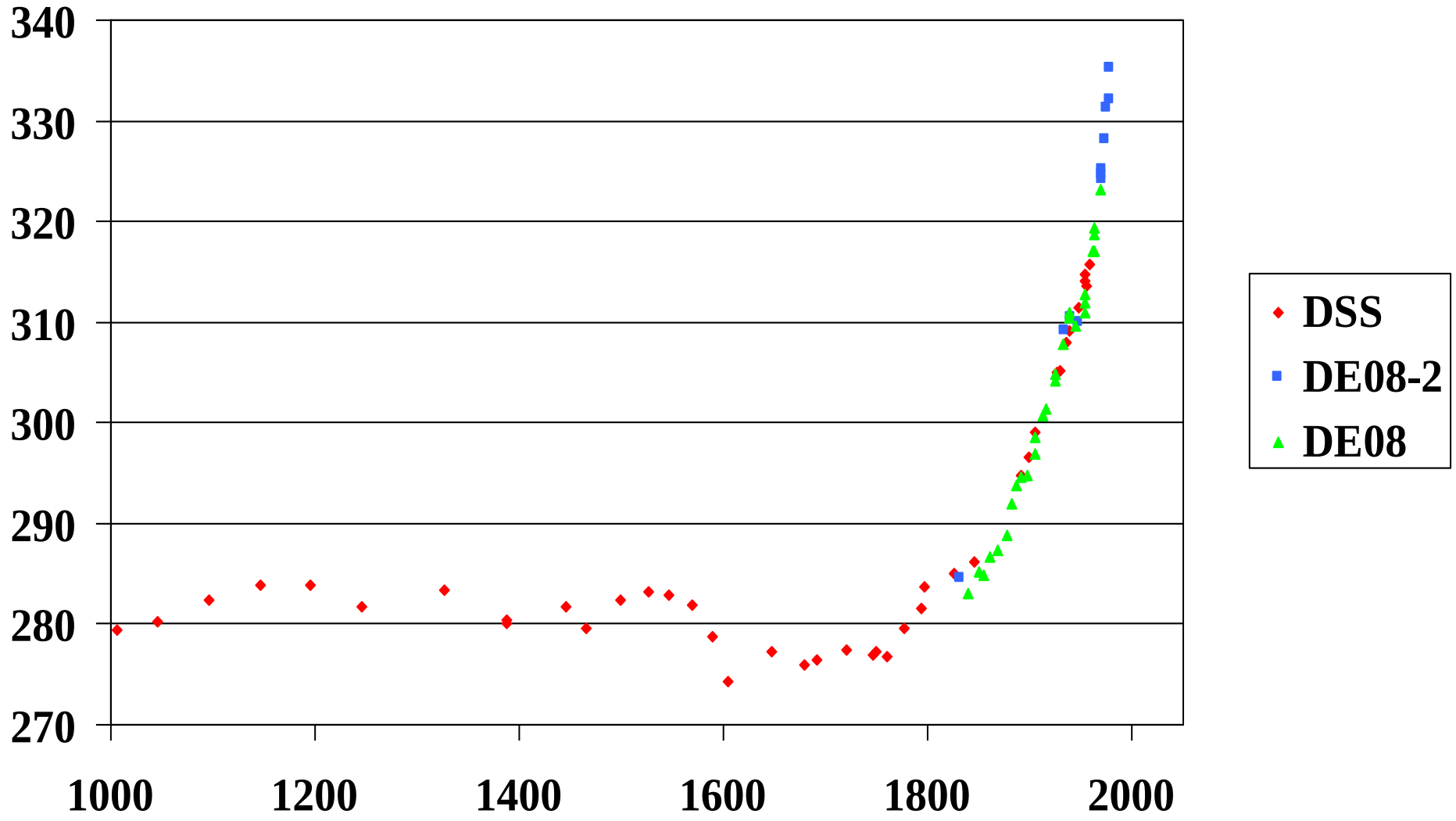


# Fossil Fuels in the 19th Century




Source: History Database of the Global Environment (HYDE), http://www.mnp.nl/hyde/

# Basic Atmospheric $CO_2$ Data (Antarctic Ice Cores)



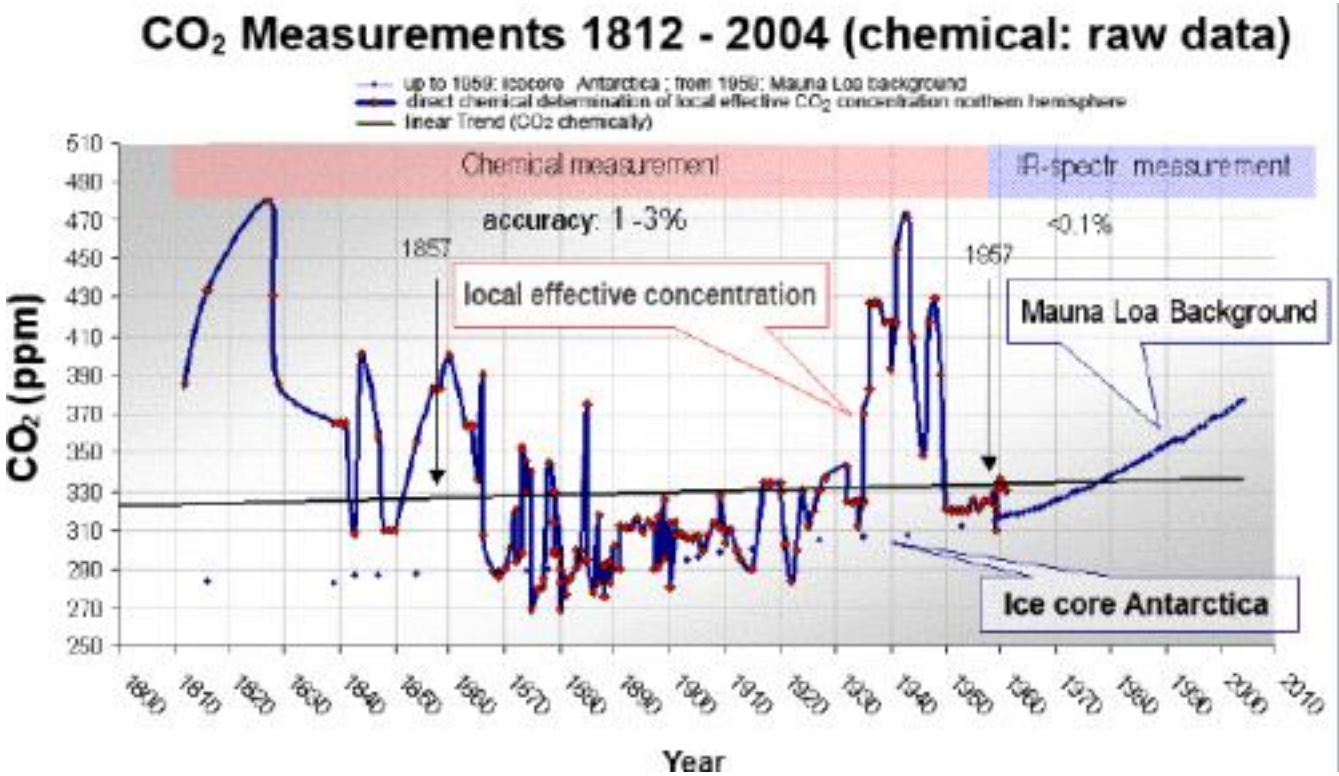
# Carbon Dioxide… Who Knew?

- In 1630, Flemish chemist Jan van Helmont isolates a "*gas sylvestre*" given off by burning wood; it's carbon dioxide ($CO_2$)
- By 1754-1756, British chemist Joseph Black has isolated and studied a gas he calls "fixed air" ($CO_2$) in a pure form
- Between 1775 and 1787, French chemists Antoine Guyton de Morveau and Antoine Lavoisier determine that fixed air is a combination of carbon and oxygen
- In 1803, British chemist **John Dalton** guesses (correctly) its precise composition

# Carbon Dioxide… What Did They Know?

- In 1861, British chemist **John Tyndall** publishes his finding that $CO_2$ in the air fosters the trapping of the Sun's heat
- But if $CO_2$ is important, it is also surprisingly difficult to measure *in situ*

Until the middle of the 20th century, many measurements of $CO_2$ are made in cities, at ground level: readings are contaminated by pollution and also by vegetation releasing carbon dioxide nearby.

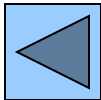


# The Greenhouse Effect… Who Knew?

- In 1894-1896, Swedish scientists **Arvid Högbom** and **Svante Arrhenius** calculate that changes in $CO_2$ concentration might bring about either an ice age or global warming; at the 1896 rate of coal (carbon) burning, doubling the amount of atmospheric $CO_2$ might take 3,000 years, so it's not an urgent worry
- Follow-up investigations suggest they overestimated the threat
- For half a century, it's believed that heat trapping by $CO_2$ quickly reaches a maximum—and that excess $CO_2$ will be absorbed by the oceans

# Back in 1861…

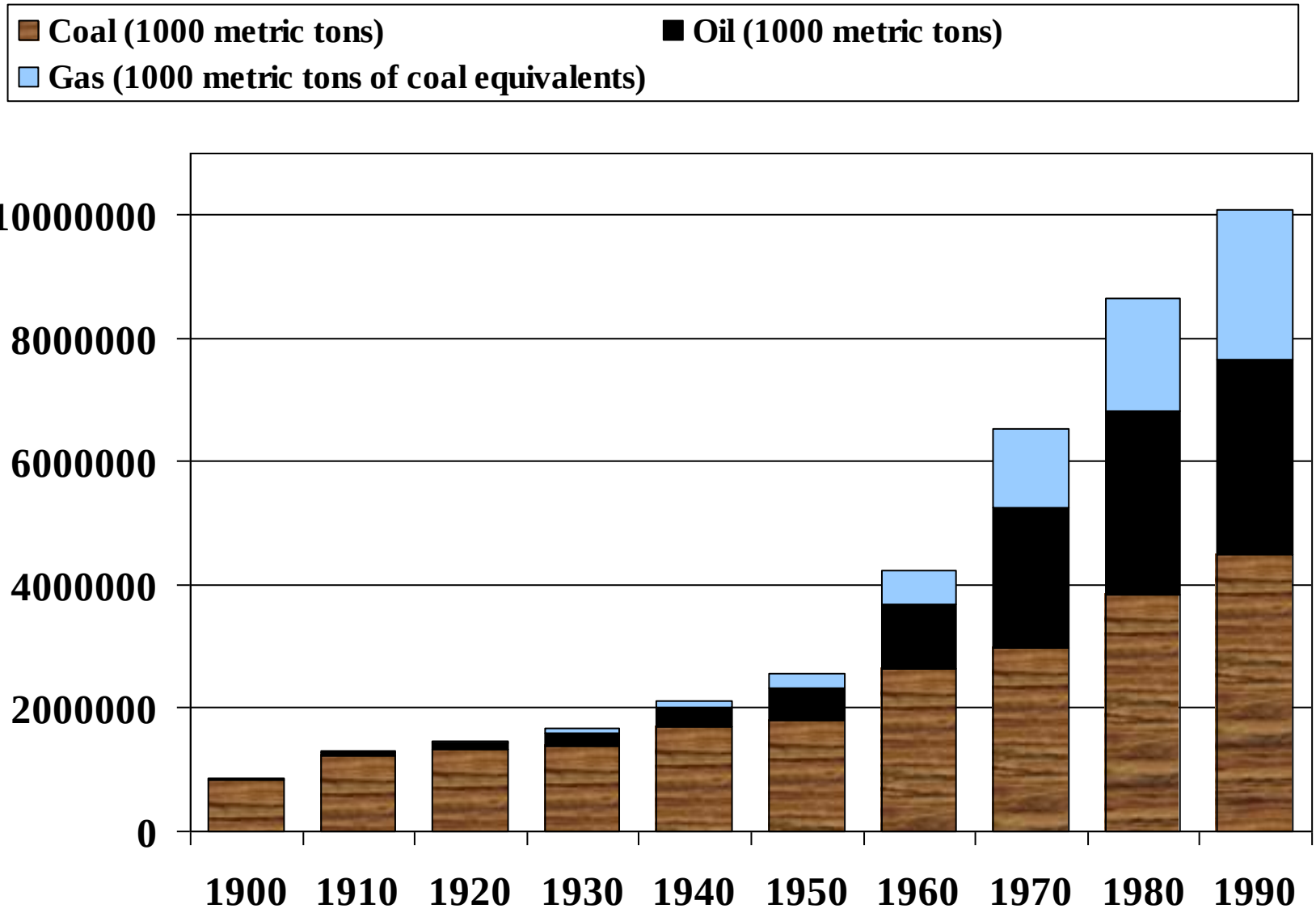
- *In Tyndall's own words*: "Now if, as the above experiments indicate, the chief influence be exercised by the aqueous vapour, every variation of this constituent must produce a change of climate. Similar remarks would apply to the carbonic acid [$CO_2$] diffused through the air; while an almost inappreciable admixture of any of the hydrocarbon vapours [*i.e.* $CH_4$] would produce great effects on the terrestrial rays and produce corresponding changes of climate. It is not therefore necessary to assume alterations in the density and height of the atmosphere, to account for different amounts of heat being preserved to the earth at different times; a slight change in its variable constituents would suffice for this. Such changes in fact may have produced all the mutations of climate which the researches of geologists reveal."



# Returning to the "greenhouse"…

- Between 1938 and 1949, Guy Stewart Callendar (1898-1964) publishes several papers linking the burning of fossil fuels, $CO_2$ emissions, and global warming since the 19$^{th}$ century
- In 1952, Lewis D. Kaplan uses a digital computer to show that heat absorption by $CO_2$ does not saturate as much at higher altitudes
- In 1957, **Hans Suess** and **Roger Revelle** prove that the oceans absorb ten times less $CO_2$ than expected
- In 1960, **Charles David Keeling** announces that his sampling of atmospheric $CO_2$ in Antarctica reveals a noticeable increase since 1957; he continues his sampling from a station on Mauna Loa (Hawaii)

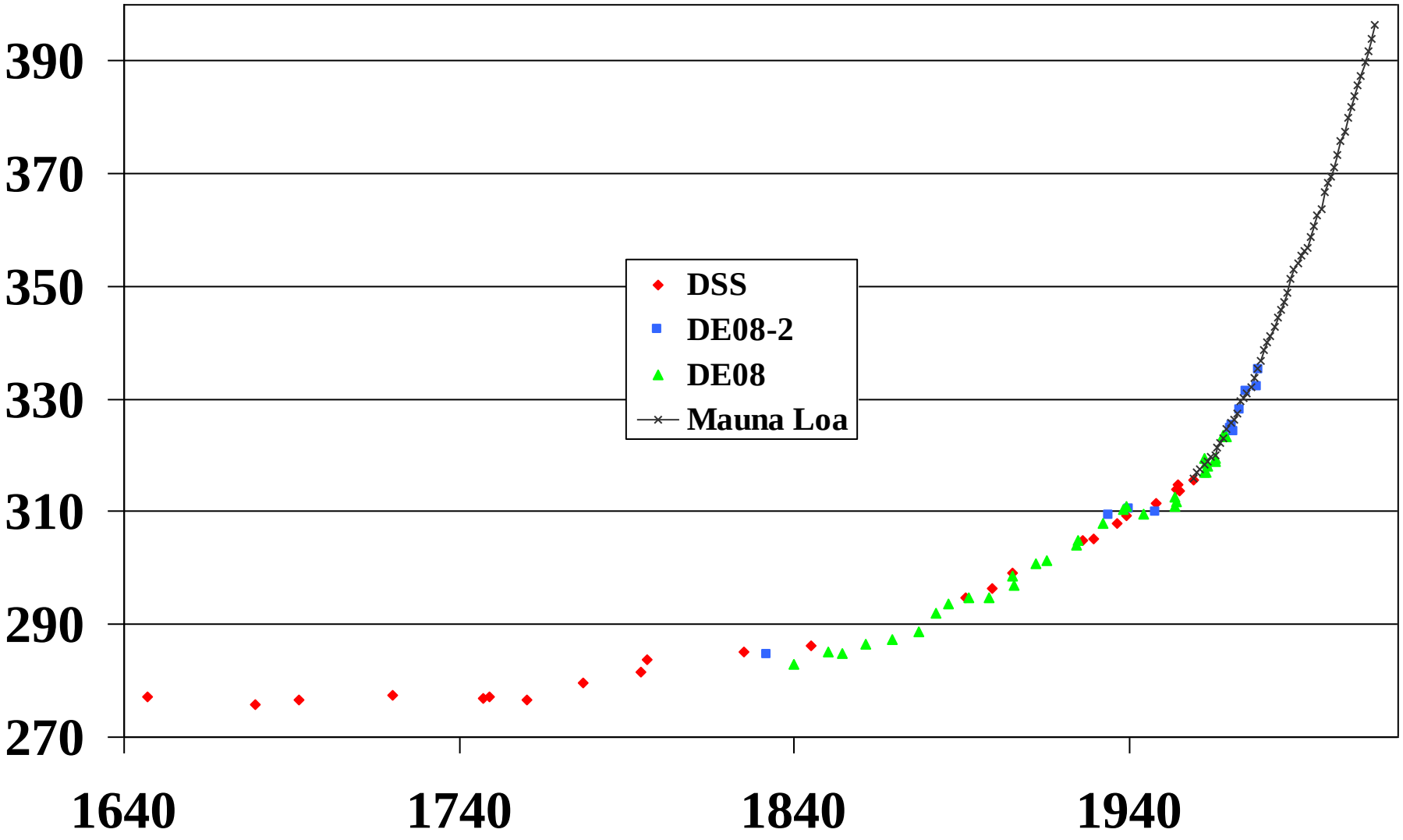
# Fossil Fuels in the 20th Century



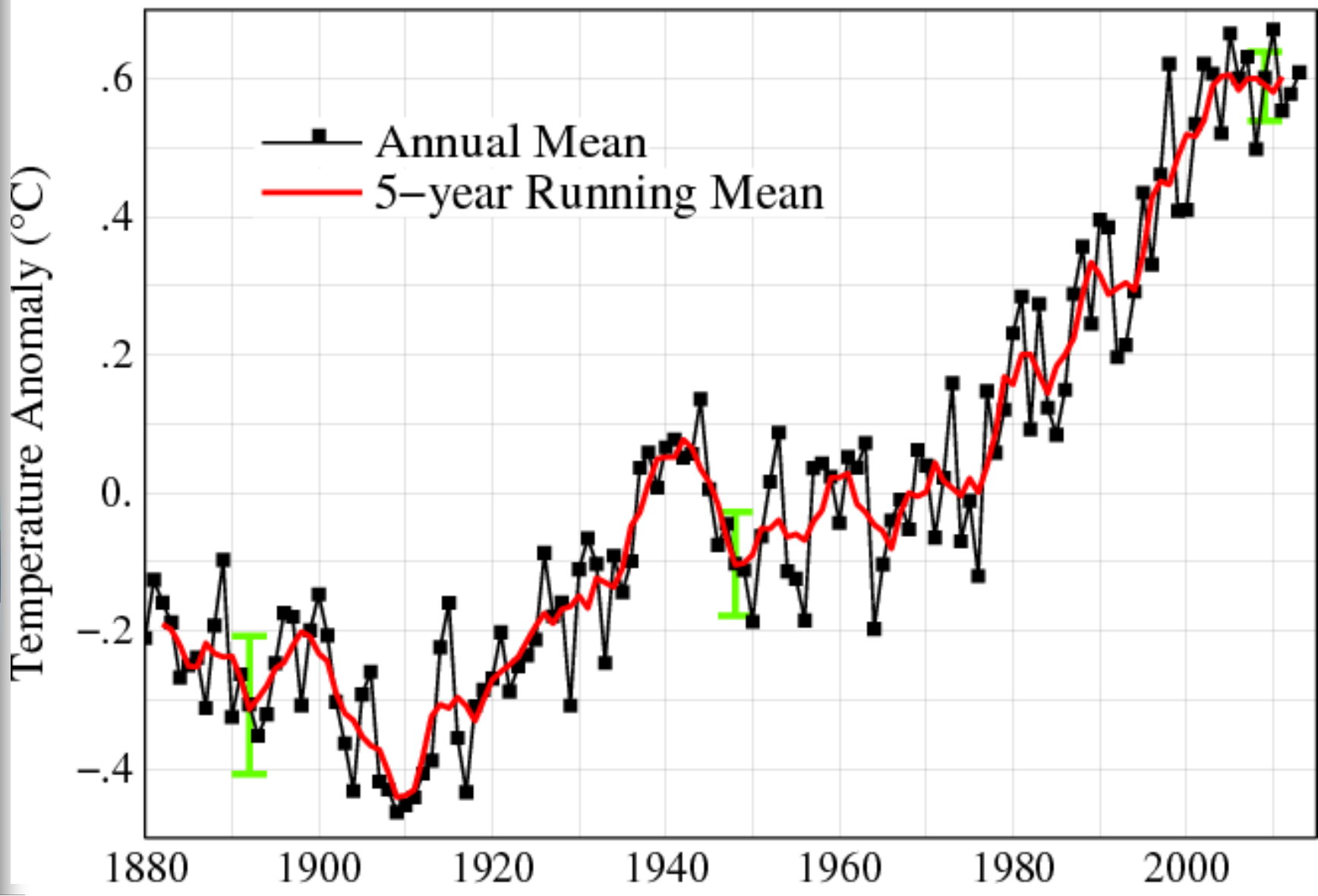

Source: History Database of the Global Environment (HYDE), http://www.mnp.nl/hyde/

# Basic Atmospheric $CO_2$ Data

## (Antarctic ice cores and Mauna Loa air samples)



# Global Temperatures (up to 2013)




Source: http://data.giss.nasa.gov/gistemp/graphs_v3/

# Interpreting the basic facts…

- (1) an increase in the human production of greenhouse gases
- (2) increased atmospheric concentrations of greenhouse gases
- (3) increasing world temperatures
- ***How are they linked?***
- 1 → 2: if anthropogenic GHG are entirely absorbed and there is a natural source of GHG…
- 2 → 3: if there is another heat source and if something counteracts the heating effect of GHG…
- ***Evidence + Occam's Razor = IPCC***

# The IPCC, since 1988 (1)

- The UN's Intergovernmental Panel on Climate Change (IPCC) does not conduct any original research:  it sifts through scientific results published in peer-reviewed journals
- The participating scientists charged with this evaluation belong to three working groups:
  - 1) Physical Climate Science
  - 2) Adaptation
  - 3) Mitigation
- Five assessments of the state of research into climate change have come out, in 1990, 1995, 2001, 2007, and 2013

# The IPCC, since 1988 (2)

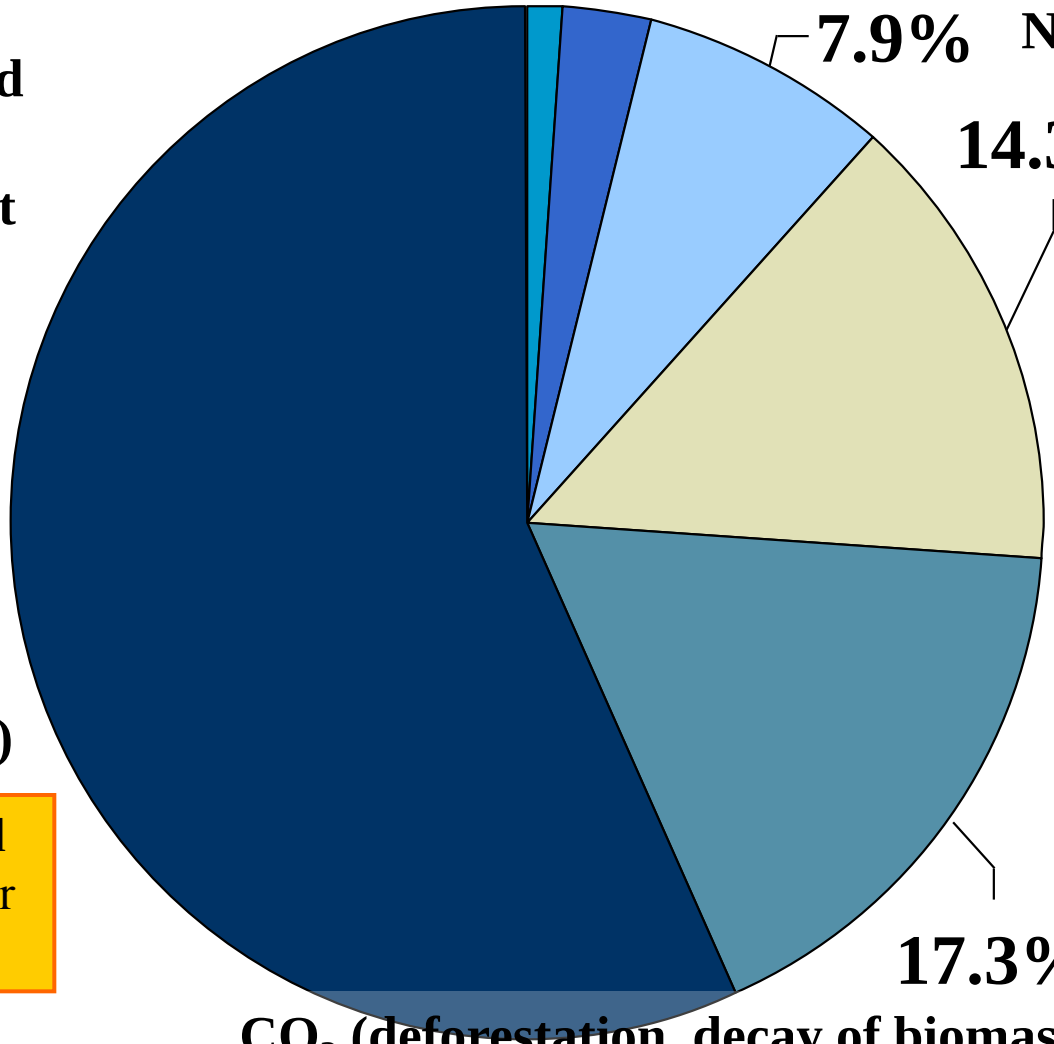
- The 24-page synthesis report in 2007 was approved by dozens of governments in the presence of 22 coordinating authors, who represented 152 writers, at the close of 3 years of work and the answering of 30,000 queries
- The full suite of 2007 reports is available in several languages and totals about 3,000 pages in all
- The IPCC reports flag two type of uncertainties:  that of an expert's qualified judgment and the intrinsic margin of error of data or a model

# Greenhouse Gases

- There are several causes of what is called climate forcing: greenhouse gases, aerosols, sunlight intensity (but not water vapour)
- W.r.t. warming, the most important greenhouse gases are: (1) $CO_2$, (2) methane, (3) ozone, (4) CFCs/halocarbons, (5) nitrous oxide
- Carbon dioxide is the single largest factor in climate forcing, methane only counting for half of carbon dioxide's overall impact
- While some aerosols are "white" (being reflective, they reflect sunlight and actually cool the atmosphere), black carbon soot also plays a role in warming the atmosphere

# Main Greenhouse Gases (World, 2004)

(% emissions by category, counted as Gt $CO_2$-eq/yr)




***F-gases*: fluorinated gases**

***$CO_2$ (other)*: cement production and natural gas flaring**

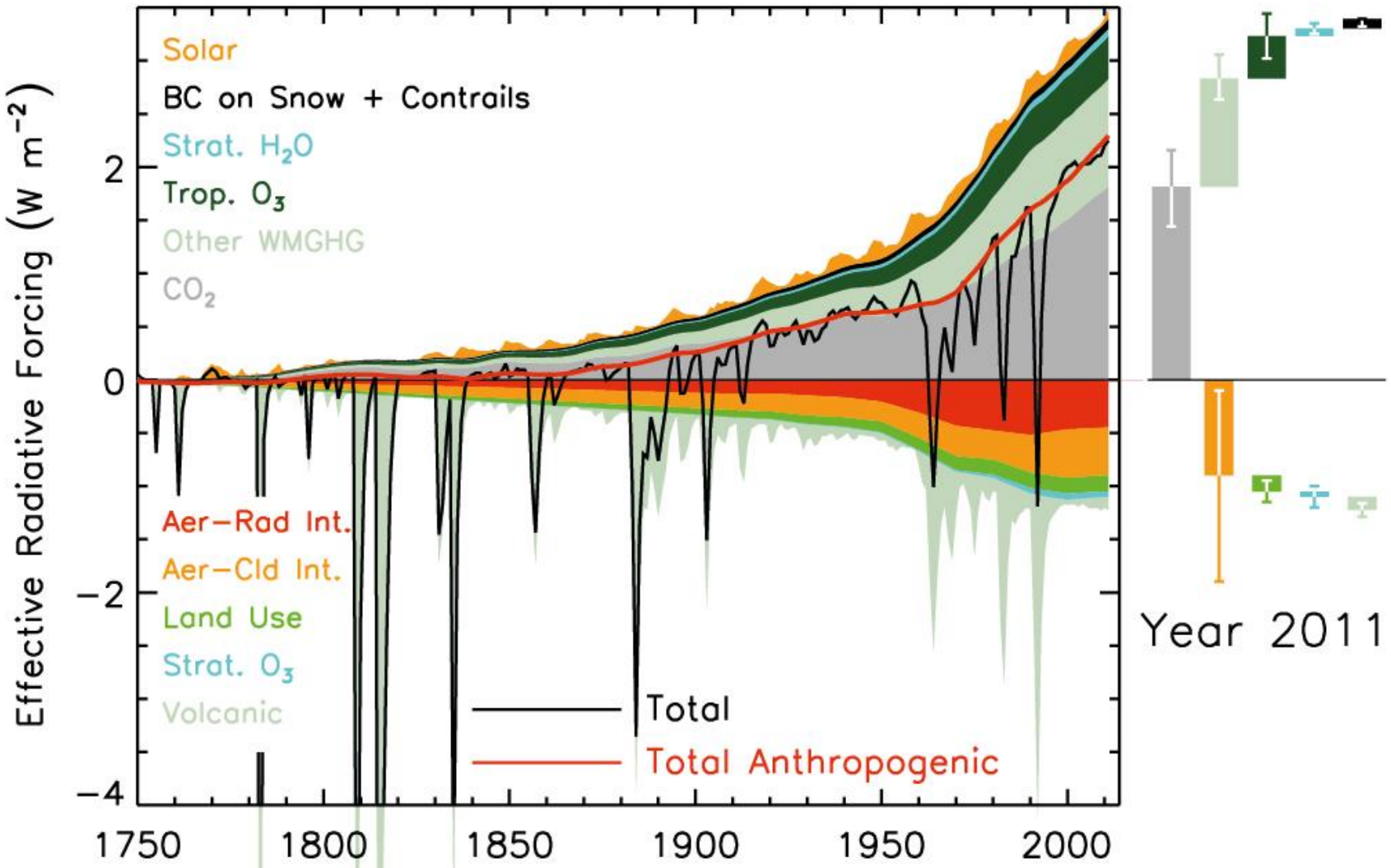
**N.B.:** The uncertainty for $CH_4$ and $NO_2$ is about 30-50%; it's larger for $CO_2$ from agriculture and forestry

From: IPCC, 2007

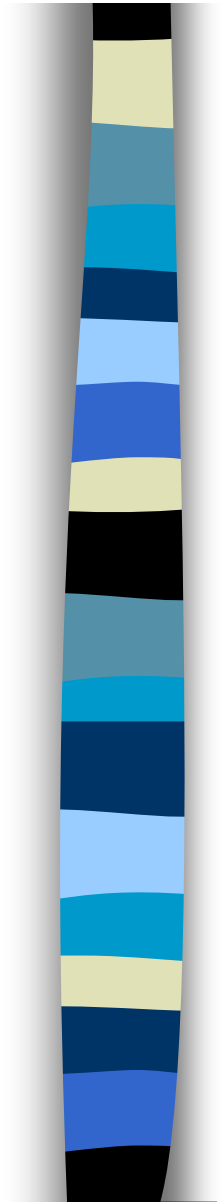
IPCC, *Fifth Assessment Report* (AR5), 2013-2014

# Historical climate forcings

Besides greenhouse gases, the climate responds to forcings acting to both warm and cool the planet's land and atmosphere, including soot on snow, the interactions between aerosols and clouds, and plane trails.



(AR5)



IPCC, *Fifth Assessment Report* (AR5), 2013-2014

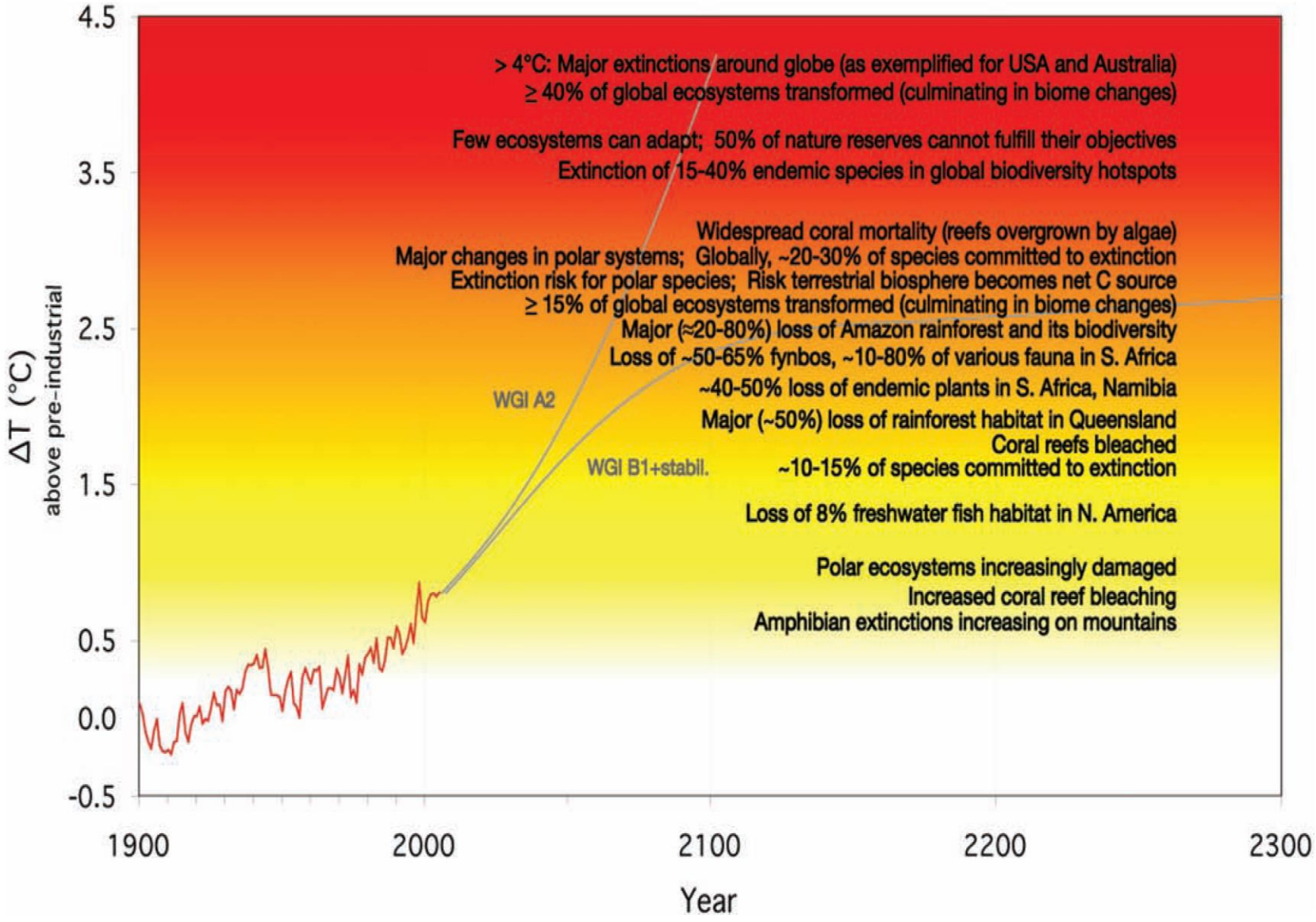
**Table 8.5 |** Confidence level for the forcing estimate associated with each forcing agent for the 1750–2011 period. The confidence level is based on the evidence and the agreement as given in the table. The basis for the confidence level and change since AR4 is provided. See Figure 1.11 for further description of the evidence, agreement and confidence level. The colours are adopted based on the evidence and agreement shown in Figure 1.11. Dark green is "High agreement and Robust evidence", light green is either "High agreement and Medium evidence" or "Medium agreement and Robust evidence", yellow is either "High agreement and limited evidence" or "Medium agreement and Medium evidence" or "Low agreement and Robust evidence", orange is either "Medium agreement and Limited evidence" or "Low agreement and Medium evidence" and finally red is "Low agreement and Limited evidence". Note, that the confidence levels given in Table 8.5 are for 2011 relative to 1750 and for some of the agents the confidence level may be different for certain portions of the Industrial Era.

| | Evidence | Agreement | Confidence Level | Basis for Uncertainty Estimates (more certain / less certain) | Change in Understanding Since AR4 |
|---|---|---|---|---|---|
| **Well-mixed greenhouse gases** | Robust | High | *Very high* | Measured trends from different observed data sets and differences between radiative transfer models | No major change |
| **Tropospheric ozone** | Robust | Medium | *High* | Observed trends of ozone in the troposphere and model results for the industrial era/Differences between model estimates of RF | No major change |
| **Stratospheric ozone** | Robust | Medium | *High* | Observed trends in stratospheric and total ozone and modelling of ozone depletion/Differences between estimates of RF | No major change |
| **Stratospheric water vapour from $CH_4$** | Robust | Low | *Medium* | Similarities in results of independent methods to estimate the RF/Known uncertainty in RF calculations | Elevated owing to more studies |
| **Aerosol–radiation interactions** | Robust | Medium | *High* | A large set of observations and converging independent estimates of RF/Differences between model estimates of RF | Elevated owing to more robust estimates from independent methods |
| **Aerosol–cloud interactions** | Medium | Low | *Low* | Variety of different observational evidence and modelling activities/ Spread in model estimates of ERF and differences between observations and model results | ERF in AR5 has a similar confidence level to RF in AR4 |
| **Rapid adjustment aerosol–radiation interactions** | Medium | Low | *Low* | Observational evidence combined with results from different types of models/Large spread in model estimates | Elevated owing to increased evidence |
| **Total aerosol effect** | Medium | Medium | *Medium* | A large set of observations and model results, independent methods to derive ERF estimates/Aerosol–cloud interaction processes and anthropogenic fraction of CCN still fairly uncertain | Not provided previously |
| **Surface albedo (land use)** | Robust | Medium | *High* | Estimates of deforestation for agricultural purposes and well known physical processes/Spread in model estimates of RF | Elevated owing to the availability of high-quality satellite data |
| **Surface albedo (BC aerosol on snow and ice)** | Medium | Low | *Low* | Observations of snow samples and the link between BC content in snow and albedo/Large spread in model estimates of RF | No major change |
| **Contrails** | Robust | Low | *Medium* | Contrails observations , large number of model estimates/Spread in model estimates of RF and uncertainties in contrail optical properties | Elevated owing to more studies |
| **Contrail- induced cirrus** | Medium | Low | *Low* | Observations of a few events of contrail induced cirrus/Extent of events uncertain and large spread in estimates of ERF | Elevated owing to additional studies increasing the evidence |
| **Solar irradiance** | Medium | Medium | *Medium* | Satellite information over recent decades and small uncertainty in radiative transfer calculations/Large relative spread in reconstructions based on proxy data | Elevated owing to better agreement of a weak RF |
| **Volcanic aerosol** | Robust | Medium | *High* | Observations of recent volcanic eruptions/Reconstructions of past eruptions | Elevated owing to improved understanding |

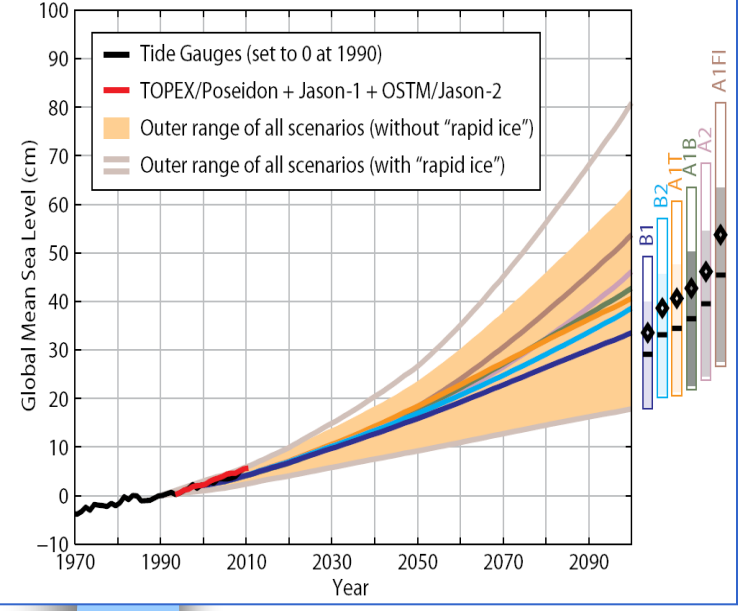
Notes:

The confidence level for aerosol–cloud interactions includes rapid adjustments (which include what was previously denoted as cloud lifetime effect or second indirect aerosol effect). The separate confidence level for the rapid adjustment for aerosol–cloud interactions is very low. For aerosol–radiation interaction the table provides separate confidence levels for RF due to aerosol–radiation interaction and rapid adjustment associated with aerosol–radiation interaction.

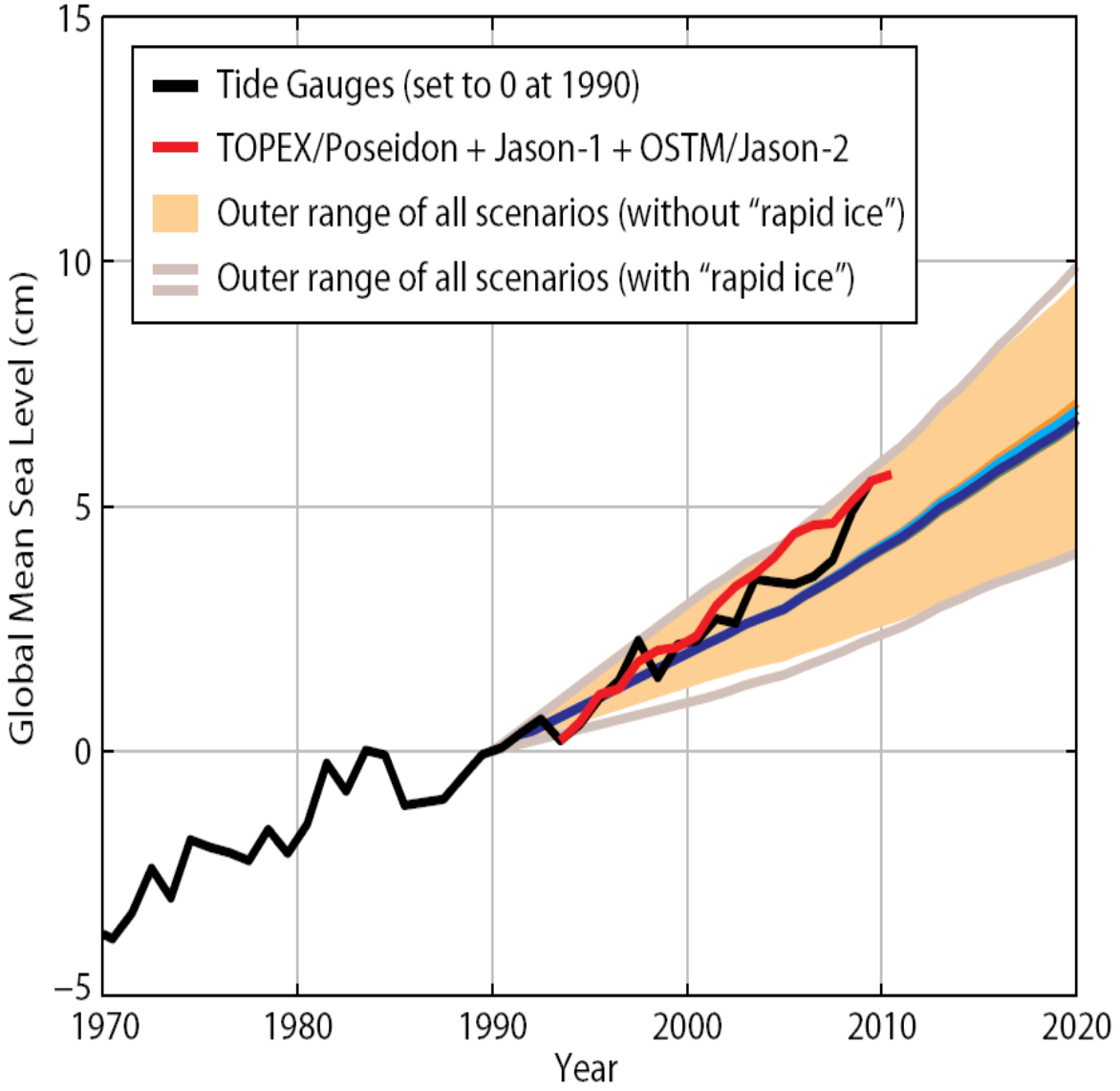
# Consequences…



# Sea level rise



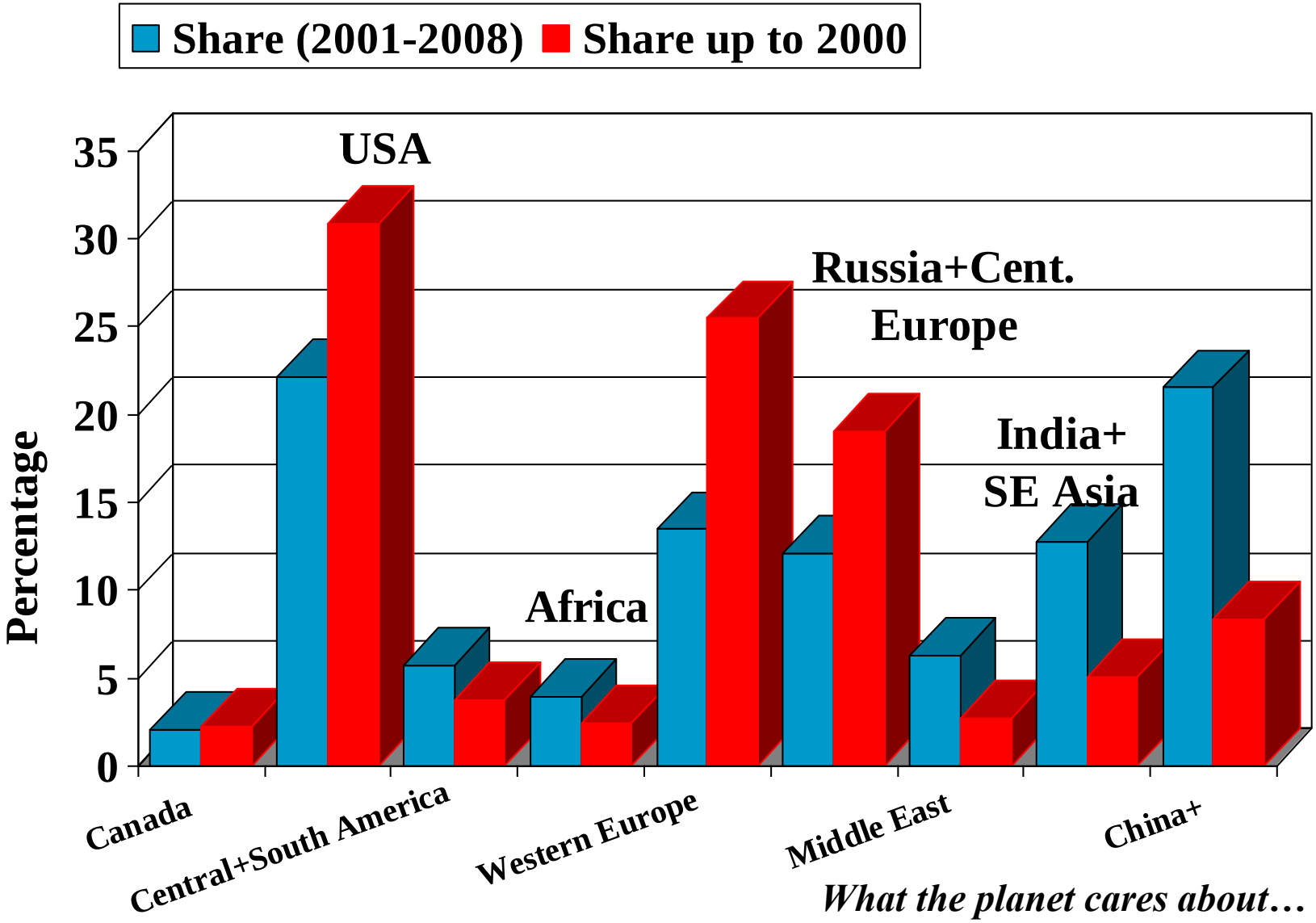

By 2100, global warming is expected to cause a rise in sea level of about 20-80 cm, though the measured rise has been running ahead of projections.




Source: J. A. Church, J.M. Gregory, N.J. White, S.M. Platten, and J.X. Mitrovica, "Understanding and projecting sea level change", *Oceanography* **24**, 2 (2011), pp. 130–143.

# Carbon Dioxide Emissions

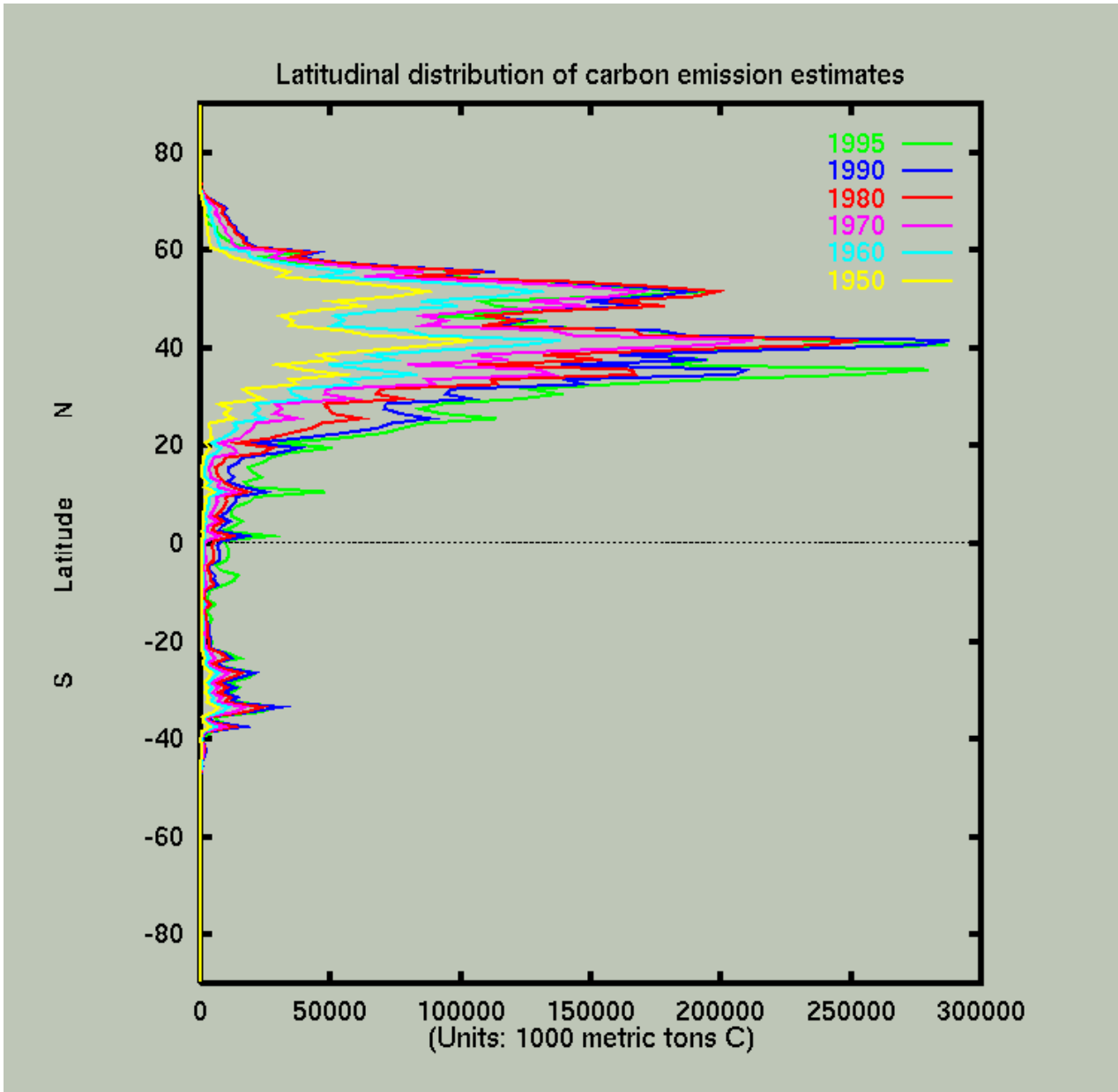
Based on annual totals of fossil fuel emissions (CDIAC, 2012)




*What the planet cares about…*

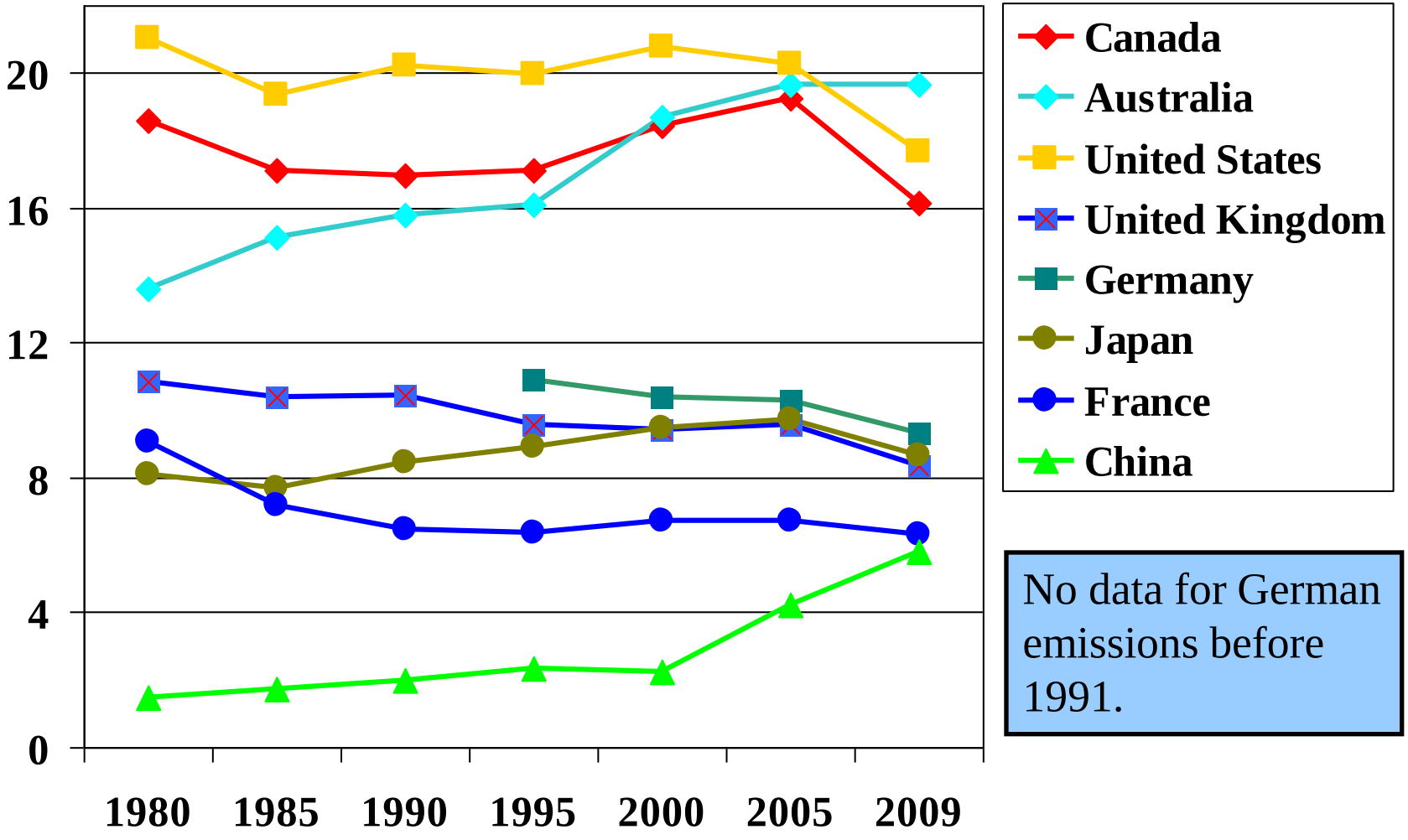
# $CO_2$ Emissions: The North-South Divide

While warming is expected to be a global phenomenon, carbon emissions resulting from the combustion of fossil fuels mainly originate in the temperate zone of the Northern hemisphere.
(Source: CDIAC)



# The Political Challenge…

(Per capita $CO_2$ emissions from the consumption of energy in metric tons, Energy Information Administration, DOE, U.S.A.)



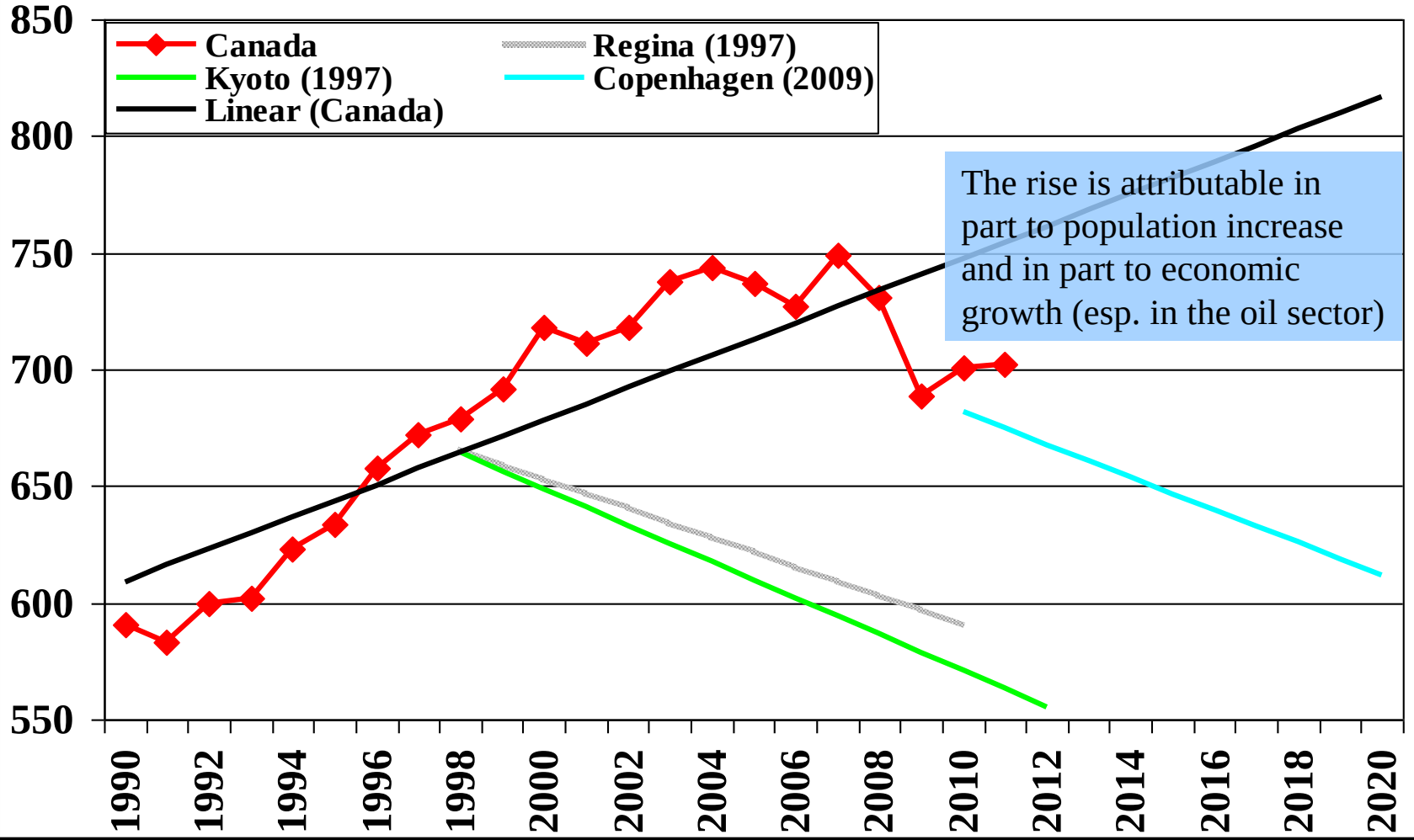

No data for German emissions before 1991.

N.B.: Numbers vary slightly depending on the emission categories included.

Canada, National Inventory Report for 1990-2011 (2013)

# Canada's (Non-)Performance

$CO_2$–equivalent emissions in Mt (excluding land use, land-use change and forestry)



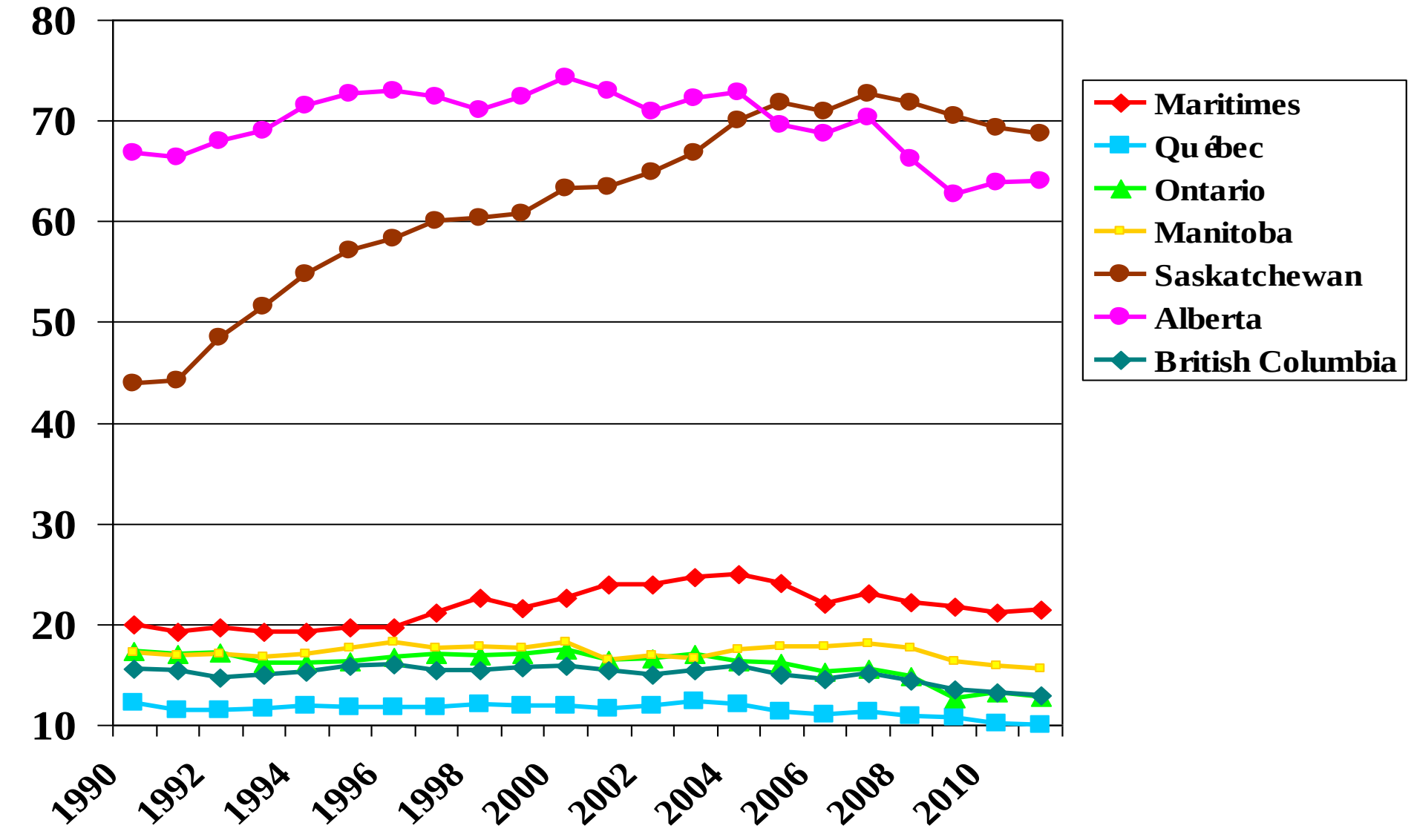

The rise is attributable in part to population increase and in part to economic growth (esp. in the oil sector)

**Nota Bene**: The federal-provincial Regina accord aimed for 1990 levels in 2010; at Kyoto, Canada agreed to aim for a 6% reduction from 1990 levels (591 Mt) by 2012; in Copenhagen, Canada offered a 17% reduction from 2005 levels (737 Mt) by 2020.

# The *real* political problem

## $CO_2$-equivalent emissions in metric ton per capita and province

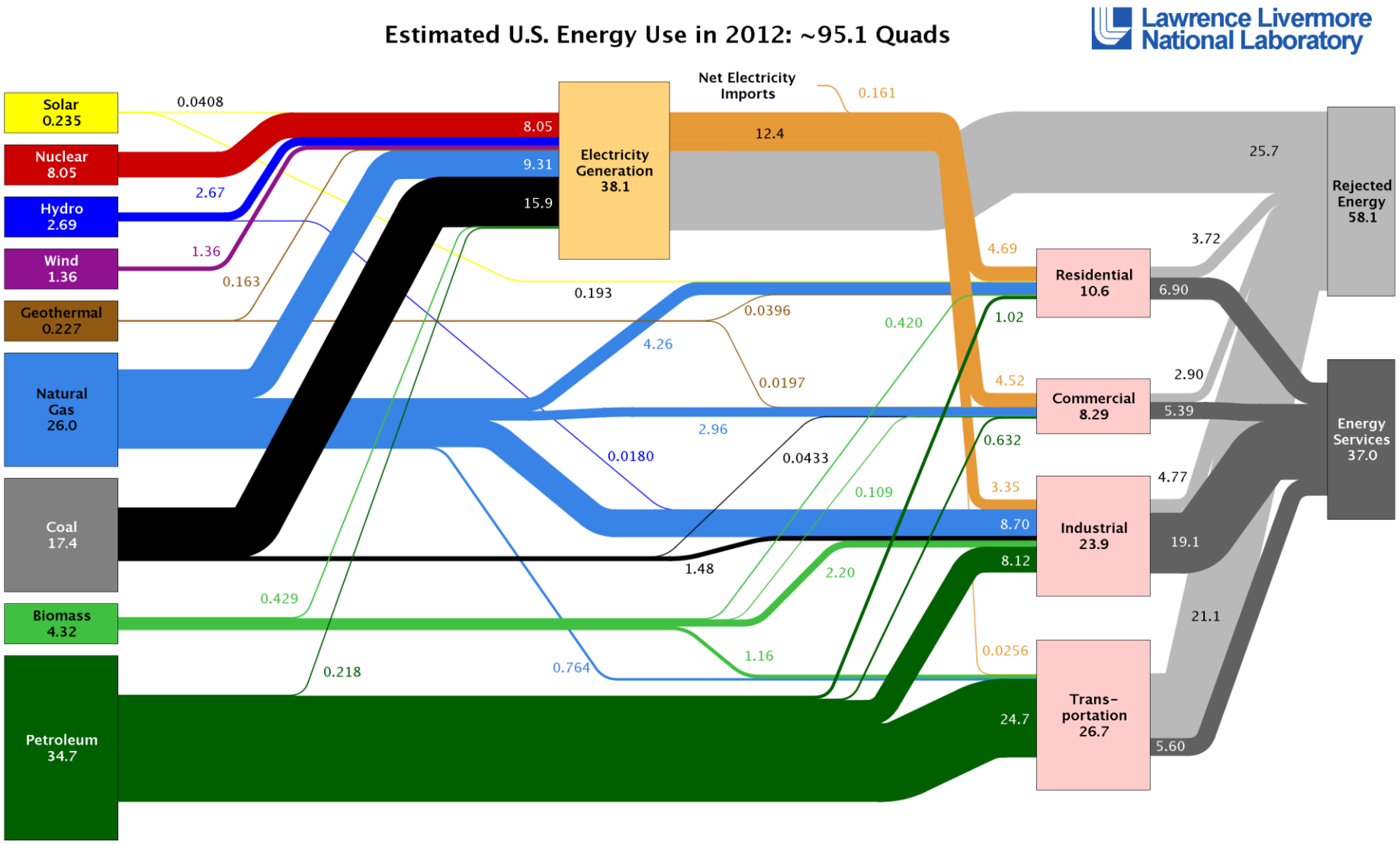
National Inventory Reports, 2002, 2006, 2010, 2013, Environment Canada



# Solutions for Canada?

- Stop all immigration
- Tax children
- Produce more plastics, make more things out of wood
- Buy international carbon credits (*i.e.* subsidize emissions reductions in… the United States or Europe!)
- Tax carbon
- Capture and sequester GHG
- Create a carbon market
- Switch to carbon-free energy sources

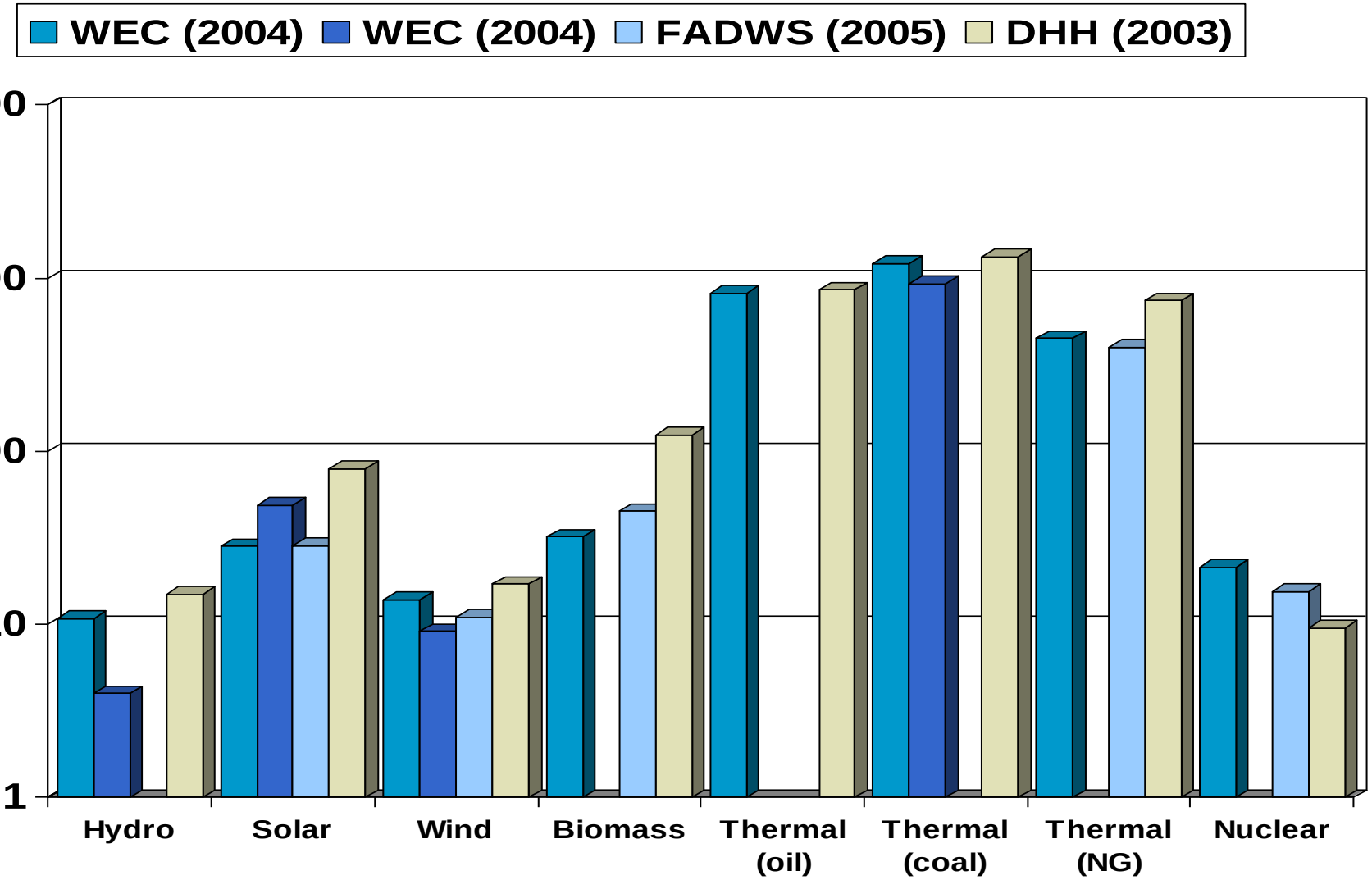
# U.S. Energy Flows in 2012




Source: LLNL 2013. Data is based on DOE/EIA-0035(2013-05), May, 2013. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Credit: DOE, Lawrence Livermore Laboratory

# Lifecycle $CO_2$-eq emissions (tons of $CO_2$/GWh)




From: Chris Lund and Wahidul Biswas, *Bulletin of Science, Technology & Society*, **28**, Number 3 (June 2008), pp. 200-209.

# *To recapitulate (3)*

- Did Canada achieve its Kyoto Protocol targets for GHG emissions reductions in 2012?
- Is the historical share (the percentage of the world's total, up to 2000) of fossil fuel emissions by China greater or smaller than its share of emissions between 2001 and 2008?
- According to the IPCC, is the level of scientific understanding of the effect of clouds on global warming greater or smaller than for the effect of greenhouse gases?
- What three (3) basic observational facts are linked by the theory of global warming?