ALTERNATIVE SOURCES: THE ROLE OF COAL AND SOLAR ENERGY

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Energy Crisis

(crisis) = (danger) $\cup$ (opportunity)

Today's talk:

- solar energy utilization
- coal utilization
- hydrogen generation

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Solar Energy

- direct capture:
  - a thermal/fluid collectors
  - b photoelectric collectors
- wind:
  - windmills
- oceans:
  - a waves
  - b currents
  - c temperature gradients
- photosynthesis

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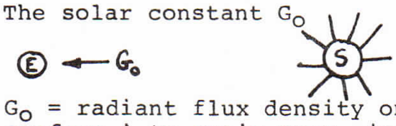
Solar Radiation

1. The solar constant G_o



G_o = radiant flux density on a surface ⊥ to sun's rays, just above earth's atmosphere

Units: energy intercepted per unit area per unit time

Value: $G_o = 1.36$ KW/m^2

2. Solar surface temperature T_s

Value: $T_s \simeq 6000^oC$

Observation: taking heat from a source at very high temperature. Thus high efficiency of conversion to work is theoretically possible.

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Solar Flux at Earth's Surface

Solar energy flux on 1 sq. metre:

normal to sun's rays, no atmosphere:
$G = G_o = 1.36$ KW/m^2

normal, with atmosphere, clear day
$G = 1$ KW/m^2

45^o, with atmosphere, clear
$G = 0.7$ KW/m^2

15^o, with atmosphere, clear
$G = 0.1$ KW/m^2

In the following talk, take $G = 0.5$ KW/m^2

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Modes of Solar Energy Use

We shall consider:

- home heating
- electric power generating station
- chemical process heating (for hydrogen generation)

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Home Heating

Wanted: store energy for home heating in winter

Solution:
- heat water during summer and store in reservoir
- use stored hot water for home heating in winter

Questions: what ground area?
what reservoir volume?

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Ground Requirement

Assumptions:
- collect for 8 hours daily for 4 months
- require equivalent of 500 gal. fuel oil

Cumulative solar energy on 1 m^2:

$8(3600)(4)(30)(500) = 1.73 \times 10^9$ J
$= 1730$ MJ

Energy equivalent of 500 gal. oil:

500 gal. $\Leftrightarrow$ 79200 MJ

Minimum ground area:

$79200/1730 = 46$ m^2

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Ground Requirement

Collection efficiency, (%)	Area (m^2)	Dimensions of area, as a square.
100	46	7m x 7m, 21' x 21'
20	230	15m x 15m, 45' x 45'
5	920	30m x 30m, 90' x 90'

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Reservoir Requirement

Assumption: heat water from 20^{o}C to 65^{o}C, taking 0.186 MJ/kg

Minimum Water Required:
$79200/.186 = 4.26 \times 10^5$ kg
$\Leftrightarrow 426$ m^3

426m^3 = 7.5m x 7.5m x 7.5m
= 23' x 23' x 23'

Conclusion: reservoir will be large but possibly feasible

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Solar Power Station

Suppose:- 1000 MW electric generating capacity
- 20% efficiency converting thermal energy to electrical

Minimum ground area:

$(1000 \times 10^6)/(.2)(500) = 10^7 \text{ m}^2$
$= 10 \text{ km}^2$

Collection efficiency, (%)	Area (m^2)	Dimensions, as a square
100	10	3km x 3km
20	50	7km x 7km
5	200	14km x 14km

Note: power on only 10 hr/day Thus average power is under 50% of that indicated.

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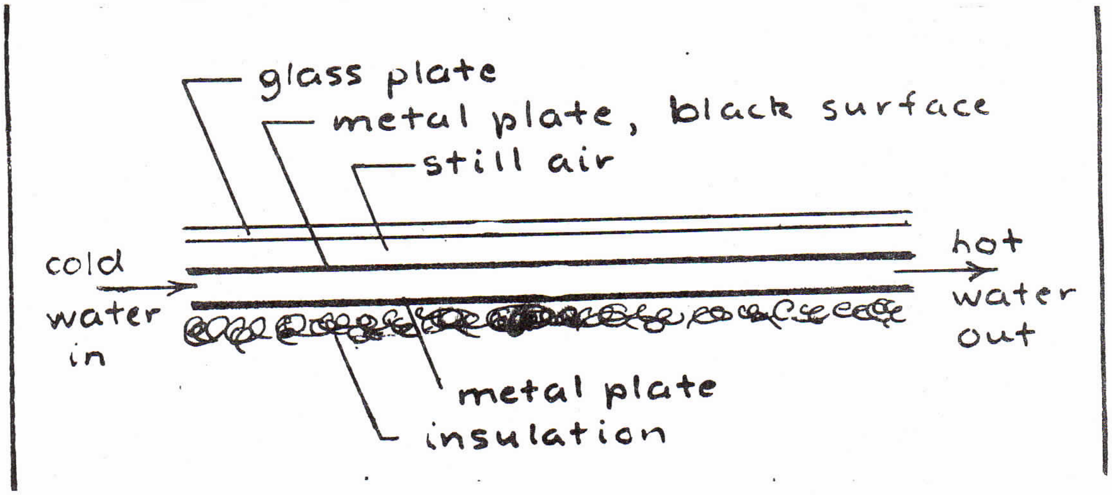
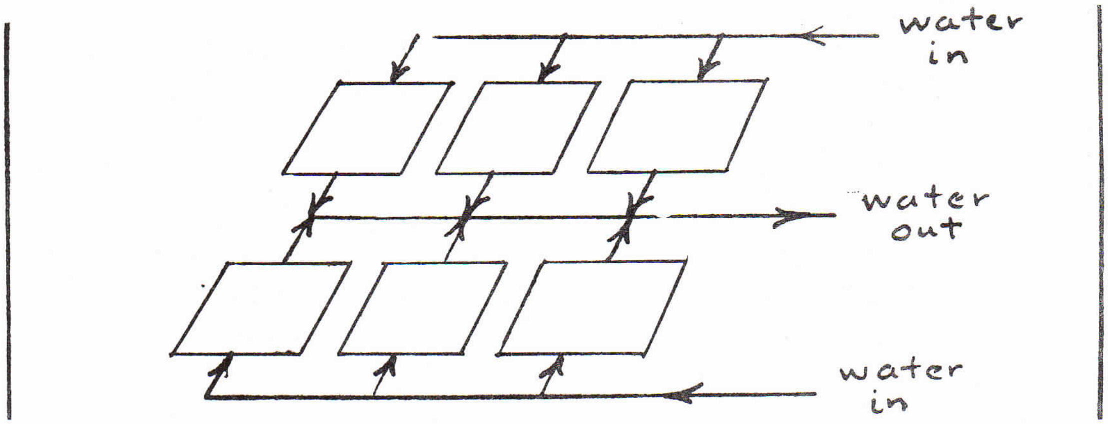
Solar Energy Collector for Home Heating

Recommended type: flat-plate collector (hot-house effect)



System: Schematic



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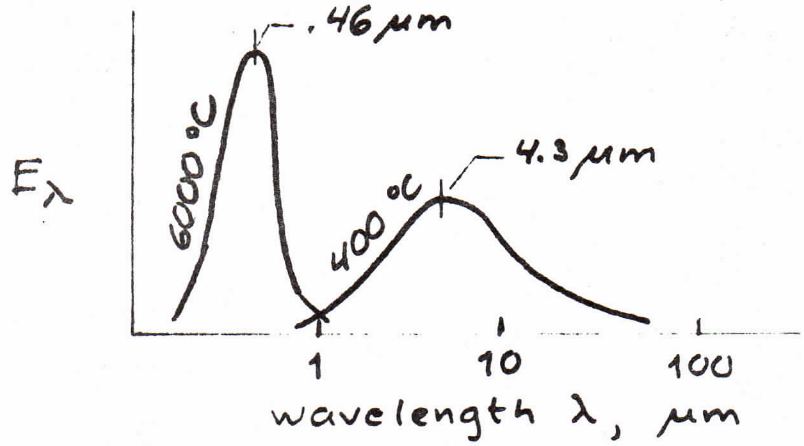
Design Characteristic of Flat-Plate Collector

Spectrum of solar radiation:



E_λ = radiant flux per unit wavelength

Visible range: .38 - .76 μm
Infrared: .76 - 1000 μm

Wien's displacement law: at the maximum in the spectrum $\lambda T = .0028978\ m \cdot K$

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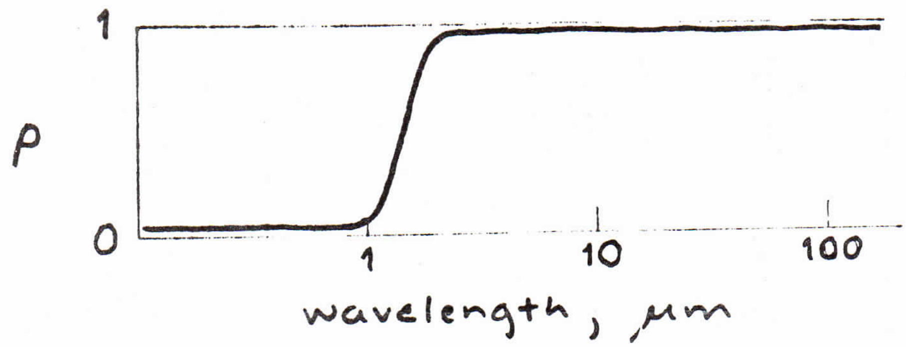
Design Characteristic of Flat-Plate Collector

Critical design parameter: reflectivity of the glass window
ρ = reflectivity (fraction reflected)

Desired characteristic:

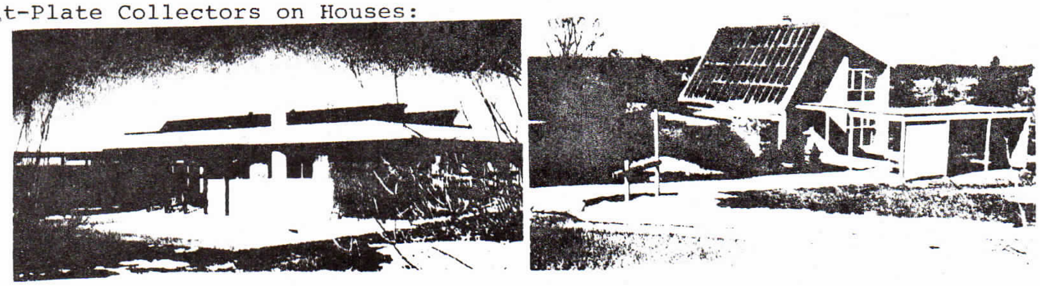


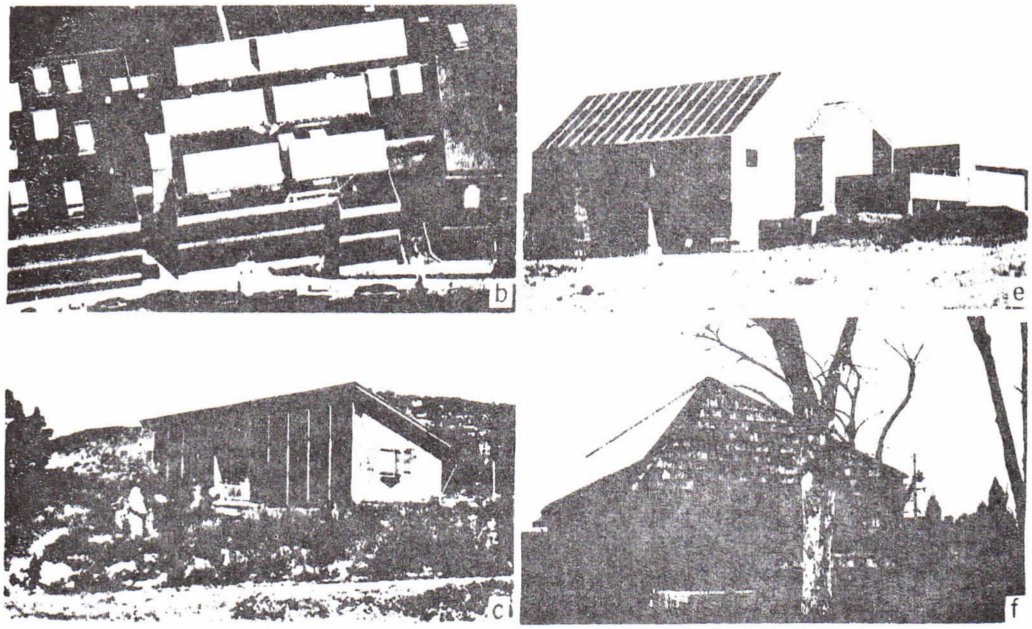
Maximum attainable temperature on collector plate:

$$T_{max} = \sqrt[4]{\frac{G}{\sigma(1-\rho_{i.r.})} + T_{window}^4}$$

Therefore if $\rho = .95$, $T_{window} = 25^oC$ and $T_{max} = 568^oC$

Flat-Plate Collectors on Houses:





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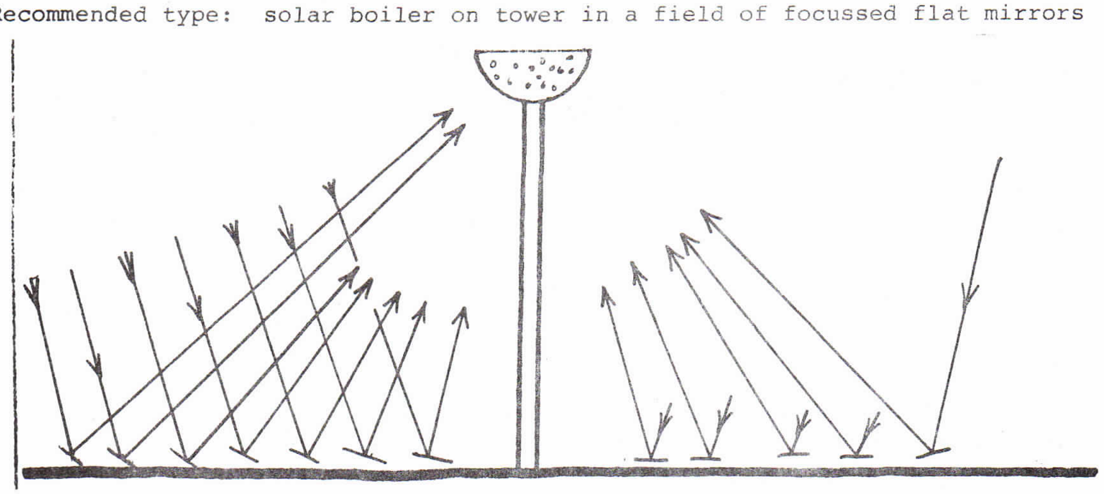
Solar Energy Collector for Power Station

Recommended type: solar boiler on tower in a field of focussed flat mirrors



Tower height: 500m Ground area: 3 km^2 Power: ~ 100MW

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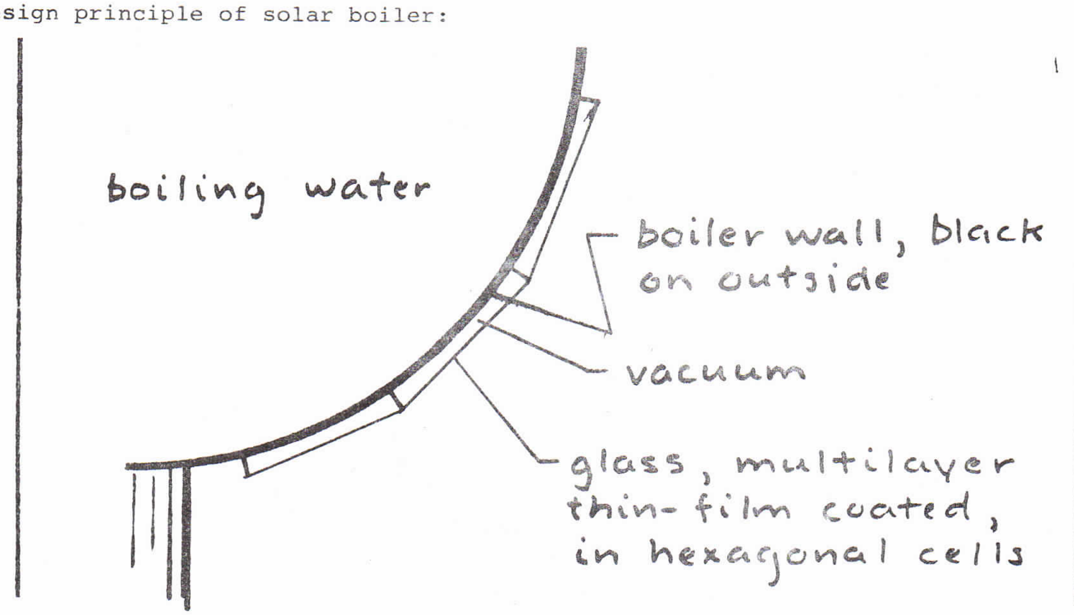
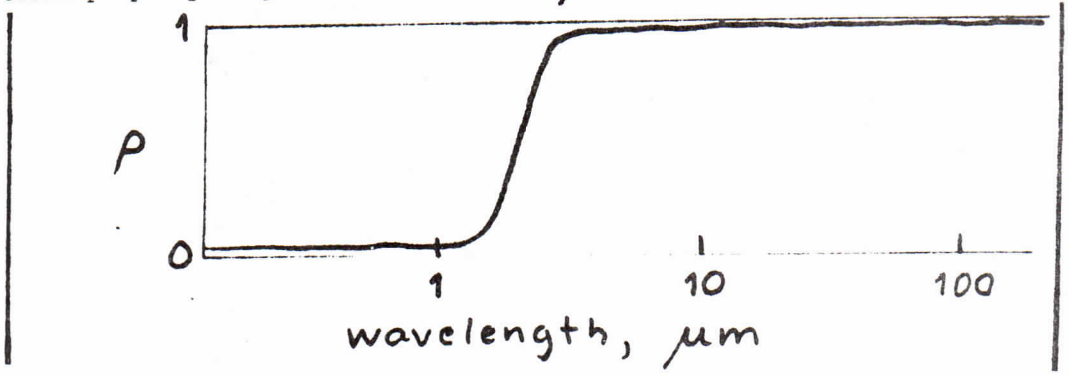
Solar Energy Collector for Power Station

Design principle of solar boiler:



Optical property of glass: reflectivity ρ



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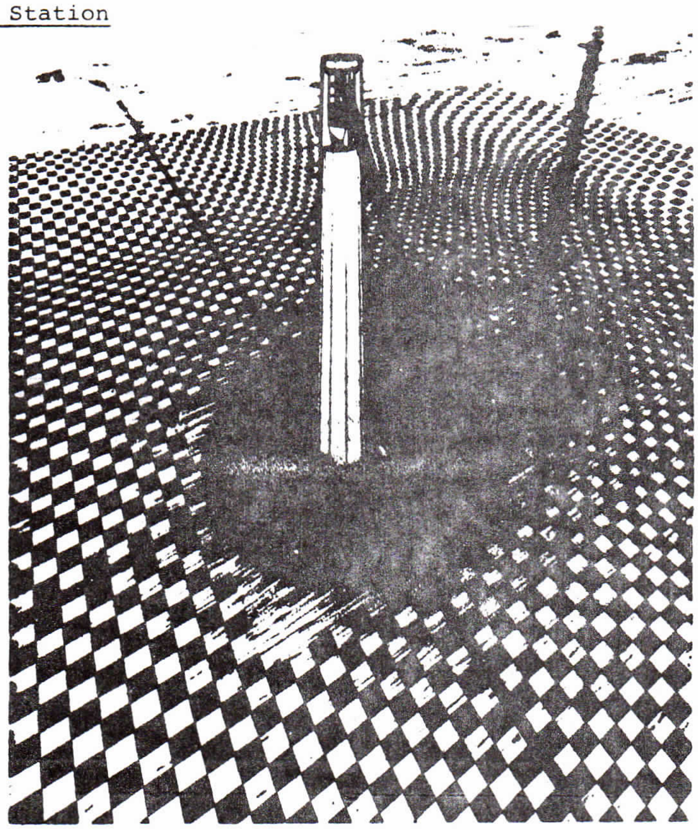
Solar Energy Collector for Power Station



Square mile (2.6 km^2) mirror array with receiver atop 450 meter tower.

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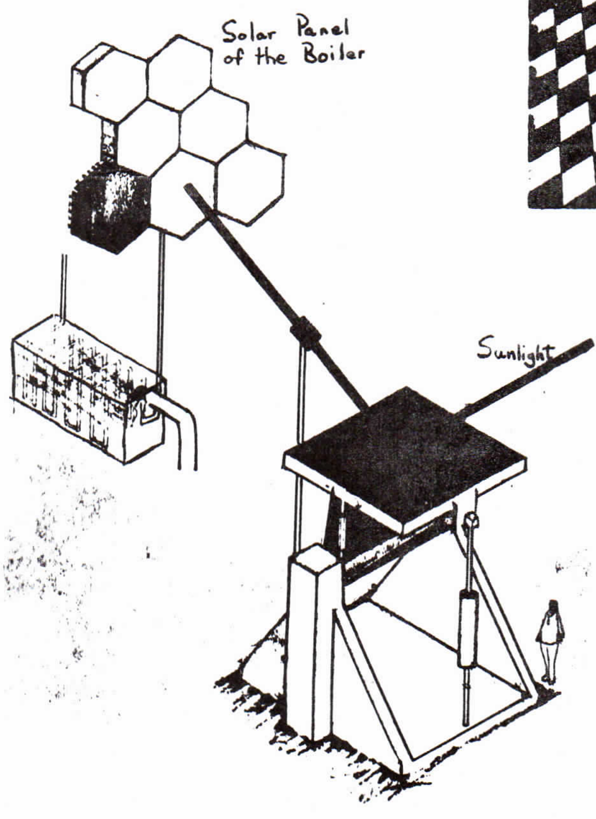
Solar Energy Collector for Power Station



Heliostat with optical sensor redirecting energy onto a segment of the receiver.

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Performance of Tower Type Solar Collector

- can produce steam at 425°C (maximum practical steam temperature)
- with gas (instead of water) as heat transfer medium, could get ~1000°C, high enough for supplying heat to any chemical process such as thermochemical H_2 production

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Assessment of Solar Energy Now

1. Systems can be built with existing, proven technology
2. Capital intensive
3. Large land areas required for power
4. Focussing type collectors only suitable for clear skies, very sunny areas (U.S. Southwest, Israel, Egypt, etc.)
5. Flat-plate collectors only suitable for small scale - eg. home heating. Feasible in Canada. Reasonably installed only in new homes.
6. In sunny central latitudes, solar cooking, drying,... very feasible

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Coal

General observations:

- domestic heating with coal undesirable
- only low-sulphur coals suitable for burning directly (in power stations, chemical processing)
- most remaining coal is high in sulphur. Should remove S before use as fuel.
- best way to remove S is to process coal into gaseous and liquid products. Sulphur is removed in course of processing quite easily.
- gaseous and liquid products can be pipelined, burned in engines, etc.

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Types of Processes Available

1. Pyrolysis

   → gas & liquid + char or coke
2. Gasification

   → fuel gas &/or chemical synthesis gas
3. Liquifaction by direct hydrogenation

   → 3-4 bl oil per ton coal, + some gas, char
4. Gasification followed by Fischer Tropsch synthesis

   → oil + gas

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Observations

1. Canada has several centuries supply of available coal
2. Several technologies are proven, many others nearly ready
3. Mining problems smaller than with tar sands
4. Plant construction times 7+ years. No starts yet in Canada, little R&D
5. Capital costs great, but worth it. Since resource will last for centuries, it is worth "gearing up" the economy to use it.

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Hydrogen

Hydrogen economy in 21st century?

Production: water splitting by
1. Electrolysis
2. Thermochemical process

Uses:
1. Pipeline gas for home, industry
2. Hydrogenation of coal
3. Automobile & tractor fuel (storage as metal hydride, e.g. MgH_2)
4. Aircraft fuel (storage in wing tanks as liquid H_2)

Advantages:
1. Abundant raw material (H_2O)
2. Virtually non-polluting in combustion (H_2 + air → H_2O + NO_x)
3. Can be pipelined
4. Highest energy per unit mass
5. Means of storing energy from intermittent sources (solar, tidal, wind, waves)

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Hydrogen: Thermochemical processes

A chemical process of water splitting, $2H_2O \rightarrow 2H_2 + O_2$

Thermal because heat must be supplied. Proposed heat sources: nuclear reactors, focussed solar collectors

Temperatures above 400°C, up to 800°C, are involved. Therefore must likely use gas as heat transfer medium (above max. steam temp. limits)

Processes under investigation by: Euratom, General Electric, Univ. of Florida, and many dozens of others

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A Typical Thermochemical Process

"BEULAH", by General Electric:

$2Cu + 2HCl(aq.) \xrightarrow{100°C} 2CuCl + H_2$

$4CuCl \xrightarrow{150°C} 2CuCl_2 + Cu$

$2CuCl_2 \xrightarrow{500°C} 2CuCl + Cl_2$

$Cl_2 + Mg(OH)_2 \xrightarrow{90°C} MgCl_2 + H_2O + 1/2(O_2)$

$MgCl_2 + 2H_2O \xrightarrow{350°C} Mg(OH)_2 + 2HCl(g)$

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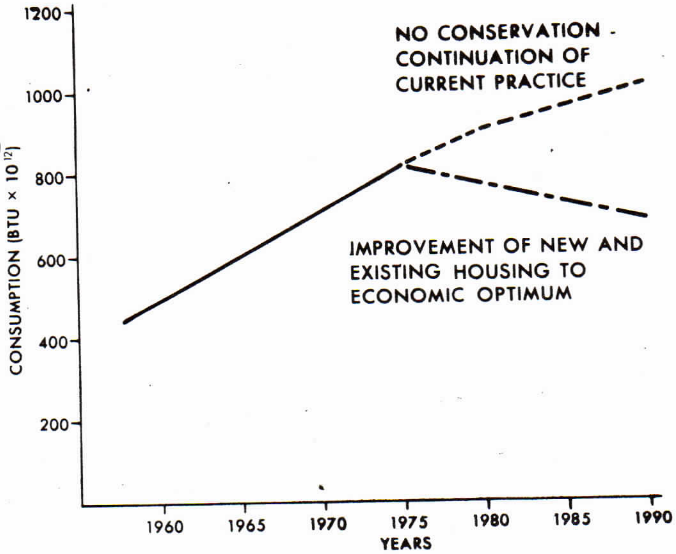
Thermochemical Processes

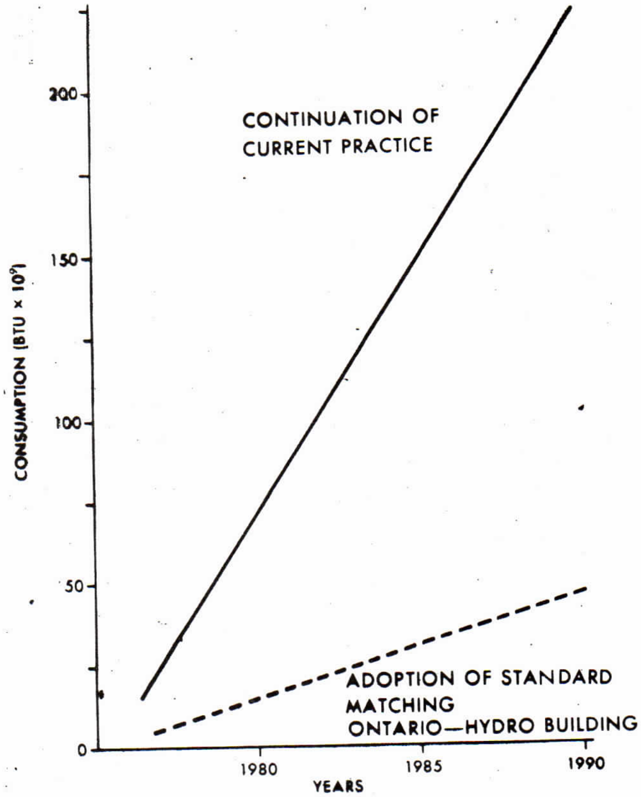
Problems:
1. In early stages of development, much lab & pilot plant work still needed
2. Severe technological problems: solid/liquid separations, corrosion...
3. Require high temperatures in some steps, as from gas cooled nuclear reactors. Canada has none.

Assessment:
1. Still far in future, but some R&D should be funded now
2. May never become practical, because of corrosion, material separation problems,...

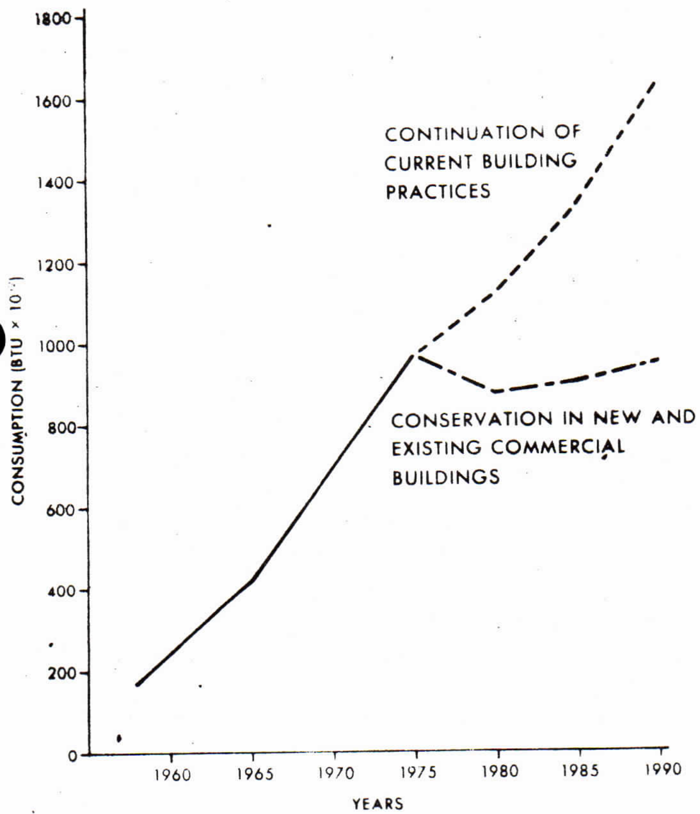
RESIDENTIAL HEATING ENERGY



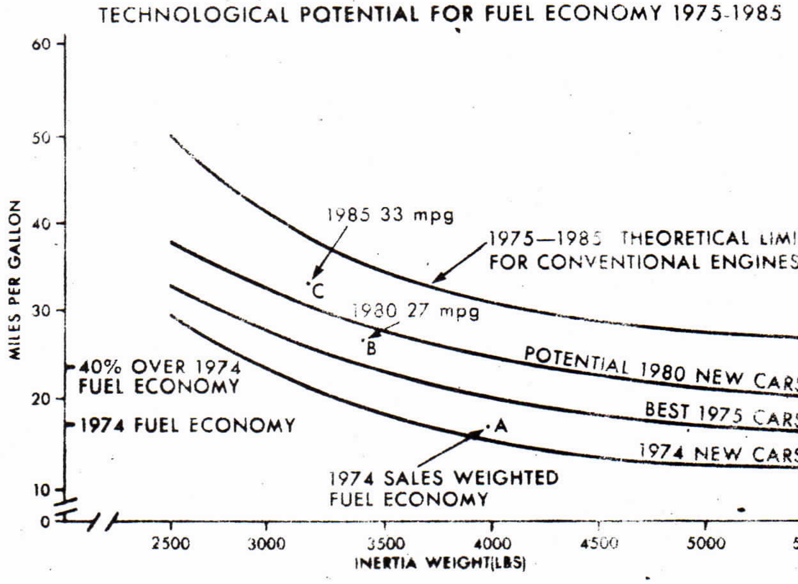
ENERGY CONSUMPTION BY OFFICE BUILDINGS BUILT AFTER 1975

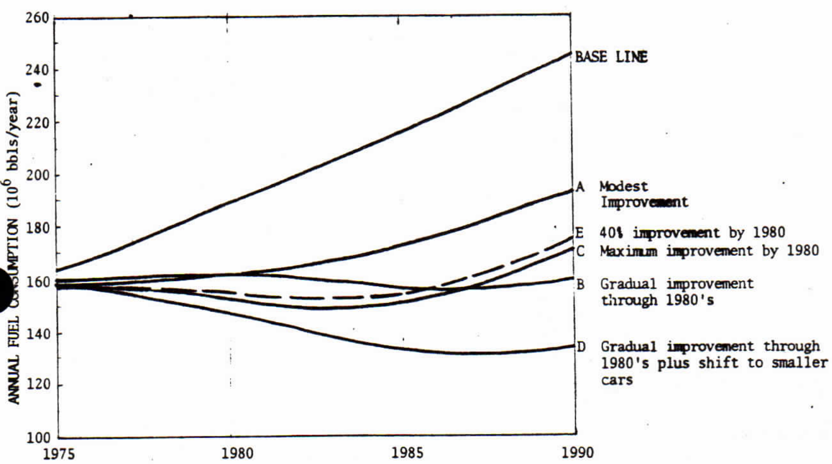


COMMERCIAL ENERGY CONSUMPTION



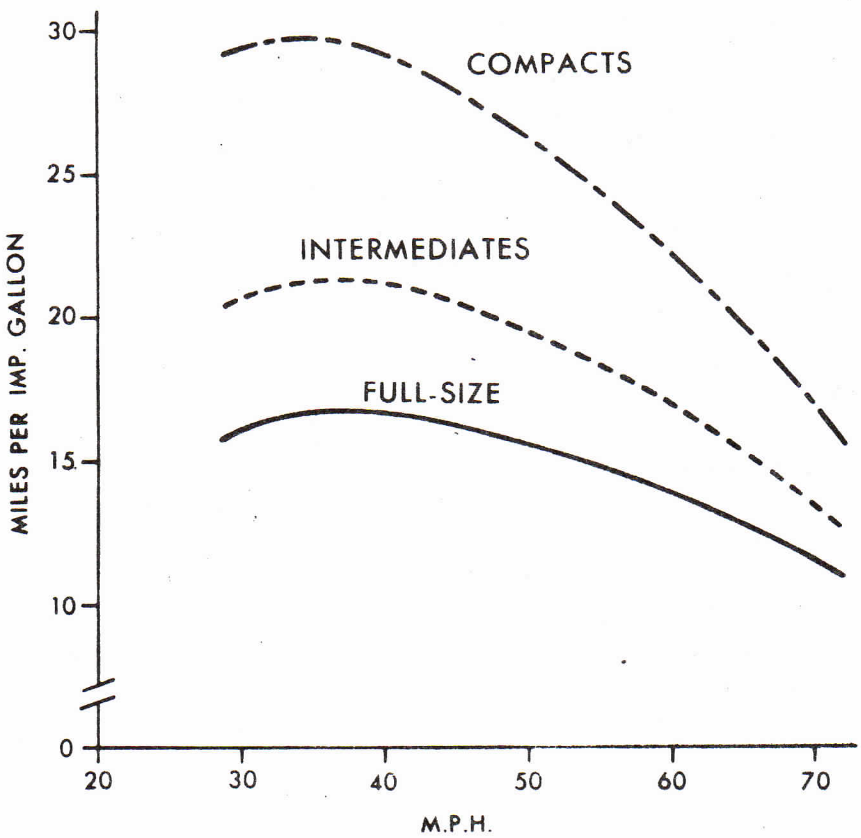
TECHNOLOGICAL POTENTIAL FOR FUEL ECONOMY 1975-1985





POTENTIAL FUEL SAVINGS BETWEEN NOW AND 1990, corresponding to four different levels of private-car improvement. The base line curve represents a steady growth in vehicle miles of 2.6 per cent per year. Curve E is based on announced industry goals(some engine changes, use of radial ti slight weight and air-drag reduction) with no significant improvements beyond 1980. Curve C is based on maximum improvements through 1980 with little change thereafter. Changes would include rapid weight and air-drag reduction, improved transmissions and optimization of conventional engines. Curve B vizualizes somewhat slower changes before 1980 but substantial improvements thereafter, including the phasing in of diesel engines for large cars between 1981 and 1989 and adoption of stratified charge engines for smaller cars. Curve D includes all the changes projected in curve B combined with a sales mix after 1980 consisting of 10 per cent large cars, 25 per cent intermediates, 25 per cent compacts and 40 per cent subcompacts, (present sales mix is 28 per cent large cars, 23 per cent intermediate, 24 per cent compact and 23 per cent subcompact). Curve A represents a 28 per cent improvement in fuel economy over the period 1974-78.

AUTO FUEL ECONOMY VS SPEED



AUTO FUEL ECONOMY vs WEIGHT