Energy and CO_2 Advantages of Wood for Sustainable Buildings

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Abstract:

This paper demonstrates the advantages of using wood materials for the design of sustainable buildings in New Zealand, providing national benefits of reducing fossil fuel energy consumption and CO_2 emissions. The relationship between fossil fuel energy consumption and CO_2 emissions is described, along with the importance of forestry in helping countries like New Zealand to meet their Kyoto Protocol obligations.

Wood-based building materials have much less embodied energy than other materials, but this paper shows that the biggest advantage of using wood is the opportunity for recovering solar energy from wood waste, a significantly greater benefit than both the stored carbon and the low embodied energy in wood materials, combined. This energy can be used in place of fossil fuel energy, hence reducing CO_2 emissions. Wood waste can come from all stages of harvesting and processing, and construction and demolition of timber buildings.

The paper describes current assessment tools for sustainable buildings. Compared with other materials, wood-based building materials score very highly for most sustainability criteria, but are penalised in the proposed New Zealand sustainability assessment scheme which places too little emphasis on energy consumption and CO_2 emissions in the life cycle assessment of building materials.

This paper also describes opportunities for much greater use of timber and engineered wood products in large buildings, using innovative technologies for creating high quality buildings with large open spaces, excellent living and working environments, and resistance to hazards such as earthquakes, fires and extreme weather events.

1. Sustainability

The objective of this paper is to demonstrate major advantages of wood over other building materials, considering the sustainability criteria of energy use and CO_2 emissions. The paper explores the extent to which current assessment tools for green and sustainable buildings are able to acknowledge these advantages.

1.1 Sustainability Objectives

In the relatively new area of sustainable building design, a key question is "how *green* and *sustainable* are different building materials?" or "how do building materials stress the planet?" The answer, of course, is "it all depends". It depends on many factors including:

- the source and production of the materials
- the type and construction and use of the building
- the definitions of *green* and *sustainable*

Many different criteria are being developed for sustainable building design, in many countries of the world. Most assessment tools consider the following topics:

- Building materials
- Energy use
- Use of water (for operating the building; for manufacturing materials)
- The environment surrounding the building, biodiversity
- The health and well-being of building users
- Costs of constructing, maintaining, moving or demolishing the building
- Future-proofing, to allow future changes of use with minimal impact

This paper cannot consider all these topics. It is limited to a brief comparison of building materials, with emphasis on energy consumption and CO_2 emissions.

1.2 Building Materials

The most commonly quoted sustainability criteria for selection of building materials is that they should score well in most or all of the following areas. Materials should be:

- Renewable
- Low energy
- Low CO_2 emissions
- Sourced locally
- Reusable and recyclable
- Minimum waste
- Non-polluting

The use of wood in timber buildings fits well with most of the above criteria. Wood is a renewable resource, containing a large quantity of solar energy, hence requiring low amounts of fossil fuel for manufacturing, and providing an independent source of energy when waste wood is burned. Using waste wood for energy production results in reduced use of fossil fuel, compared with recycling of metals and glass which use additional fossil fuel energy. Energy from waste wood is solar energy which has been stored in the wood for a few years.

Wood is often sourced locally, although is sometimes transported around the world, so the energy implications of long distance shipping need to be investigated. Wood can be recycled, but not in the extensive manner of meltable materials like metals and glass. Modern timber construction produces little waste, but that produced can be burned for energy. The production of wood is generally non-polluting at all stages although there have been problems in the past with polluted sites from chemical preservative processes.

There have been many international studies investigating the amount of energy required to manufacture building materials. The best figures in New Zealand are those from Alcorn [1]. Some of that energy comes from hydro or geothermal electricity, and some from burning of fossil fuel, with very little from burning of wood waste. Burning of fossil fuels is associated with increasing levels of carbon dioxide CO_2 in the atmosphere. It is possible to calculate the fossil fuel component of energy used to make building materials, and the building industry is searching for ways to reduce such emissions.

2 Forestry and the Kyoto Protocol

It is well known that trees absorb carbon from the atmosphere, some of which is retained in wood and wood products, and that carbon absorbed by forests can be used to offset emissions of carbon dioxide from burning of fossil fuels [2]. Hence some countries are using commercial forestry to help meet their Kyoto Protocol commitments. In order to maximize the benefit from the carbon pool in forests, it is not only necessary to make new plantings every year, but also necessary to ensure that existing forest cover remains in place in perpetuity, either managed for timber production or as a protected forest [3].

Carbon retained in timber buildings or other wood products might also be used to offset CO_2 emissions from burning fossil fuels, depending on changes to the Harvested Wood Product (HWP) rules set under the UN's Kyoto protocol. The current HWP assumption is that all carbon in a forest is "instantly oxidised" at harvest – a simplistic and incorrect assumption in the Kyoto accounting system.

For a country like New Zealand, it is clearly in the national interest for there to be a large and continuing investment in plantation forestry, with most of those forests remaining as production forests in perpetuity. There have been major discussions between the government and the forest owners to try to find market-related measures to make this happen, but a positive outcome is not very likely in the short term [4].

The annual harvest of plantation wood in New Zealand is currently around 20 million m^3, yielding about 4.5 million m^3 of sawn timber, the balance going to plywood and MDF production, pulp and paper, or being exported as logs [5]. Given that one cubic metre of radiata pine wood contains about 210 kg of elemental carbon, equivalent to 0.73 tonnes of CO_2, the current annual log harvest amounts to around 14.7 million tonnes of CO_2 sequestered from the atmosphere, with a similar amount left behind as harvesting residues on the forest floor or in the ground as roots and stumps. The government's wood availability forecasts (based on age class distribution of the existing plantation estate) show the annual harvest increasing to 30 million m^3 per year within the next decade (assuming replanting of the existing estate but no new plantings), equivalent to around 22.7 million tonnes of sequestered CO_2. The Australian situation is different but the same principles apply [6].

The biggest long term contribution of forestry to Kyoto commitments is to burn wood or wood waste for energy, instead of burning fossil fuel. The CO_2 emissions from burning of wood are not a greenhouse gas problem like burning of fossil fuel because the energy from wood is simply renewable solar energy which has been stored in the wood for a few decades, and the release of CO_2 is part of a natural cycle which will occur anyway. Energy from wood waste can be a by-product of increased use of wood as a building material, as explored further below.

3. CO_2 Emissions and Energy Issues for Building Materials

Considering global CO_2 emissions, the main benefits of using more timber as a building material are:

1. An increase in the pool of carbon in wood and wood products
2. Reduction of fossil fuel use in manufacturing wood rather than more energy intensive materials such as steel, concrete and aluminium (less embodied energy)
3. Displacement of fossil fuel by burning of wood waste materials

Two other areas of energy use in buildings need to be considered:

4. Fossil fuel energy used for heating and cooling over the life of the building
5. Fossil fuel energy used in constructing the building

3.1 Carbon Stored in Materials and Released During Manufacture

The most often quoted reason for building in wood, from a climate change perspective, is the increase in the pool of carbon stored in wood and wood products. The carbon sink for wood and wood products in new New Zealand buildings is roughly half a million tonnes of CO_2 per year [7], but this benefit is small compared with items 2 and 3 listed above. The carbon is only stored for the life of the building and returns to the atmosphere when timber buildings are finally demolished, and the wood decays or is burned.

The manufacturing of some materials results in a chemical release of CO_2 to the atmosphere. This is a particular problem for manufacturing of cement where the process of converting limestone to quick-lime gives CO_2 emissions of about 0.5 tonnes of CO_2 per tonne of cement [8]. This needs to be included in any assessment of the greenhouse gas implications of building materials.

3.2 Embodied Energy

"Embodied energy" is the energy required to manufacture building materials. The fossil fuel component of embodied energy results in CO_2 emissions. Estimates of embodied energy are available for New Zealand building materials [1]. A recent BRANZ report [8] shows that embodied energy is up to 9% of lifetime energy use for several New Zealand buildings. This percentage will increase as new buildings become more thermally efficient.

The amount of fossil fuel energy used to manufacture all building materials is steadily reducing. Modern steel mills, aluminium smelters and cement plants use less energy than earlier ones. Modern cement plants use dry technology which requires much less energy than the traditional wet cake process, and an increasing trend to burn wood waste to provide renewable energy. A complete energy balance and a CO_2 balance considers the lifetime use of different building materials, considering such issues as cement and aggregate production, use of recycled steel, and the transportation of materials [12].

Because of the large amount of stored solar energy in wood, it takes less energy to manufacture logs into timber than to manufacture materials like cement and concrete, and much less than most metallic materials such as steel and aluminium, depending on the proportion of recycled product in each material. Many medium sized wood processing plants in New Zealand are close to energy-neutral, operating on-site combined heat and power plants driven by steam boilers fired by wood residues, so that the embodied energy in sawn and processed wood from such plants is not obtained from fossil fuel. The only significant embodied energy derived from fossil fuel is then the component from harvesting and trucking which uses diesel fuel. Data on this energy is increasingly available from Life Cycle Inventory (LCI) databases for most materials. Comparisons of total embodied energy for several alternative building designs are available for New Zealand [7], USA [9, 10], and Europe [9].

3.3 Energy from Wood Waste

The best way to use plantation forestry to reduce fossil fuel CO_2 emissions is to burn wood or wood waste for energy, as a significant by-product from greater use of wood as a construction material. Alternatively, increased availability of wood as a building material may be seen as a significant by-product of woody biomass fuel production. The resulting energy is solar energy which has been stored in the wood for a few decades. As shown in Figure 1, the wood or wood waste may come from many different parts of the wood chain, including

- Forest harvesting
- Wood processing
- Waste on the construction site
- Demolition of the building

The benefits of these energy sources have been demonstrated in recent European studies, considering many different options. Energy recovery from wood waste has been investigated for alternative forestry scenarios, with and without timber buildings as part of the cascade chain [13]. There will be continuing debate as to how much of the logging site waste can be recovered as fuel. Wood residues at sawmills and processing plants have been used in this way for many years. One issue which needs consideration in New Zealand is the relatively high proportion of construction timber which has been chemically treated with wood preservatives.

The easiest way to use energy from wood waste is as a heating fuel, but conversion of wood waste into liquid or gaseous fuels for transport and other uses is being seriously investigated. The energy available from wood waste needs to be assessed at all steps in the New Zealand forestry, construction and demolition industries, along with the resulting reductions in fossil fuel use and carbon emissions.

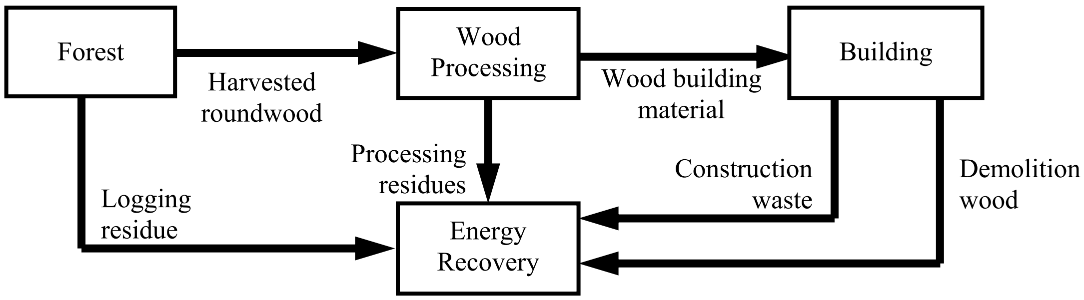

Figure 1. Schematic flow chart of wood materials during the building lifecycle [11].

3.4 Heating and Cooling Energy

Space heating is the largest use of energy for the thermally inefficient buildings found in many parts of New Zealand. Over the life of a building this energy may be much larger than the embodied energy in the materials. However, heating and cooling energy use is dropping because modern buildings of all materials are using more insulation for higher thermal efficiency, and new designs make use of "passive solar architecture" to entrain and store solar energy in parts of the building, which will make embodied energy more important in the future. The reinforced concrete industry is quick to promote the benefits of concrete as a good thermal storage material, and some timber buildings may have components such as ceramic tiles or concrete-timber composite floors designed to store energy. Thermal storage is not needed if buildings have sufficient thermal insulation, and new research is showing that buildings with exposed wood interiors may be much more thermally efficient than previously thought, because of moisture movement in and out of the wood surfaces during heating and cooling (L.Bellamy, pers.com).

Recent international studies into comparative building materials assume that the heating and cooling energy can be designed to be the same for all materials, over the life of the building [11]. More research is needed into innovative methods of reducing energy requirements for heating and cooling of all buildings, with thermal insulation, passive solar architecture and use of wood waste energy.

3.5 Construction Energy

The energy required to construct a building is not highly dependant on the building materials. Construction site energy has been estimated to be only 5% to 10% of embodied energy in materials [11]. Most studies into comparative building materials assume that the construction energy is the same for all materials. No analysis of construction site energy in New Zealand is known.

4. Environmental Assessment Tools for Buildings

There are a large number of new organisations and related environmental assessment tools for buildings [14]. In New Zealand there are two main organisations working in this area:

- The New Zealand Green Building Council www.nzgbc.org.nz
- Beacon Pathway www.beaconpathway.co.nz

Some of the most often quoted international assessment tools are:

- LEED (US) www.usgbc.org
- Green Globes(US) www.thegbi.org
- BREeam (UK) www.breeam.org.uk
- Athena (Canada) www.athenasmi.ca
- BASIX (Australia) www.basix.nsw.gov.au
- Green Star (Australia) www.gbcaus.org

4.1 New Zealand Green Building Council

The NZ Green Building Council www.nzgbc.org.nz has been modifying the Australian Green Star tool for use in New Zealand, initially with office buildings, as *Green Star NZ – Office Design*. It is highly desirable that there be only one widely accepted assessment tool in New Zealand, other than the proliferation of tools in some other countries. In due course there will be a process whereby the NZ Green Building Council will certify designs and award ratings (for categories 4, 5 or 6 stars). To use *Green Star* it is necessary to assign a large number of *category points* in each of 8 main topic areas shown in Table 1. The *Green Star* spreadsheet modifies these with *environmental weighting* to provide a *single score* which leads to a *Green Star Rating* for the building.

Topic	Points	Weighting	Notes
Management	14	10%	Plans for environmental mgt in design and use
Indoor environment quality	26	20%	Ventilation, noise, indoor air quality
Energy	34	20%	
Reduced energy use	15	8.8%	Improved energy efficiency of the building
CO_2 emissions	10	5.9%	On site energy generation
Energy management	9	5.3%	Switching, metering, reduced peak load
Transport	11	10%	
Car parking	3	2.7%	Reduced provision of car parking, small spaces
Cycling	3	2.7%	Bicycle parking facilities
Public transport	5	4.5%	Access to public transport
Water consumption	12	15%	Use of rainwater, recycled water, efficient plumbing
Materials	25	10%	
Recycling office waste	2	0.8%	Floor space provided for recycling of waste
Reuse of materials	6	2.4%	Reuse of façade materials or building structure
Integrated fit out	3	1.2%	Reduced waste during fit out
Recycled aggregate	3	1.2%	Applies if concrete > 1% of total contract value
Recycled steel	2	0.8%	Applies if steel > 1% of total contract value
Sustainable timber	2	0.8%	All timber recycled or FSC certified
Other materials	7	2.8%	No asbestos, good carpets, paints etc
Land use and ecology	8	10%	Improved ecological value of site, surrounding land.
Emissions	12	5%	Reduced waste water, lighting & cooling emissions. Not $_{CO2}$ emissions.
TOTAL	142	100%	
Innovation	5		Not clear how innovation points are included

Table 1. **Summary of scoring system in *Green Star NZ – Office Design*** (adapted from NZGBC website, 10 Jan 2006).

The scoring system in *Green Star NZ – Office Design* is in draft form, and subject to change. Some of the embedded calculation tools do not work properly and the derivations are not clear to the user. Table 1 shows that the assessment scheme covers a very large number of topics, such that the individual weightings for many separate topics are very low.

The main category of interest to this paper is **Energy** which surprisingly has a weighting of only 20%. A major deficiency is that embodied energy in building materials and energy obtained from burning construction waste are not included anywhere. Embodied energy will become increasingly important relative to heating and cooling energy as all buildings become more energy efficient. For embodied energy and resulting CO_2 emissions, the recent BRANZ report [8] has shown that it is not difficult for a quantity surveyor to include these items, with a small addition to the normal schedule of quantities which is routinely available for most new buildings. The carbon pool in building materials can be handled in the same way. In the **Energy** category CO_2 emissions are only included explicitly in the 6% encouragement for on-site energy generation. Burning of wood wastes to replace fossil fuel energy should be included in this topic, as described elsewhere in this paper.

The **Transport** category is concerned with reducing energy use and CO_2 emissions, by encouraging the use of small cars, cycling and public transport. There is no recognition of the reduced transport energy benefits of locally-sourced materials.

In the **Materials** category there are points available for many small benefits. It can be seen that if all the steel is from a recycled source, all the concrete aggregate is recycled and all the timber is recycled or from renewable forests (eco-certified by the Forest Stewardship Council, FSC) the total combined benefits are less than 3% of the total score. In order to get all these points it is only necessary to use a small quantity of each material. There is no mention of the greatly reduced CO_2 emissions from timber cladding compared with bricks, or timber window frames compared with aluminium, both of which should be included, for example. The significant CO_2 emissions in the manufacture of cement are not accounted for, as recycled aggregate does not result in any less cement in concrete.

The **Water** category only considers water consumption in the use of the building, with no account of water used or wasted in manufacturing of materials, where forests have a very positive benefit compared with other materials.

4.2 Life Cycle Assessment

Some organizations promote more comprehensive tools for full Life Cycle Assessment (LCA), which can be carried out for the materials, the building components, or for the whole building. If these are to become widely used in New Zealand, it is important that there is agreement on which tools to use and how they will relate to the *Green Star* tools. Some LCA tools include the following:

- Athena Environmental Impact Estimator www.athenasmi.ca
- Envest (UK) http://envestv2.bre.co.uk/
- BEES (US) www.bfrl.nist.gov/oae/software/bees.html

4.3 Defining System Boundaries

When assessing impacts of alternative building materials, it is important to be clear about the system boundaries, to compare "like with like". Ideally the time phases should include the entire building process from planning to recycling, including:

- Planning
- Design
- Sourcing of materials
- Construction
- Operation of the building
- Refurbishment
- Demolition
- Recycling

Environmental impacts during sourcing of materials are critical for many building materials. Assessment tools must consider the whole-of-life sequence of events on the same basis for all materials. For wood this includes:

- Obtaining suitable land
- Planting, growing, harvesting trees
- Transporting logs and forest products
- Processing of structural and non-structural wood components
- Timber treatment (chemical preservatives)

There may be a very different list for other building materials, so the system boundaries must be kept uniform.

4.4 Consideration of wood materials

Some assessment tools have been criticised for not fairly comparing the entire life cycle of building materials such as wood, in Australia [6], the USA [15 – 17] and Europe [14]. The European studies are have the most comprehensive analysis of benefits accruing from energy derived from wood waste.

5. Case Study: BRANZ report E408

A recent report from BRANZ [8] studies the potential for increased use of wood in New Zealand government buildings. This is a very thorough and useful report, although it does not cover all areas addressed in this paper.

The report investigates two single-storey buildings; a school gymnasium and a small medical centre. Each of the building was designed three times, once each with steel, concrete and timber structural members. Full costing and material quantities were assessed for each option. The report includes excellent notes on a number of alternative environmental assessment schemes for buildings of this type, along with quantification of the embodied energy and stored carbon in each building.

5.1 Embodied Energy

In the initial construction phase, the timber option used considerably less energy to manufacture the building materials, resulting in less embodied energy. This reduced energy usage, combined with a larger amount of stored carbon, gave CO_2 emissions about half of those for the concrete and steel buildings.

5.2 Lifetime Energy

A serious problem with this report is that the thermal design of the timber buildings was inadequate, leading to a poorly insulated building. Hence a 50 year assessment of energy requirements for heating and cooling shows much larger energy use in the timber building than in the concrete or steel buildings. The calculated CO_2 emissions over the 50 year life, including the construction phase, is such that any benefit of lower embodied energy at the construction stage is cancelled out by the poor thermal design, and all three designs have approximately equal CO_2 emissions over the 50 year life.

When considering costs of construction, the timber building had cheaper initial cost, but was more expensive to heat, again because of the inadequate thermal design.

5.3 Items Not Included

The BRANZ report made no attempt to quantify the energy available from burning of wood waste, yet European studies show that with regard to fossil fuel energy use and CO_2 emissions, the beneficial effects of burning wood waste are much greater than the combined benefits from carbon storage and lower embodied energy in wood-based materials.

The report does not include multi-storey timber buildings, so an analysis of new and conventional styles of multi-storey timber buildings will be carried out at the University of Canterbury in 2007.

5.4 International Case Studies

International case studies are beginning to appear. Comparisons have been made between timber, concrete and steel houses in the USA [9], and between four storey timber and concrete apartment buildings in Sweden and Finland [11]. The Scandinavian studies have included detailed investigation of energy from waste wood.

6. Opportunities for Increased Use of Timber in Buildings

There are many opportunities for increased use of timber in buildings in New Zealand, and many potential benefits including those outlined above. A few of these opportunities are described below:

6.1 Conventional Timber Construction

A recent BRANZ report [18] investigates the potential for greater use of timber in government and private sector buildings in New Zealand, identifying half a million square metres floor area of eligible projects each year, with modest carbon dioxide emission savings of 64,000 tonnes per year. An earlier investigation [7] considered a scenario where up to half of all New Zealand apartment, hotel and motel buildings could be constructed with light timber framing, ten percent of commercial office buildings built with glulam or LVL frames, half of industrial buildings with a timber structure, and at least half of all new houses could have increased use of timber in floors, windows and other components.

This scenario results in reduced CO_2 emissions (over three quarters from house construction) most from displacement of energy intensive brick cladding and aluminium windows with wood products, the balance being displacement of steel and concrete structural members by wood in a variety of buildings. The scenario assumed no changes in the energy used for heating and cooling of buildings. This scenario has a 20% decrease in energy needed for manufacture of building materials, with the 6.7 PJ decrease in fossil fuel use being 1.5% of the total national consumption. The predicted 500,000 tonne reduction in atmospheric carbon dioxide emissions is 20% of that used for the manufacture of building materials, but only 0.8% of the national total emissions of 62 million tonnes, small but a step in the right direction.

This scenario requires a 17% increase wood use and results in a corresponding 17% increase in temporary carbon storage. The additional wood needed for construction could easily be made available from current exports which are about half of national production.

6.2 New Forms of Timber Construction

New forms of timber construction being developed at the University of Canterbury have the potential to revolutionise large scale timber buildings. The new technology can be used for single storey industrial buildings or 2 to 6 storey multi-storey timber buildings [19]. All these buildings will have:

- Heavy timber beams, columns, or walls
- Large structural members prefabricated off site
- Main timber structure of glulam or LVL members
- Post-tensioned connections for easy buildability and high seismic resistance
- Removable partitions and cladding
- Timber-concrete composite floors

The performance requirements for these buildings will be:

- Wide open spaces, with maximum flexibility of use
- Residential, educational or commercial uses, which can be changed over time
- Safety in fire, earthquakes, or extreme weather events
- Excellent acoustic performance
- Excellent thermal behaviour
- Durability for hundreds of years
- All the sustainability benefits of wood
    - Low energy, CO_2 emissions
    - Recyclable, non-polluting etc

The wood quantities, costs, and energy benefits of these new types of buildings have yet to be analysed in detail. The buildings will be attractive and functional as well as being more green and sustainable than traditional building construction.

7. Conclusions

1. This paper demonstrates major advantages of wood over other building materials, leading to national reductions in fossil fuel use and CO_2 emissions The main component, in increasing priority, are:

- An increase in the pool of carbon in wood and wood products
- Less embodied energy in wood than in many other materials.
- Displacement of fossil fuel by burning of wood waste materials

Recent European studies show that the benefit from the third bullet point is greater than the other two combined.

2. The currently proposed sustainability assessment schemes for buildings in NZ have:

- Too little attention to energy and CO_2 issues
- No consideration of embodied energy in building materials
- No recognition of the potential for extracting solar energy from wood waste

3. There are huge opportunities and benefits for new forms of timber buildings. The main benefits are:

- New forms of industrial and multi-storey timber buildings
- Large potential markets in New Zealand and internationally
- High added value to NZ timber resources now being exported as logs
- More forests will be planted to service the demand
- Greatly reduced fossil fuel energy use and CO_2 emissions in the long term

4. The best way to reduce CO_2 emissions is to move from fossil fuel to renewable energy. This should include forestry to produce wood as a storage medium for solar energy. New Zealand would be much better placed to meet its Kyoto obligations with:

- More trees,
    - more managed forests,
        - more bio-energy from wood
            - more timber buildings

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