How is carbon stored in trees and wood products?

Science

Theory Lesson

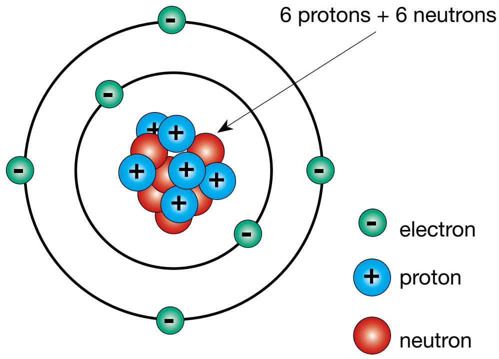
Lesson information

Level:	Junior secondary school Year 10
Duration:	Approximately 3 lessons
Summary:	Sustainably managed forests play an important role in mitigating climate change by taking carbon out of the atmosphere and storing it, as well as providing society with a natural and renewable resource. To understand how carbon is stored and cycled in trees, we need firstly to have a look at the properties of carbon. We will also learn how to use formulas for calculating carbon storage, and understand that some carbon is lost during processing and manufacturing, while most is recovered and used, then stored for the life of wood products.

Background information

Properties of carbon

Carbon is represented by the symbol ‘C’ and is the 6th element in the periodic table of elements, with an atomic number of 6 and an atomic mass of 12.001. It is a non-metal and the fourth most abundant element in our solar system, only surpassed by hydrogen, helium and oxygen. Carbon can take the form of coal, charcoal, and diamonds, and also forms the major component of all living things including trees. At atmospheric pressure carbon occurs naturally as either a solid or a gas. The melting/sublimation point of carbon is the highest of all naturally occurring elements at 3550°C.



Carbon atom

How is carbon cycled in ecosystems?

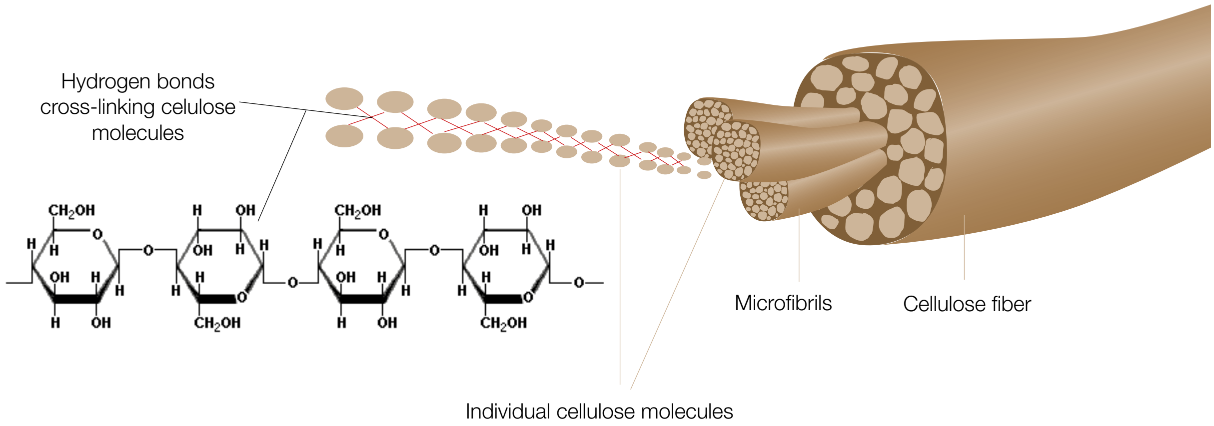
Carbon is cycled through ecosystems in several different forms. It has a tendency to be attracted to oxygen and form gaseous compounds such as carbon dioxide (CO_2) and carbon monoxide (CO) which in high concentrations can be considered air pollutants and play a role in climate change. Carbon dioxide gas can be removed from the atmosphere by trees through photosynthesis. This process involves plant cells converting the carbon from carbon dioxide to a solid form in sugars (the carbohydrates glucose and starch) that can be stored in leaves, stems, trunks, branches and roots, and contribute to tree growth. Oxygen is released back into the atmosphere as a by-product of photosynthesis which animals depend upon for survival.

The chemical formula for photosynthesis

$6\ CO_2 + 12\ H_2O$ + photons ➔ $C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$

(carbon dioxide + water + light energy ➔ glucose + oxygen + water).

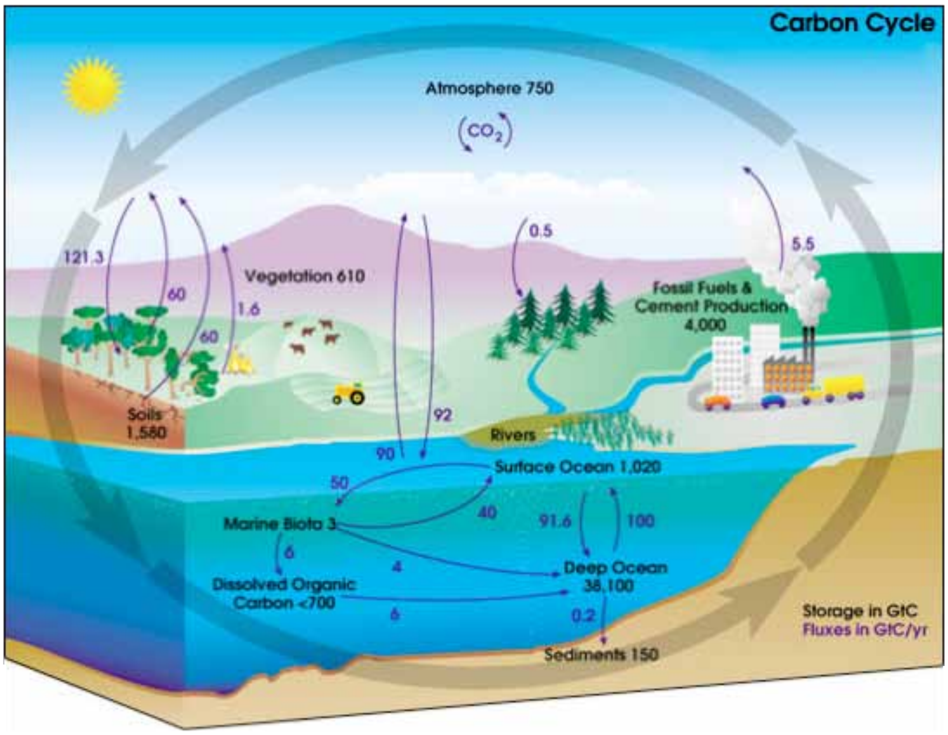
Starch is also stored in reproductive tissue including flowers, fruit, nuts, pods or cones, while glucose is used in respiration to help keep the tree alive. Cellulose is another sugar manufactured by the plant and is particularly important in plant cell walls to help maintain structure and keep plants upright. Wood is around 40% cellulose.



Structure of cellulose

The carbon cycle demonstrates the various phases of carbon through living things, the soil, water and atmosphere. If the carbon cycle was in equilibrium, the rate at which carbon is removed from stores would equal the amount being taken out of the atmosphere. The current concern about the carbon cycle is that it is considered to be out of equilibrium in response to human intervention.

The burning of fossil fuels high in carbon has disturbed the natural balance of the cycle and enhanced the rate at which carbon is returned to the gas phase. This increase in carbon gas in the atmosphere, particularly as carbon dioxide and methane, has been found to contribute to global warming and is referred to as the ‘man-made greenhouse effect’ – the process where greenhouse gases trap infrared radiation in the atmosphere and cause the earth to warm.



The Carbon Cycle:

Black numbers indicate how much carbon is stored in various reservoirs. Blue numbers indicate how much carbon moves between reservoirs each year. "GtC" stands for GigaTonnes of Carbon

(Source: New World Encyclopedia)

Why are forests and wood products important in helping tackle climate change?

Australia's annual greenhouse gas emissions were estimated at 592 million tonnes CO_2equiv per year (ABARES 2012, DCCEE 2012) and have been projected to increase to 690 million tonnes per year in 2020. Australian forests and wood products store or sequester approximately 57 million tonnes of carbon dioxide which offsets around 10% of the total greenhouse gases emitted in Australia. This takes into consideration a loss of carbon from forests each year of approximately 4.4 million tonnes due to prescribed burning, wildfires and wood harvested for energy.

Carbon constitutes approximately 50% the dry mass of trees and when wood from these trees is used to produce wood products the carbon is stored for life in that product. For framing in our homes this carbon storage is life is around 100 years, around 30 years in furniture, 30 years in railroad ties and around 6 years in pallets and paper. Carbon stored in wood is only released back to the atmosphere when the wood product is burnt or decays.

Calculating the amount of carbon stored in trees and sawn timber

The amount of carbon stored in trees depends on a number of things including tree species, growth conditions in the environment, age of tree and density of surrounding trees. There are a number of ways you can calculate the CO_2 stored in trees and in wood products depending on the available information and we're going to show you a couple of formulas Foresters use in their jobs to do just this.

Calculating CO_2 stored in trees based on mass of tree

We're going to use some assumptions for this formula. Firstly, the formula we'll use will obtain an average estimate over the life span of a sample tree, and secondly, will exclude stores in soil carbon.

Some generalisations:

- 35% of the green mass of a tree is water so 65% is solid dry mass;
- 50% of the dry mass of a tree is carbon;
- 20% of tree biomass is below ground level in roots so a multiplication factor of 120% is used; and
- To determine the equivalent amount of carbon dioxide, the carbon figure is multiplied by a factor of 3.67.

CO_2 sequestered per tree (kg) =
Tree mass (kg of fresh biomass) x 65% (dry mass) x 50% (carbon %) x 3.67 x 120%

Example:
For a 12 year old spotted gum tree weighing 600kg green, then the amount of CO_2 sequestered by the entire tree = 600kg x 65% x 50% x 3.67 x 120% = 859 kg CO_2 or 72 kg CO_2 /yr

The example above assumed the mass of the tree was 600kg. But what if you don't know the mass of the tree and need to calculate this in order to determine the CO_2 stored?

The mass of a tree can be estimated using parameters of volume and wood density.

Tree mass (kg) = Volume of the tree (m^3) x density of wood (kg/m^3)

Firstly standing tree volume needs to be calculated, and this can be done using formulas for either cone shaped or cylindrical shaped trees and by measuring diameter. The diameter can be measured at breast height of the tree which is approximately 1.3m above ground level.

Volume (m^3) =

Tree height (m) x diameter^2 (m^2) x 0.7854)/3
(for conical shaped trees e.g. pines)

OR

Tree height (m) x diameter^2 x 0.7854
(for cylindrical shaped trees e.g. eucalypts)

Once you've got your volume you can then use an average dry oven density of 700 kg/m^3 for hardwood eucalypts of and 400 kg/m^3 for softwood pine to calculate the tree mass.

Example: For a eucalypt tree of height 8 metres with a diameter of 40cm, the volume would equal 8m x 0.4m^2 x 0.7854 = 1.0 m^3.

- The tree mass can be estimated at 1m^3 x 700kg/m^3 = 700 kg.
- The amount of carbon dioxide sequestered in this tree would therefore be 700kg x 65% x 50% x 120% x 3.67= 1002 kg of CO_2 or 1.002 tonnes

Finally if you would like to know the CO_2 sequestered per tree per year you need to look at the CO_2 and divide it by the age of the tree.

CO_2 sequestered per tree per year (kg) = X / age of the tree (yrs)

Calculating amount of CO_2 stored in construction timber

The amount of carbon in sawn timber logs can be calculated using average rates of recovery after processing which is estimated at around 35% for hardwoods such as eucalypts, and 50% for softwoods such as pine.

The standard moisture content for air dried timber (and wood products) is 12% or another way to look at it is that 88% of moisture has been removed.

So to calculate the CO_2 in construction timber the variables you need is the air dry mass of the log, the percentage of moisture removed and the recovery rate.

CO_2 sequestered in construction timber **(kg) = air dry mass of saw log (kg) x 88% (oven dry mass) x 50% (carbon %) x 3.67 x recovery rate (%)**

Example: For a 150 kg white cypress saw log (softwood) seasoned in a timber yard then processed into square posts, the amount of carbon sequestered in the timber posts = 150kg x 88% x 50% x 3.67 x 50% = 84.8 kg carbon dioxide

The remaining mill waste from processing has various uses such as providing sawdust for the manufacture of engineered wood products and biomass for renewable energy production.

Woody stem showing annual growth rings.

Using annual growth rings to estimate tree age

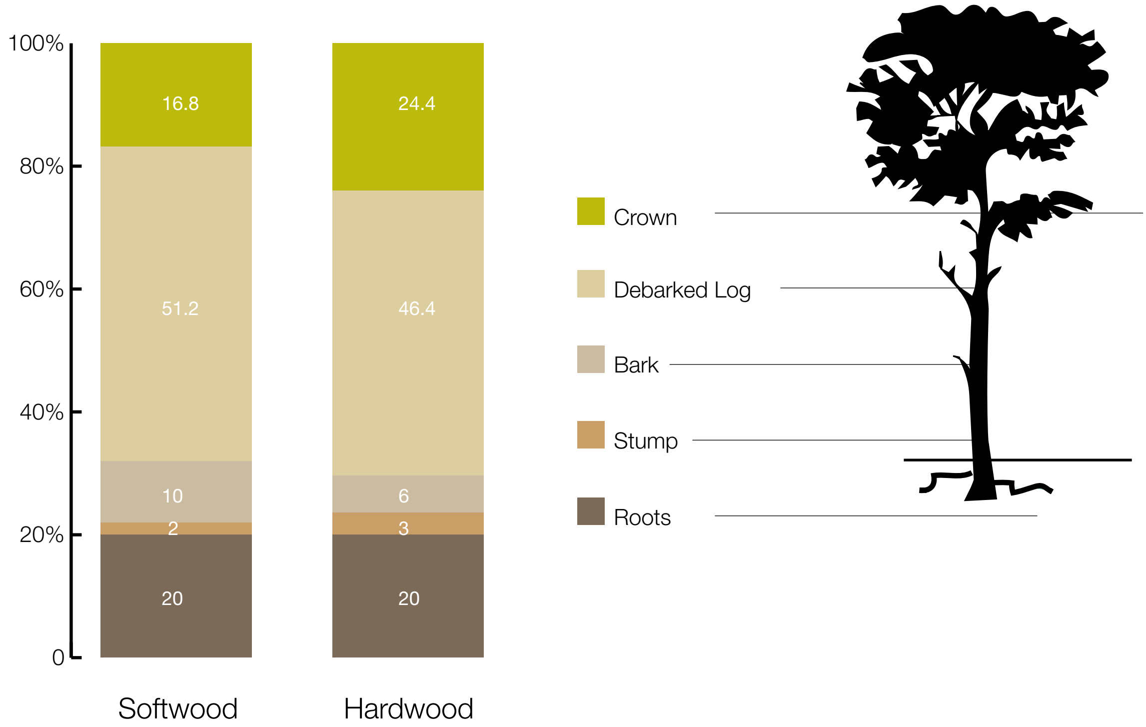
An increase in tree height and canopy cover is not the only indication of tree growth. The age of a cut tree can be determined by growth rings, where each year there forms a new layer of conductive tissue known as xylem. Tree growth occurs outwards from around the centre of the tree, so the rings nearest the centre are the oldest."

Newly felled saw logs awaiting pickup

Wooden beams for use in construction

Carbon distribution throughout a tree

Carbon stores in tree biomass are distributed in different proportions throughout the tree in the stump, trunk (bark and debarked log), crown and roots as shown below, and differ for softwood and hardwood species. You can use the average percentages below to understand the carbon stored in tree biomass.

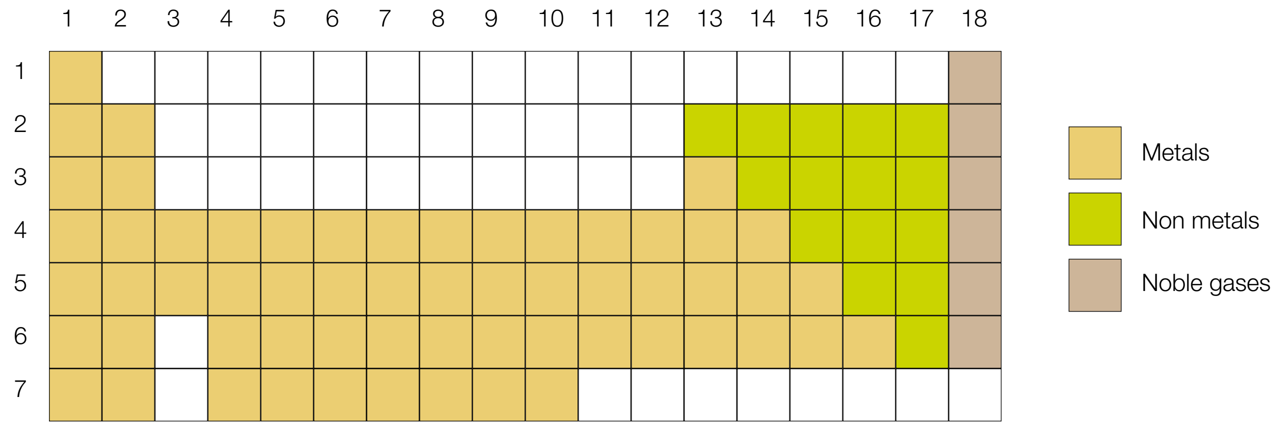


Conclusion

- Carbon is cycled through ecosystems in several different forms, but mainly CO_2 (carbon dioxide gas).
- Some CO_2 is removed from the atmosphere by trees through the process of photosynthesis using light energy from the sun.
- Australian forests and wood products store or sequester approximately 57 million tonnes of CO_2 which offsets around 10% of the total greenhouse gases emitted in Australia.
- Carbon constitutes approximately 50% the dry mass of trees and when wood from these trees is used in wood products, the carbon is stored for the life of that product.
- There are different formulas you can use to determine the CO_2 sequestered in trees and in wood products.

Questions

1. Indicate and label where carbon is placed on the following representation of the periodic table



2. Is carbon a metal, non-metal, halogen or noble gas?

3. What is the name and symbol of the major greenhouse gas removed by trees from the atmosphere in the process of photosynthesis?

4. How does this gas contribute to global warming in the atmosphere?

5. Write the chemical formula for photosynthesis.

Problems to solve

1. Calculate the amount of CO_2 sequestered during the growth of a spotted gum eucalypt plantation forest on an annual basis (per year) using the equations provided. Based on the forest being 12 years of age, 200 hectares in size at a thinned density of 650 trees/hectare, and each tree having an above ground green mass of 600 kg.

2. How much CO_2 would be sequestered in a sawn hardwood timber beam processed from a log of diameter 50 centimetres and length of 8 metres using a recovery rate of 35%. Use equations provided and show all working out.

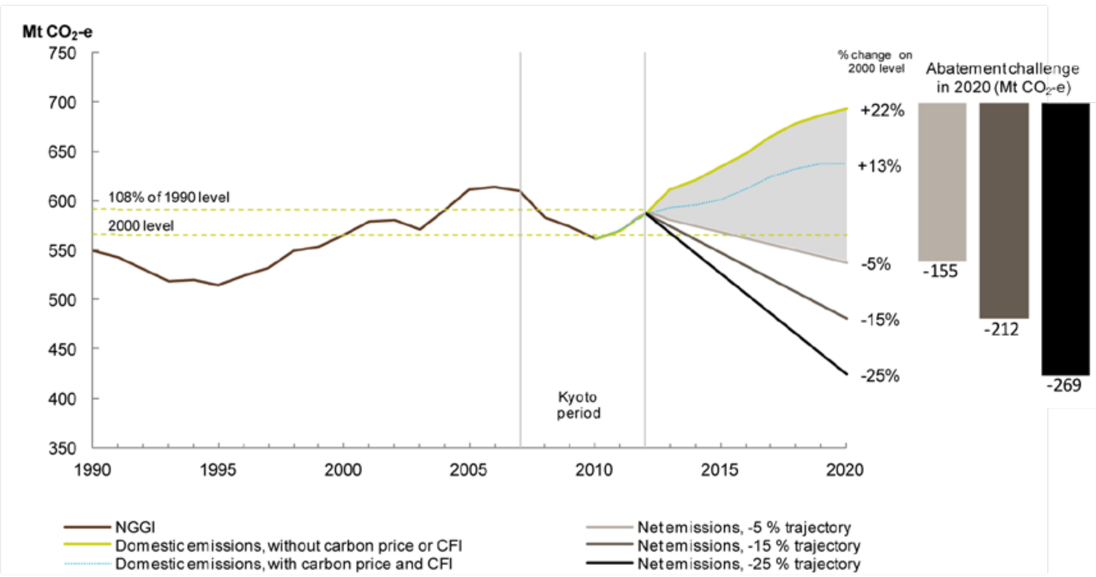
3. What proportion of biomass (%) of a hardwood tree would you expect to find in the trunk after the bark has been removed for log production?

Class activities

1. Calculate the amount of carbon dioxide stored in a tree on your school grounds. First find the diameter of the tree (m) and estimate the height (m) so you can work out the volume of the tree. Assume average density of either 700 kg/m^3 for hardwood eucalypts of and 400 kg/m^3 for softwood pine to calculate the tree mass, that can then be substituted into the formula.

2. Australia's annual greenhouse gas emissions were estimated at 592 million tonnes and have been projected to increase to 690 million tonnes in 2020. Urgent action is required to reduce emissions. Research and discuss measures that could be taken to reduce greenhouse gas emissions including industry actions and personal actions.

Australia's emissions trends, 1990 to 2020

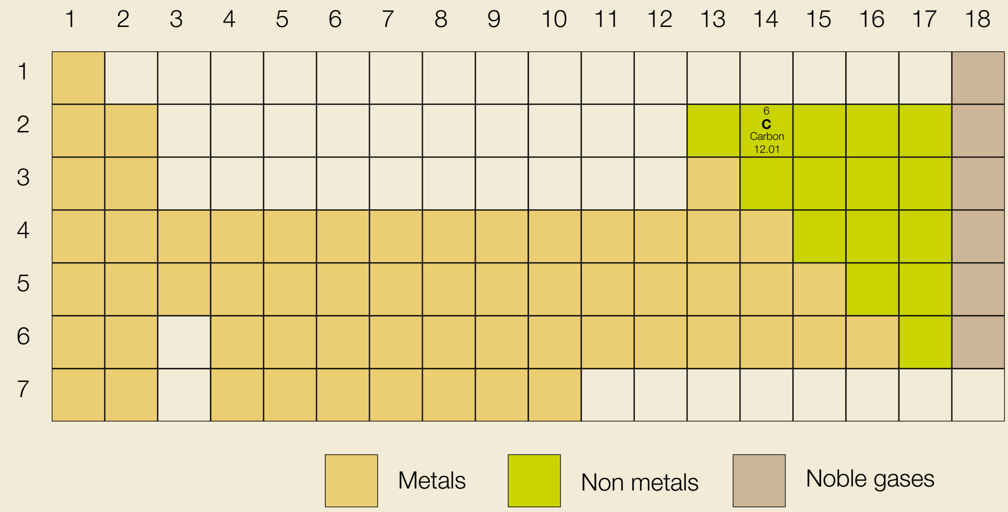


Note: Trajectories to the 2020 target range are illustrative; they begin in 2012 and assume a straight line reduction to the target. The Government will set the actual trajectory following advice from the Climate Change Authority.

source: DCCEE 2012

ANSWERS to Questions

1.



2. Non-metal

3. Carbon dioxide; CO_2

4. Carbon dioxide in the atmosphere traps infrared radiation, affecting global temperature. When the concentration of carbon dioxide in the atmosphere becomes higher than the rate at which it is sequestered or broken down at the earth's surface, this contributes to global warming.

5. $6\ CO_2 + 12\ H_2O + \text{photons} \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$
(carbon dioxide + water + light energy ➔ glucose + oxygen + water).

ANSWERS to Problems

1. Amount of CO_2 stored per tree =
600 kg x 65% x 50% x 3.67 x 120 = 859 kg CO_2/tree

Forest is 200 ha x density of 650 trees/ha = 130,000 trees

The carbon dioxide sequestered =
(0.859 tonnes CO_2/tree x 130,000 trees)/12 years =
111,670 tonnes CO_2/12 years = 9,306 tonnes CO_2/yr

2. Volume of tree = 8m x 0.52 x 0.7854 = 1.57m^3

Tree mass = 1.57m^3 x 700 kg/m^3 = 1099 kg

Carbon dioxide stored tree =
1099kg x 65% x 50% x 120% x 3.67 = 1,573 tonnes CO_2

Carbon dioxide stored in hardwood beam if 35% recovery = 550.5 kg CO_2

3. 35%

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