

Much of what we do  
is counter to nature

1

*UNNATURAL PROCESS*

2

*UNNATURAL PROCESS*

*CARS DO NOT GO UPHILL  
OF THEIR OWN ACCORD*

3

Some things do happen naturally

4

*NATURAL PROCESS*

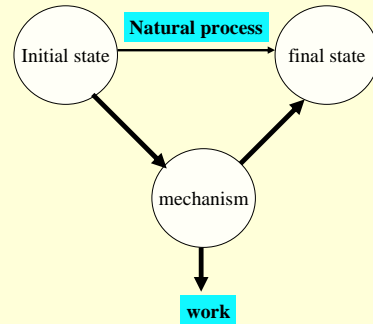
5

*NATURAL PROCESS*  
*PETROL BURNS IN AIR*

6

# THERMODYNAMICS

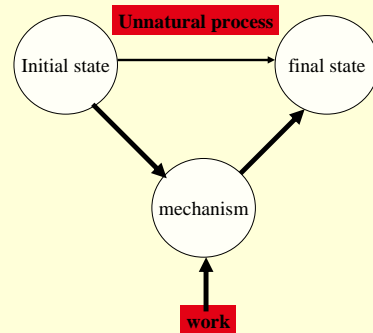
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A NATURAL PROCESS  
can often be conducted via a  
MECHANISM  
that will Produce  
USEFUL WORK

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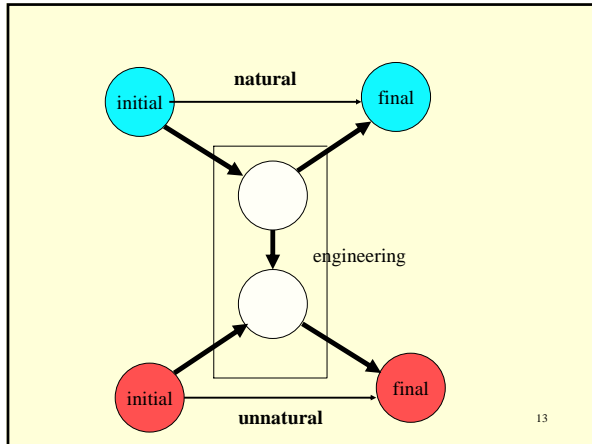
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To Drive an  
unnatural process  
always requires  
a source of  
ENERGY

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A Large part of  
ENGINEERING  
consists of finding ways of using  
NATURAL PROCESSES  
to drive  
UNNATURAL PROCESSES

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**UNNATURAL PROCESS**

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*UNNATURAL PROCESS*  
*CARS DO NOT GO UPHILL  
 OF THEIR OWN ACCORD*

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*UNNATURAL PROCESS*  
*CARS DO NOT GO UPHILL  
 OF THEIR OWN ACCORD*

*NATURAL PROCESS*  
*PETROL BURNS IN AIR*

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*UNNATURAL PROCESS*  
*CARS DO NOT GO UPHILL  
 OF THEIR OWN ACCORD*

*NATURAL PROCESS*  
*PETROL BURNS IN AIR*

**ENGINEERING SOLUTION**  
**DEVISE A MECHANISM THAT  
 BURNS PETROL  
 TO PUSH CAR UP HILL**

Our commonest sources of  
**ENERGY**  
 are  
**FOSSIL FUELS**

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HYDROCARBON PLUS AIR

gives

ENERGY

plus

CARBON DIOXIDE

WITH

NITROGEN

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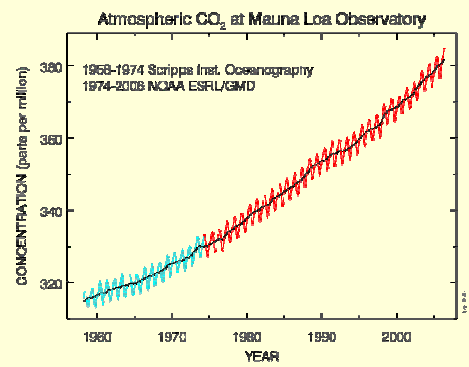
## CONSEQUENCES OF BURNING FOSSIL FUEL

- PRODUCTION OF GREENHOUSE GAS CARBON DIOXIDE
- EXHAUSTION OF FOSSIL FUELS

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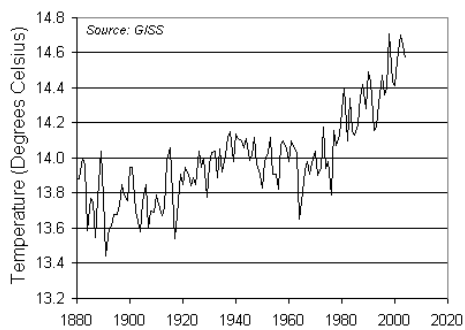
THERE IS A PLACE CALLED "AWAY"

21



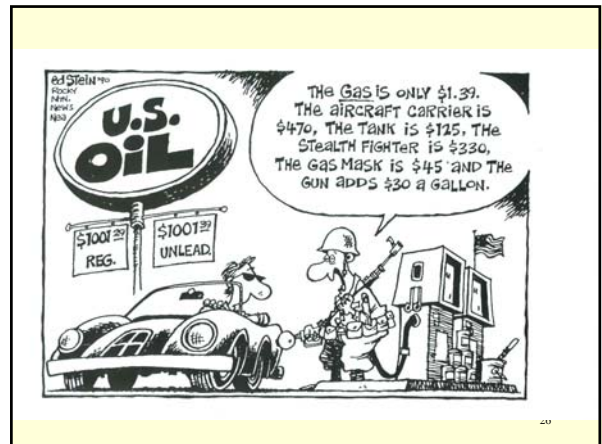
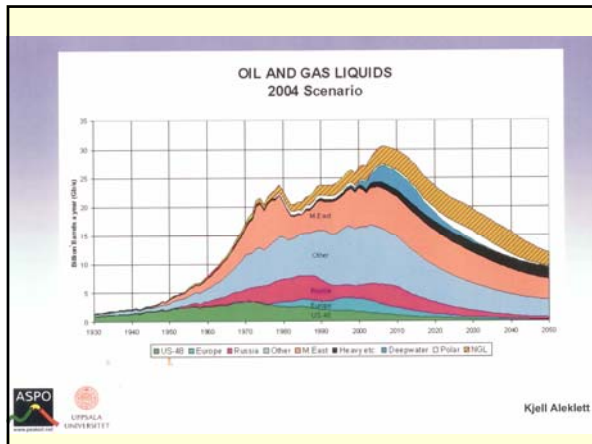
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Average Global Temperature, 1880-2004



we can always find more

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THE FREE LUNCH  
IS  
OVER

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We are caught between the  
**ROCK**  
of  
**GLOBAL WARMING**  
and the  
**HARD PLACE**  
of  
**FOSSIL FUEL EXHAUSTION**  
liquids and gases first

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But Wait I hear you cry

29

But Wait I hear you cry

After the oil is gone there is still  
lots of coal

30

But Wait I hear you cry

After the oil is gone there is still lots of coal

Can't we burn that

31

But Wait I hear you cry

After the oil is gone there is still lots of coal

Can't we burn that

Capture the carbon dioxide

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And send it

**AWAY**

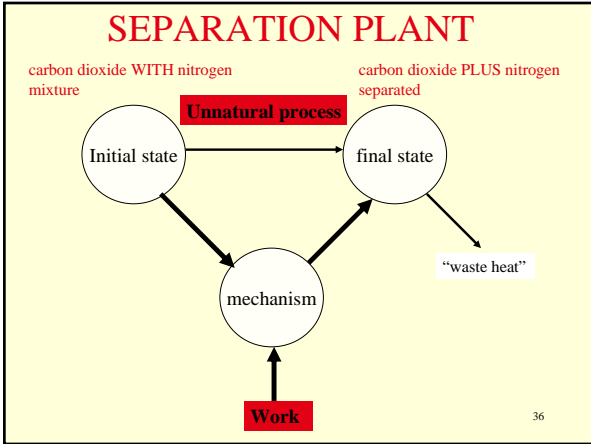
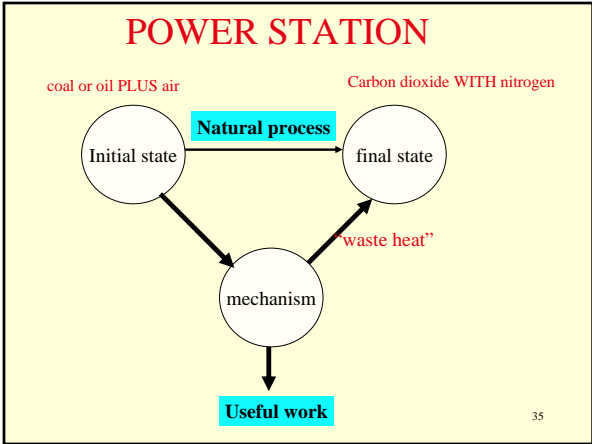
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We know a bit about separating carbon dioxide from other gases

This is common in natural gas processing where we get mixtures of methane and carbon dioxide

As at KAPUNI

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For mechanism

1:find substance that dissolves one and not the other

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For mechanism

1:find substance that dissolves one and not the other

2:Bubble mixture through solvent letting insoluble gas escape

38

For mechanism

1:find substance that dissolves one and not the other

2:Bubble mixture through solvent letting insoluble gas escape

3:Remove dissolved gas from solvent

39

For mechanism

1:find substance that dissolves one and not the other

2:Bubble mixture through solvent letting insoluble gas escape

3:Remove dissolved gas from solvent

4:recycle the solvent

40

For mechanism

1:find substance that dissolves one and not the other

2:Bubble mixture through solvent letting insoluble gas escape

3:Remove dissolved gas from solvent

4:recycle the solvent

5:liquefy the carbon dioxide

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For mechanism

1:find substance that dissolves one and not the other

2:Bubble mixture through solvent letting insoluble gas escape

3:Remove dissolved gas from solvent

4:recycle the solvent

5:liquefy the carbon dioxide

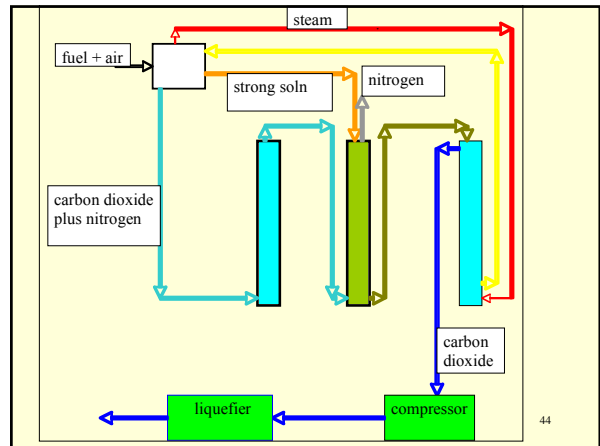
6: put it “away” somewhere

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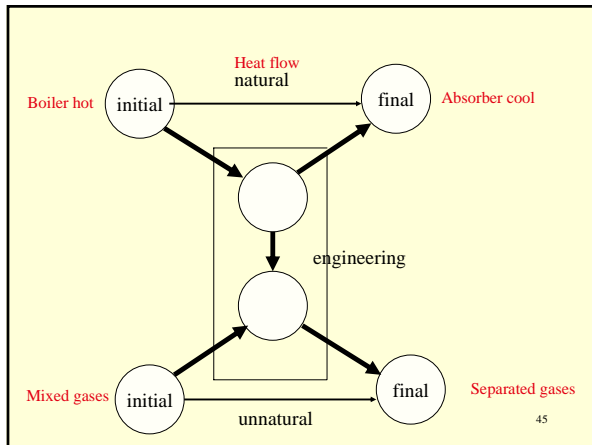
There are several solvents for carbon dioxide

The commonest in commercial use is monoethanolamine  
MEA

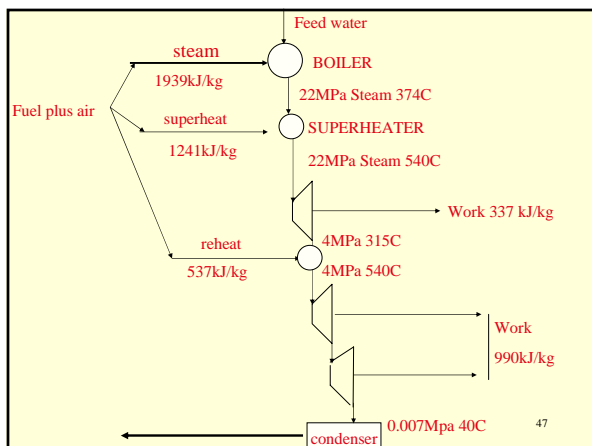
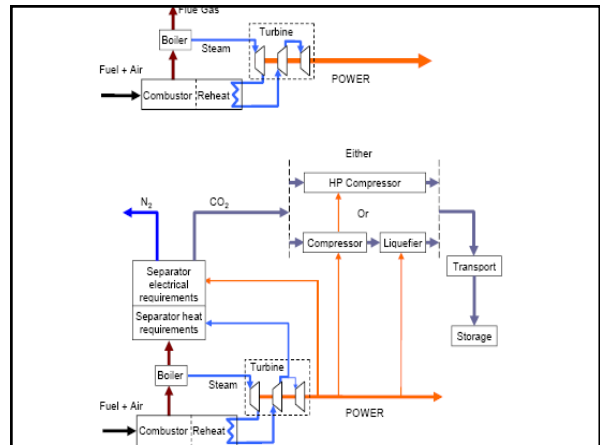
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**NOW FOR COMPARISON**  
**CHOOSE THE SAME CO2 OUTPUT**  
**BUT**  
**SEPARATE AND LIQUEFY THE CO2**

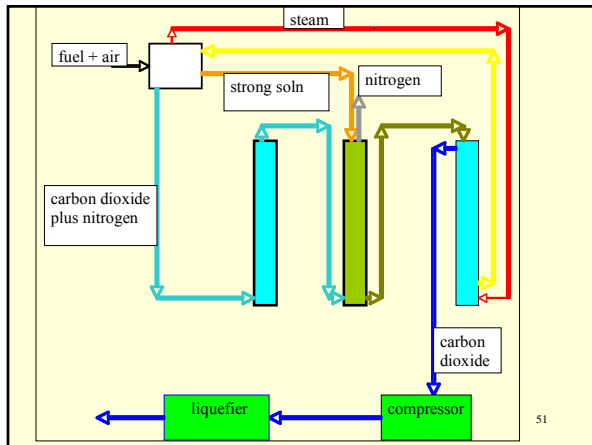
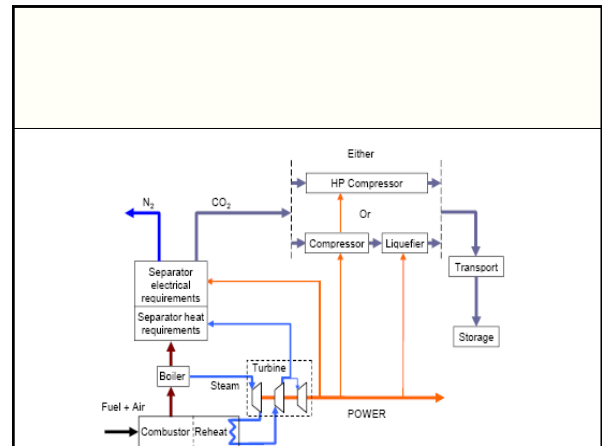
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IDEAL CASE  
MINIMUM POSSIBLE ENERGY  
ALL STEPS ISENTROPIC CONST TEMPERATURE

- UNMIX AT 300K 164 kJ/kg CO<sub>2</sub>
- COMPRESS 20 bar 169 kJ/kg CO<sub>2</sub>
- COOL to 253K 4 kJ/kg CO<sub>2</sub>
- LIQUEFY AT 253K 52 kJ/Kg CO<sub>2</sub>
- TOTAL 389 kJ/Kg CO<sub>2</sub>

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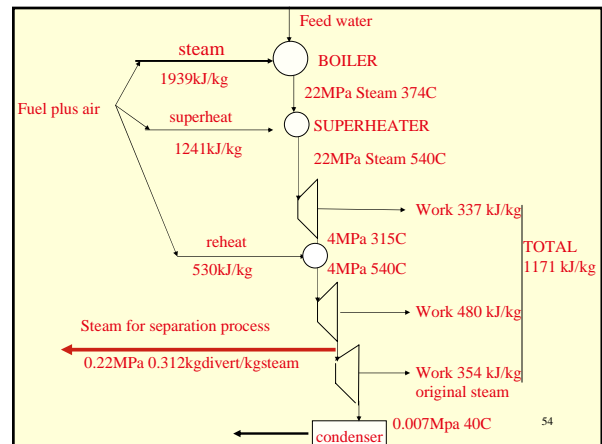
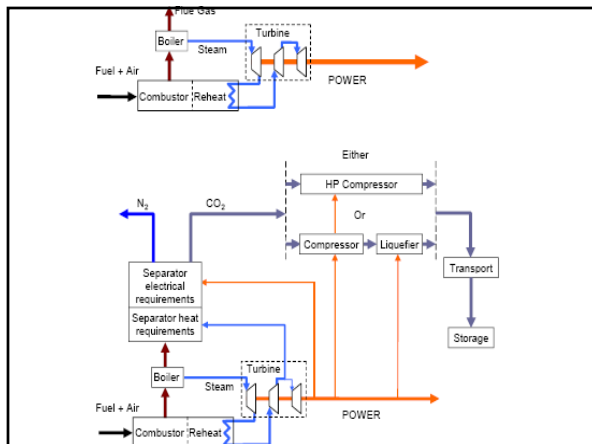
STEAM REQUIREMENT FOR SEPARATION

Minimum work required =  $xRT \ln x + (1-x)RT \ln(1-x)$  per mole of mixture  
= 216.7 k J/kg carbon dioxide

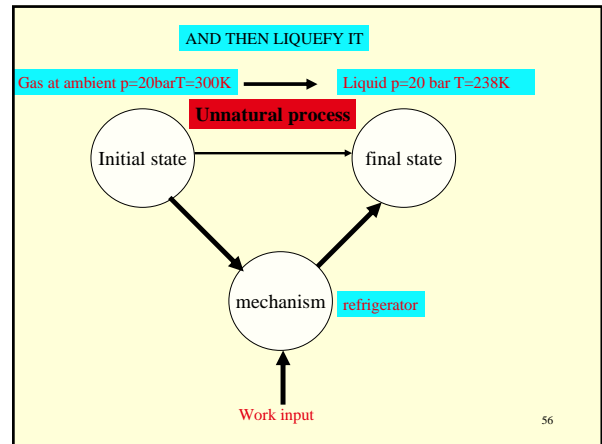
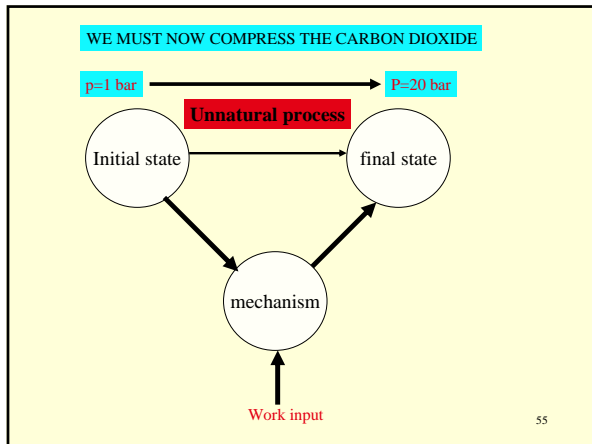
BUT BECAUSE OF THE WAY THE PROCESS IS CONDUCTED THE MINIMUM PRACTICAL STEAM REQUIREMENT IS THAT WHICH PROVIDES THE HEAT OF REACTION AT 400K

HEAT OF REACTION IS APPROX 2000 kJ/kg CO<sub>2</sub>

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**REAL CASE (LIQUEFACTION)  
USING REASONABLE EFFICIENCIES**

- UNMIX AT 300K 350-400 kJ/kg CO<sub>2</sub>
- COMPRESS 20 bar 310-320 kJ/kg CO<sub>2</sub>
- COOL to 253K AND
- LIQUEFY AT 253K 260-300 kJ/KCO<sub>2</sub>
- PARASITIC ENERGY 350-400 kJ/KCO<sub>2</sub>
- TOTAL 1270-1420 kJ/Kg CO<sub>2</sub>

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**REAL CASE(HIGH PRESSURE GAS)  
USING REASONABLE EFFICIENCIES**

- UNMIX AT 300K 350-400 kJ/kg CO<sub>2</sub>
- COMPRESS 200 bar 580-650 kJ/kg CO<sub>2</sub>
- PARASITIC ENERGY 350-400 kJ/KCO<sub>2</sub>
- TOTAL 1280-1450 kJ/Kg CO<sub>2</sub>

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**CARBON DIOXIDE/ENERGY (GCV)  
for  
VARIOUS FUEL TYPES**

- MAUI SALES GAS 52.8 g/MJ
- FUEL OIL(power stn) 72.5 g/MJ
- LIGNITE 95.2 g/MJ

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**Increase in primary fuel**

- High efficiency gas CCGT best case 11%
- Lignite mid range 55%
- Low efficiency lignite worst case 78%

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- To this must be added the energy cost of transport and sequestering
- These costs will be very case specific

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And the final question is

Where is "AWAY"?

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