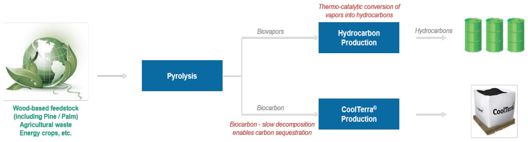
ChE-304 Problem Set 1

Week 1

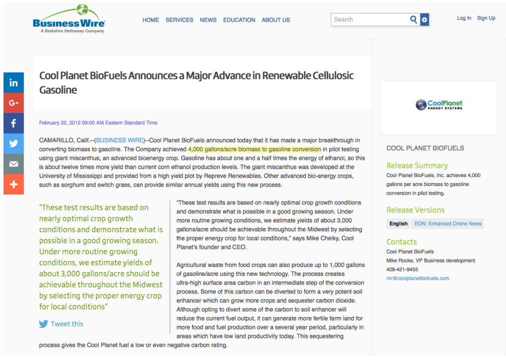
Problem 1

Every few months a new "miracle technology" appears.



Serious company: investements from BP, Google Ventures, Conoco Phillips…

Claims to produce hydrocarbons and biocarbon.



Cool Planet BioFuels Announces a Major Advance in Renewable Cellulosic Gasoline

February 22, 2012 09:00 AM Eastern Standard Time

CAMARILLO, Calif.--(BUSINESS WIRE)--Cool Planet BioFuels announced today that it has made a major breakthrough in converting biomass to gasoline. The Company achieved 4,000 gallons/acre biomass to gasoline conversion in pilot testing using giant miscanthus, an advanced bioenergy crop. Gasoline has about one and a half times the energy of ethanol, so this is about twelve times more yield than current corn ethanol production levels. The giant miscanthus was developed at the University of Mississippi and provided from a high yield plot by Repreve Renewables. Other advanced bio-energy crops, such as sorghum and switch grass, can provide similar annual yields using this new process.

"These test results are based on nearly optimal crop growth conditions and demonstrate what is possible in a good growing season. Under more routine growing conditions, we estimate yields of about 3,000 gallons/acre should be achievable throughout the Midwest by selecting the proper energy crop for local conditions"

"These test results are based on nearly optimal crop growth conditions and demonstrate what is possible in a good growing season. Under more routine growing conditions, we estimate yields of about 3,000 gallons/acre should be achievable throughout the Midwest by selecting the proper energy crop for local conditions," says Mike Cheiky, Cool Planet's founder and CEO.

Agricultural waste from food crops can also produce up to 1,000 gallons of gasoline/acre using this new technology. The process creates ultra-high surface area carbon in an intermediate step of the conversion process. Some of this carbon can be diverted to form a very potent soil enhancer which can grow more crops and sequester carbon dioxide. Although opting to divert some of the carbon to soil enhancer will reduce the current fuel output, it can generate more fertile farm land for more food and fuel production over a several year period, particularly in areas which have low land productivity today. This sequestering process gives the Cool Planet fuel a low or even negative carbon rating.

COOL PLANET BIOFUELS

Release Summary

Cool Planet BioFuels, Inc. achieves 4,000 gallons per acre biomass to gasoline conversion in pilot testing.

Release Versions

English | EON: Enhanced Online News

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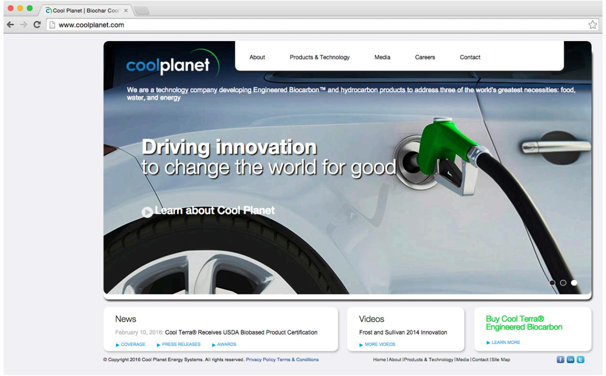

We are a technology company developing Engineered Biocarbon™ and hydrocarbon products to address three of the world's greatest necessities: food, water, and energy

February 10, 2016: Cool Terra® Receives USDA Biobased Product Certification

Frost and Sullivan 2014 Innovation

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Impressive number: **3000-4000 gallons/acre gasoline**

Should you invest?

This was a real question that William Banholzer got when he was CEO of Dow Chemical.

Hint: Let's use the first law to calculate the absolute minimum amount of biomass that would require and see if it is a realistic amount to expect from one acre…

Solution:

1^{st} Law:

$$\Delta U = Q + W \quad (\Delta E_p \text{ and } \Delta E_k \approx 0)$$

Since $P = P_{atm}$ (cst), let's use ΔH:

$$\Delta U + W_{PV} = \Delta U + P\Delta V = \Delta H = Q + W_{sh} = 0$$

$$\rightarrow \Delta H_{Biomass} = \Delta H_{Gasoline}$$

We can use HHV (reference state = fully oxidized products):

$$\Delta H_{Biomass,HHV} = \Delta H_{Gasoline,HHV}$$

$HHV_{biomass}$= 18 MJ/kg

$\text{HHV}_{\text{gasoline}}$= 47 MJ/kg

4000 gallons gas per acre ≈ 11’070 kg/acre

with HHVs:

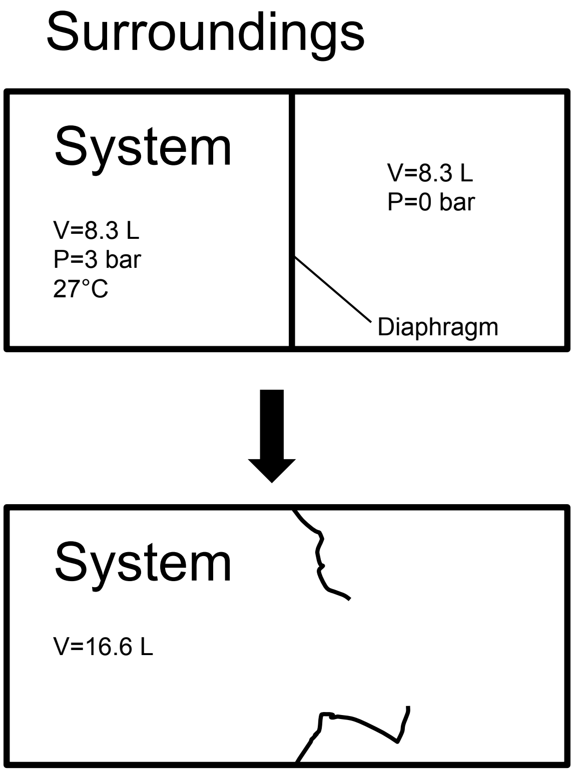
biomass needed $> 11'070\text{ kg } \times \frac{47\ MJ/kg}{18\ MJ/kg} = 28'900\ kg$

Is this realistic? This is easy to google…

No! 8-15 to/acre typical (records are around 25 to/acre)

Problem 2

Assume we have a perfectly isolated system with 1 mole of an ideal gas at a pressure P = 3 bar in a 16.6 L chamber that is isolated by a diaphragm from another 16.6 L chamber that has been evacuated. What is the change in entropy?



Reminder: for an ideal gas $U=f(T)$ only and $U \neq f(p,V)$

Solution:

This is a highly irreversible change (i.e. an explosion!). However, we can approximate this by a reversible process.

First lets explore the state change (which does not depend on whether or not the change is reversible):

We know that $\Delta U=0$ (isolated system→ no W or Q).

If $U=f(T)$ and $\Delta U=0$, then $\Delta T=0$

Therefore, we have the final T and V but we need P, we need an EOS!

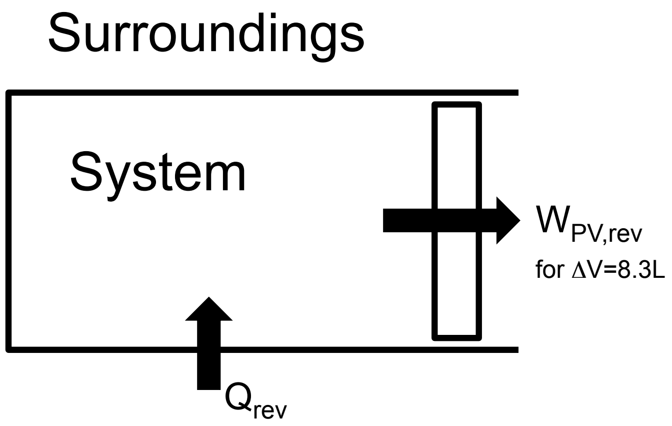
$PV=nRT$

From the ideal gas law for $\Delta T=0$

We have $p_1V_1= p_2V_2$

Therefore, for a doubling of the volume, the pressure drops by half→ p_2=1.5 bar

We now know the initial and final states! So, we can design a reversible process to go from the 1st to the 2nd stage:



Remember, $DU = 0 = Q_{rev} + W_{rev} \quad \rightarrow Q_{rev} = -W_{rev} = \int_{V_I}^{V_F} PdV = \ nRT \int_{V_I}^{V_F} \frac{dV}{V} = nRT[\ln{(V)}]_{V_I}^{V_F} = nRT \ln\left(\frac{V_F}{V_I}\right)$

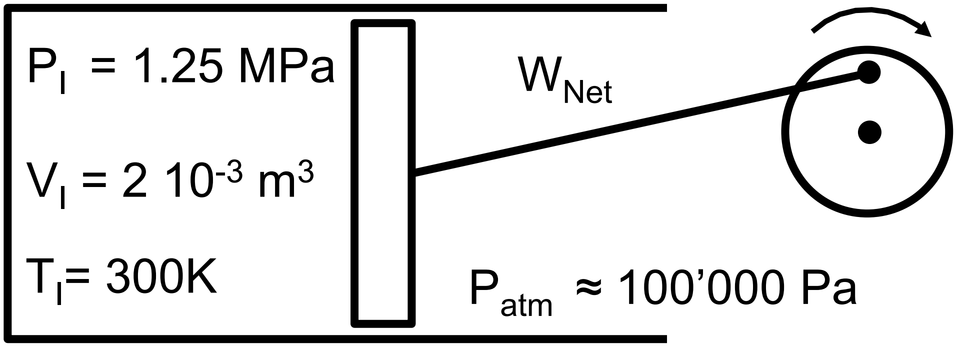
Remember that $\Delta S_{system} = S_2 - S_1 = \int_{S_1}^{S_2} \frac{dQ_{rev}}{T_{System}}$

Here T= cst → $\Delta S_{system} = \frac{1}{T_{system}} \int_{S_1}^{S_2} dQ_{rev} = \frac{Q_{rev}}{T_{system}} = nR\ \ln\left(\frac{V_F}{V_I}\right) =$

$1\,mol\,\left(8.314\ \frac{J}{mol\,K}\right)$ ln (2) = 5.8 J/K

Problem 3

In order to properly understand PV work, let's calculate the work done in a single reversible expansion stroke of a piston. In this case, the gas is air and it is assumed that it acts ideally. The expansion occurs until the gas inside the cylinder is at atmospheric pressure. You can assume that the piston and cylinder are perfectly isolating.



Recall that for an ideal gas where c_p and c_V are constant

$P_1\ V_1^k = P_2\ V_2^k$ or PV^k= constant with $k=c_p/c_V \approx 1.4$ for air

Calculate W_{Net}, as well as T_{final} and V_{final} of the gas.

Solution:

First let's calculate the total work done by the gas (eq. 1.4):

$$W_{tot} = \int_{V_I}^{V_F} PdV$$

Here P, V and T are all changing. However, $PV^k = A$ (we are calling the constant A):

$$W_{tot} = \int_{V_I}^{V_F} PdV = A\ \int_{V_I}^{V_F} \frac{dV}{V^k} = -\frac{A}{k-1}\left[\frac{1}{V^{k-1}}\right]_{V_I}^{V_F} = \frac{A}{k-1}\left[\frac{1}{{V_I}^{k-1}} - \frac{1}{{V_F}^{k-1}}\right]$$

Knowing that:

$P_I V_I^k = P_F V_F^k = A \rightarrow \frac{1}{V^k} = \frac{P}{A} \rightarrow \frac{1}{V^{k-1}} = \left(\frac{P}{A}\right)^{\frac{k-1}{k}}$ Let's use this relation in the equation above:

$$W_{tot} = \frac{A}{k-1}\left[\left(\frac{P_I}{A}\right)^{\frac{k-1}{k}} - \left(\frac{P_F}{A}\right)^{\frac{k-1}{k}}\right]$$

Now let’s take $\left(\frac{P_I}{A}\right)^{\frac{k-1}{k}}$ out of the bracket:

$$W_{tot} = \frac{A}{k-1}\left(\frac{P_I}{A}\right)^{\frac{k-1}{k}}\left[1 - \left(\frac{P_F}{P_I}\right)^{\frac{k-1}{k}}\right]$$

Let’s use $P_I V_I^k = A$

$$W_{tot} = \frac{P_I V_I^k}{k-1}\left(\frac{P_I}{P_I V_I^k}\right)^{\frac{k-1}{k}}\left[1 - \left(\frac{P_F}{P_I}\right)^{\frac{k-1}{k}}\right]$$

Simplify:

$$W_{tot} = \frac{P_I V_I^k}{k-1}\frac{1}{V_I^{k-1}}\left[1 - \left(\frac{P_F}{P_I}\right)^{\frac{k-1}{k}}\right] = \frac{P_I V_I}{k-1}\left[1 - \left(\frac{P_F}{P_I}\right)^{\frac{k-1}{k}}\right]$$

If we plug in the numbers:

$$W_{tot} = \frac{1'250'000 \ \times \ 2\,10^{-3}}{1.4-1}\left[1 - \left(\frac{100'000}{1'250'000}\right)^{\frac{0.4}{1.4}}\right] = 3213\,J$$

To this, we need to subtract the work needed to push back the atmosphere:

$$W_{PV} = \int_{V_I}^{V_F} P_{atm} dV = \ P_{atm}(V_F - V_I)$$

We need to calculate V_F:

$$P_I V_I^k = P_F V_F^k \ \rightarrow V_F = \left(\frac{P_I V_I^k}{P_F}\right)^{1/k} = \left(\frac{1250000\ (2\ 10^{-3})^{1.4}}{100000}\right)^{1/1.4} = 0.01215\,m^3 = 12.15\,l$$

$$W_{PV} = P_{atm}(V_F - V_I) = \frac{100'000(12.15-2)}{1000} = 1015\,J$$

Therefore the net work produced is:

$$W_{net} = W_{tot} - W_{PV} = 3213 - 1015 = \boldsymbol{2198\,J}$$