Composites' impact on the Energy Efficiency in the industry sector

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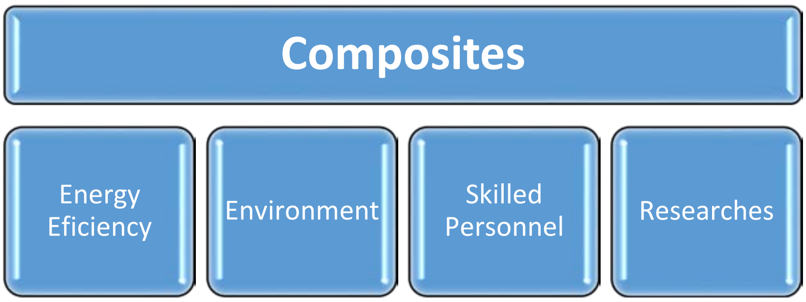

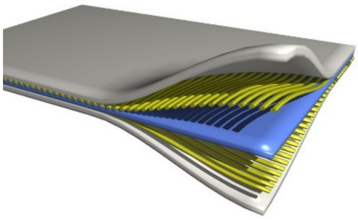

***Composite Materials** is One of solutions for energy issues and challenges*

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1. Introduction:

The concept of *energy efficiency* has been developed since the first energy crisis in 1973. Lovins (1976) was among the first to develop a definition of energy efficiency: using less energy to produce greater economic output. It can be expressed as a ratio of useful outputs to energy inputs for a system. (1)

Energy intensity is a widely used indicator to measure energy efficiency, generally defined as primary energy consumption per unit of economic output. It is usually expressed as tonnes of oil equivalent (toe), or tonnes of coal equivalent (TCE), or mega joules per thousand dollars of GDP (1).

Energy efficiency contributes to climate change mitigation via reducing energy consumptions and hence GHG (Greenhouse Gas) emissions. Improving energy efficiency has widely been accepted as a cost-effective approach to mitigating GHG emissions. In its Fifth Assessment Report, the IPCC 2014 (Intergovernmental Panel on Climate Change) shows that energy efficiency plays the second largest role in attaining climate stabilization targets up to 2030.

In its World Energy Outlook, the IEA (2013) estimates that in 2020, energy efficiency will be responsible for 50 % of the energy-related CO2 emissions abatement necessary to bring down CO2 concentration to the level compatible with limiting the long-term temperature increase to 2 °C, which is equivalent to 450 CO2 ppm.

The IEA (2013) proposed a scenario to reduce 5.9 Gt of GHG emissions between 2010 and 2030 by using eight measures. Energy efficiency which is the most effective measure to GHG emission reduction contributes to 42 % (Fig. 1).

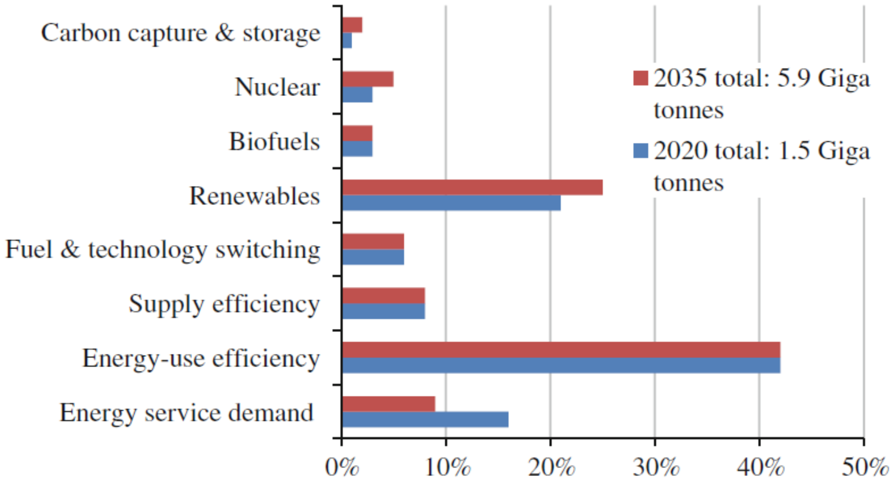


Fig. 1. Projection of GHG emission reduction by technologies (from IEA data 2013) (1)

Energy-efficient technologies refer to technologies that reduce the amount of energy required to provide goods and services. For example, home insulation technology allows a building to use less heating and cooling energy to achieve and maintain a comfortable temperature.

Improvements in energy efficiency are generally achieved by adopting a more efficient technologies or production processes or by application of commonly accepted methods to reduce energy losses. (2)

For example, using *carbon fiber and lighter metals*, manufacturers have managed to reduce the weight of cars while maintaining durability and strength. Engines in lighter vehicles operate more efficiently than engines of the same size in heavier vehicles.

One of solutions for energy issues and challenges is composite materials.

2. Energy & Energy Efficiency Challenges: (2)

The epic challenge of the 21st century is filling the gap between energy supply and demand with clean, reliable and inexpensive energy. Despite extraordinary advances in technology, rapid economic growth in countries like China and India will require more energy. Some solutions are being implemented today, but many will come from the next generation of entrepreneurs, engineers and scientists.

In order to rise to this grand challenge, we must consider the following issues: (2)

I. Encouraging Growth of Alternative Energy Sources:

Many research aims to be sustainable and economically competitive with today's fossil fuels. While alternative energy resources such as wind, solar and biofuels appear to be among the most promising, significant breakthroughs are still required to make them viable sources of future energy supply. The wind blows where and when it wants. Similarly, the sun only shines during the day and is most intense in sparsely populated areas. How do we effectively transport this energy from such remote areas to big cities? How can we efficiently store energy generated during the day for use in homes at night? The challenge will be to bridge these supply limitations with a 24-hour demand for electricity throughout the world. This means making our electricity grid more efficient and streamlined while developing storage systems to allow wind and solar energy to be saved for times of peak use.

Another source of future alternative energy may come from the world's vast reserves of natural gas.

It is likely that meeting tomorrow's energy needs will require not just one but all of these alternatives working alongside traditional fossil fuels.

II. New Transportation Technologies:

A large portion of the oil produced globally is directly processed into transportation fuels like gasoline and diesel. These fuels dominate the transportation industry because they combine reliability, affordability and performance. But, large swings in gasoline prices at the pump during the past few years are growing symptoms of this century's energy challenge. In order to meet surging demand over the next 50 years, alternatives to these transportation technologies are vital.

Among the alternatives being considered is equipping vehicles with the ability to consume clean and affordable natural gas. Already a proven technology, many challenges still remain—pipelines, service stations, and vehicles must all be adapted to accommodate the fuel. It will also be important to develop cutting-edge electric cars to offset the demand for gasoline and diesel fuel. Eventually, refueling your car may be as easy as plugging it into to an electrical outlet in your garage. On the distant frontier of alternative transportation technologies are novel ideas such as the use of algae or other micro-organisms to convert the sun's energy into liquid fuel that can be used like oil. Another emerging technology involves hydrogen-powered cars that transform hydrogen into electricity. The major promise of this technology is that water is the only waste product released. Scientific breakthroughs in these areas are still required to make these technologies competitive with today's fuels.

III. Reducing Environmental Impact:

Already great strides have been made to ensure that oil and gas producers make as little impact as possible on the natural environments in which they operate. This includes drilling multiple wells from a single location or pad to minimize damages to the surface, employing environmentally sound chemicals to stimulate well production, and ensuring a seamless transition from the wellhead to the consumer.

Another major environmental obstacle to low-impact fossil fuel production is the highly intensive process of mining coal. Currently, coal-powered plants are one of the largest sources of electricity in the world. *The transition to cleaner sources of energy such as wind, solar and natural gas will reduce the impact of coal production on the environment.*

Substantial work will be required to address the impact of oil and gas consumption, notably the emission of carbon dioxide as a major byproduct. Among the proposed solutions to this problem is the sequestration, or storage, of carbon dioxide in old oil and gas fields. Storage of carbon dioxide from power plants and other industrial facilities would require collecting and processing the gas, compressing it to high pressures, and then injecting it into the small spaces between rock grains deep below the surface. Here, the key challenge is capturing and storing the CO2 emissions on a sustainable scale. Can we store enough CO2 to realize a meaningful reduction in emissions released to the environment? How do we best collect CO2 released as a byproduct of various industrial processes? Can we do this in a reliable and cheap manner? How do we ensure that once it is stored, it will not be released into the atmosphere again? Ultimately, reducing emissions will require storing carbon dioxide, developing new alternative sources of energy and, perhaps most importantly, using less.

IV. Increasing Energy Efficiency:

Meeting energy demand over the next century will require not just producing more, but also *using what we do produce more efficiently* while supplying consumers with affordable energy to allow them to maintain a comfortable standard of living. *New technologies and new cultural habits will be needed.* Electricity generated on the wind-swept prairies must be carried efficiently to houses and businesses in cities. Doing so remains difficult, since a large portion of useable electricity is lost to heat as it travels long distances through wires and cables. *By improving efficiency, less total energy will be needed to power everything we use.* Accordingly, scientists are working to streamline the electricity grid, modernizing transmission cables with new materials that allow electrons to move more easily, producing less waste.

Another energy-saving efficiency can be found in hybrid cars. These cars capture a portion of the energy traditionally wasted as heat from friction between the tires and brakes. In hybrid cars, this contact recycles some of that wasted energy into electricity that can then offset some of the gasoline used in the car’s engine.

Becoming more energy efficient will also require us to change how our buildings are made, how we heat our homes, and how we light our classrooms.

V. Skilled personnel - Recruiting the Next Generation of Engineers and Scientists:

Over the next 10 years, a large number of people in the energy industry will retire. But their retirement will not lessen the growing demand for affordable, reliable and clean energy. Accordingly, *new engineers and scientists will be needed in every discipline***.** This new wave of young minds will have to take on larger roles and bigger projects earlier in their careers than their predecessors, making *the transfer of knowledge and ideas from one generation to the next a top priority in the coming years*

VI. Energy Sustainability: Will We Run Out of Fossil Fuels?

Most of the world’s energy needs are met through fossil fuels such as coal, oil and natural gas. Fossil fuels are nonrenewable resources, and demand for this energy is projected to increase. While there is enough supply for several more decades, what will happen when it starts running low? How will we keep the air clean with increased usage? There are ways to reduce waste and use existing technologies to keep the air cleaner by reducing fossil fuels emissions. Options like these are part of a concept called energy sustainability.

Energy sustainability is about finding the balance between a growing economy, the need for environmental protection and social responsibilities in order to provide an improved quality of life for current and future generations. In short, it is meeting the needs of the present without compromising the needs of the future.

Energy sustainability can inspire technical innovation with an environmentally conscious mindset. Regulations designed to reduce air, water and waste emissions from energy-related activities such as coal mining and electricity generation also help with energy sustainability, as do people who conserve energy.

3. Composite Materials & Energy:

3.1. Introduction:

The United Nations Climate Change Conference held in Paris at the end of 2015 was hailed as a major victory, bringing about a global agreement between 55 countries to reduce the effects of climate change by limiting global warming to less than 2 degrees Celsius and to accomplish zero greenhouse gas emissions between 2030 and 2050 (3).

Greenhouse gases absorb infrared radiation, trapping heat in the atmosphere, thus creating the greenhouse gas effect which leads to global warming. *Sixty-five percent of greenhouse gas is carbon dioxide pumped into the environment through the burning of fossil fuels and industry processes*, particularly in the production of electricity and heat.

There is no disputing that *the main solution for offsetting global warming is to increase the use of renewable energy sources*; sources which exist freely in nature, never run out and are eco-friendly. The research and development of solar power, wind power, hydroelectricity and bio-fuel alternatives are crucial.

Likewise, *the use of **composites** in renewable energy will play an increasingly vital role through the manufacture of structures which enable the harnessing of sustainable energy sources.* Factors such as the reduced weight compared to metallic structures, lower transportation and erection costs, and most importantly, lower maintenance costs over the lifespan of the structure are already positioning composites as a de facto material enabling economical solutions to large scale projects (3).

Lightweight, high-strength, and high-stiffness composite materials have been identified as a key cross-cutting technology in U.S. clean energy manufacturing with the potential to reinvent an energy efficient transportation sector, enable efficient power generation, provide new mechanisms for storing and transporting reduced carbon fuels, and increase renewable power production. In order to fulfill this promise, advanced manufacturing techniques are required that will enable an expansion of cost- competitive production at commercial volumes. This Technology Assessment identifies where manufacturing operations – from constituent materials production to final composite structure – can benefit from technological advances. By reaching cost and performance targets at required production volumes, these advances have the potential to transform supply chains for these clean energy and associated markets. (4)

Typically, a *composite material* is made of reinforcement and a matrix. The reinforcement material provides the mechanical strength and transfers loads in the composite. The matrix binds and maintains the alignment or spacing of the reinforcement material and protects the reinforcement from abrasion or the environment.

These lightweight composites enable many applications where the potential *energy savings and carbon emissions reduction* occurs in the use phase. Primary examples of these use phase savings derive from opportunities such as fuel savings in lighter weight vehicles, efficient operation at a lower installed cost in wind turbines that displace non-renewable energy sources, and use of compressed gas tanks for natural gas and, ultimately, hydrogen as fuels storage with lower environmental impact than petroleum-derived fuels

Resin and fibers can be combined in a multitude of ways and further processed through a series of forming and consolidation steps. The specific manufacturing technique is dependent on the resin material, the shape and size of the component, and the structural properties required by the end use application. This technology assessment will address limitations to material, manufacturing and recycling processes to make FRP composites for several critical clean energy applications. *FRP composites for automotive, wind turbine blade, and compressed gas storage applications are highlighted as primary examples for clean energy applications*, but are not exhaustive. There are other applications including industrial equipment and components such as heat exchangers and pipelines, geothermal energy production, structural materials for buildings, fly-wheels for electricity grid stability, hydrokinetic power generation, support structures for solar systems, shipping containers and other systems which can also benefit from lower cost, high strength and stiffness, corrosion resistant, and lightweight composite materials to impact national energy goals.

One industry analysis predicts the global carbon fiber polymer composite market alone to grow to $25.2 billion by 20206 and, in the next 10 years, there is a projected growth of 310% growth in carbon fiber use in industrial applications—primarily for energy applications. Research will be needed to overcome the challenges associated with advanced carbon FRP composite materials and their manufacture. *High priority challenges include the high cost, low production speed, energy intensity of composite materials, recyclability as well as improved design, modeling, and inspection tools.* Addressing the technical challenges may enable U.S. manufacturers to capture a larger share of the high-value-added segment of the composites market and could support domestic manufacturing competitiveness. (4)

3.2. Potential of FRP Composites for Clean Energy Applications: (4,5)

- **Transport:**

Lightweighting is an important end-use energy efficiency strategy in transportation.

For example, a 10% reduction in vehicle weight can improve fuel efficiency by an estimated 6%–8% for conventional internal combustion engines, or increase the range of a battery-electric vehicle by up to 10%.11

A 10% reduction in the weight of all vehicles in the U.S. car and light-duty truck fleet could result in a 1.06 quad (1.12 exajoule [EJ]) annual reduction in energy use and a 72 million metric ton (MMT) reduction in CO2 emissions.

The DOE Vehicles Technology Office (VTO) estimates savings of more than 5 billion gallons (19 billion liters) of fuel annually by 2030 if one quarter of the U.S. light duty fleet utilizes lightweight components and high-efficiency engines enabled by advanced materials.

- **Wind Turbines:**

Supplying 20% of U.S. electricity from wind could reduce carbon dioxide emissions from electricity generation by 825 million metric tons by 2030.

In wind energy, high strength and stiffness, fatigue-resistant lightweight materials like carbon fiber composites *can support development of lighter, longer blades and increased power generation.* In addition, "using lighter blades reduces the load-carrying requirements for the entire supporting structure and saves total costs far beyond the material savings of the blades alone." Not only could there be cost savings for land-based wind applications by reducing the structure of the turbine tower, but significant savings in reducing the support structure for offshore wind applications, where larger more efficient turbines are possible.

While high performance carbon fiber has been used for highly loaded areas (i.e. spar caps) by some manufacturers, glass fiber composites with lower specific properties are the dominant materials for the overall blade due to lower cost. Capital cost of turbine structures and blade is a significant contributor to the levelized cost of electricity (LCOE) for wind generation. As a result, *any enhancement in structural properties of materials must be balanced against the increased cost, to ensure the overall system costs do not increase disproportionately with the increased power capacity and energy production.*

For longer blades, the use of carbon fiber is favorable due to the possible weight reduction of the blade. One study estimates a 28% reduction for a 100m carbon fiber spar cap blade design compared to the glass fiber equivalent. Materials account for similar relative proportion of cost based on models by Sandia National Laboratory for a 100m all glass (72%) or all carbon (75%) blade; however, carbon fiber cost would need to drop 34% to be competitive. A combination of material optimization and lower costs could enable use of carbon fiber in future blades.

- **Compressed Gas Storage:**

According to an analysis by the Fuel Cell Technologies Office (FCTO), fuel cell electric vehicles using hydrogen can reduce oil consumption in the light-duty vehicle fleet by more than 95% compared to today's gasoline internal combustion engine vehicles; by more than 85% compared to advanced gasoline hybrid electric vehicles; and by more than 80% compared to advanced plug-in hybrid electric vehicles. *Full commercialization of fuel cell systems using hydrogen will require advances in hydrogen storage technologies including lightweighting and cost reduction.*

- **Industrial and Other Applications:**

Industrial applications also merit some review.

According to the World ***Corrosion*** Organization, the annual cost of corrosion and its prevention worldwide is $2.2 trillion, more than 3% of the world's economy, and a 2002 study by the Federal Highway Administration estimated U.S. corrosion costs at approximately 3.1% of GDP, approximately $276 billion at that time.

CFRP composites offer corrosion resistance and could potentially replace metals in structures such as tanks, piping, cooling towers, and railcars used for chemical transport and other applications.

In addition to being lightweight, the ability to withstand corrosive environments has led to increased use of composites in deep-water drilling and hydraulic fracturing.

The lightweight composites can enable energy savings in applications where large amounts of energy use and carbon emissions occur in the use phase, such as fuel savings in lighter-weight vehicles.

Other energy benefits of FRP composites include more-efficient wind turbine operation at a lower installed cost, and compressed gas storage tanks for natural gas (and ultimately, hydrogen) that enable increased use of fuels with a lower life cycle environmental impact. Lower cost, high strength and stiffness, corrosion resistant, and lightweight composite materials could also provide benefits in diverse applications including industrial equipment and components, pipelines, structural materials for buildings, fly-wheels for energy storage, support structures for solar energy systems, shipping containers, and continued use of FRP composites in aerospace applications.

These lightweight materials may deliver energy savings during the use phase or facilitate performance that cannot be attained with materials that do not have such high strength and stiffness characteristics.

One important advantage of composite materials such as CFRP composites is that the material properties can be tailored to the application. Unlike most metals and ceramics that are isotropic (the mechanical properties are the same in all orientations), composites can be anisotropic, which results in a different response to the applied force depending on fiber orientation and load direction.

The applications for composite materials have become more diverse and the market has grown significantly.

Research will be needed to overcome the challenges associated with carbon FRP composite materials and their manufacture, including high costs, low production speeds, high energy intensity, and poor recyclability as well as needs for improved design, modeling, and inspection tools.

3.3. Barriers to Increased Utilization of Composites in Clean Energy Applications: (4)

Responses to a Request for Information (RFI) released by U.S. Department of Energy (DOE) Advanced Manufacturing Office (AMO) in 2013 indicated that *the top five most important R&D areas for composites are:*

- high speed production (low cycle times);
- low cost production (noted by respondents as highly connected to production speed);
- *energy efficient manufacturing;*
- recycling/downcycling technologies;
- innovative design concepts.

Additional obstacles identified in this assessment include unproven crashworthiness for composite parts, *a lack of design tools, sunk capital in other technologies, workforce resistance, a lack of standards, a lack of assured supply, insufficient repairability, and poor compatibility with commodity resin systems.*

Energy Intensity Barrier:

The Life cycle energy analysis of composite materials includes four stages of a life cycle: (6)

1. material production phase,
2. manufacturing phase,
3. use phase,
4. end-of-life phase.

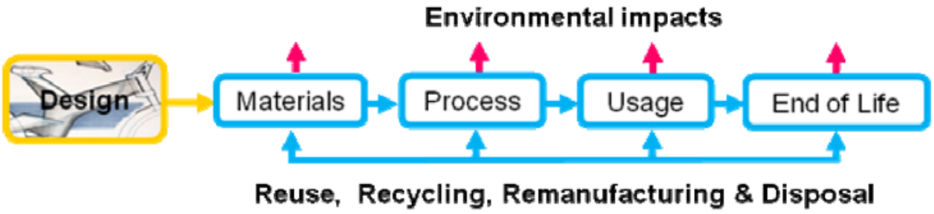
Cost estimation models (CEMs) indicate that composite structures may be cost-effective in some applications because they can eliminate large assembly costs. (6)

Such a cost reduction can lead to expanding application areas of composite structures.

Additional motivations for composite use might come from its environmentally benign aspects, i.e., energy savings and emission reduction during the use phase.

LCA Life cycle assessment is a useful technique for estimating the environmental performance of products, materials, and services from extraction of raw materials to final disposal, which encompasses extraction, materials processing, manufacturing, transport, use, re-use, maintenance, and recycling. (6)

Life cycle assessment aims at offering a systematic view of product and process evaluation by tracking down the major inputs and outputs of materials and energy, identifying and quantifying the energy and material uses, and assessing the environmental impact



Product life cycle stages

Figure 2. (7)

Life-cycle energy advantages are a balance between energy-intensive advanced composites production and the energy savings and greenhouse gas emissions reductions that mainly occur in the application end-use phase, such as from fuel savings in lightweight vehicles.

Manufacturing energy intensity can be an important barrier in the overall life cycle energy balance.

One study estimates that carbon fiber composites are three to five times more energy intensive than conventional steel on a weight basis.

As a result of the highly energy-intensive manufacturing process, it can take years before the use phase energy benefits of lightweight composites offset the added manufacturing energy. This tradeoff is explored for adoption of CFRP composites in light-duty vehicles in the *Novel Low-Cost Carbon Fibers for High-Volume Automotive Applications* case study. (5)

Conventional steel is produced by well-established processes that have undergone over 150 years of optimization and energy intensity improvements, while FRP composites are currently produced by relatively new processes that have promising opportunities for optimization and energy intensity improvements. Raw materials for reinforcement and matrix constituents are often derived from energy-intensive petroleum processing, and high temperatures are required in the manufacture of both carbon and glass fibers.

To reduce the energy intensity of FRP composites, high-quality, lower energy raw materials and lower energy production technologies are needed.

Figure 3 (5) illustrates potential energy savings opportunities in the fabrication of 1 kg of carbon fiber-reinforced polymer composite based on a review of state-of-the-art and applied R&D technologies under development. It is noted that manufacturing energy intensity—and therefore the magnitude of potential savings opportunities—depends strongly on fabrication parameters such as component design, fiber content, use of recycled material, choice of matrix polymer, and consolidation method. In addition, life cycle energy benefits for lightweighting depend on factors such as substitution factors and use phase parameters such as vehicle travel distance. *A key goal of the recently announced Institute for Advanced Composites Manufacturing Innovation (IACMI) is to reduce the embodied energy of CFRP by 50% in five years to ensure and accelerate the use-phase benefits of these materials.*

Figure Estimated onsite energy savings opportunities for 1 kg of carbon-fiber reinforced polymer composite, broken down by sub-process. Energy intensities and savings opportunities are based on a 40 wt% epoxy – 60 wt% carbon fiber composite part fabricated via resin transfer molding.[47] Note that manufacturing energy intensity depends on the precursor, ratio of fibers to polymer, the type of resin, and manufacturing process chosen.

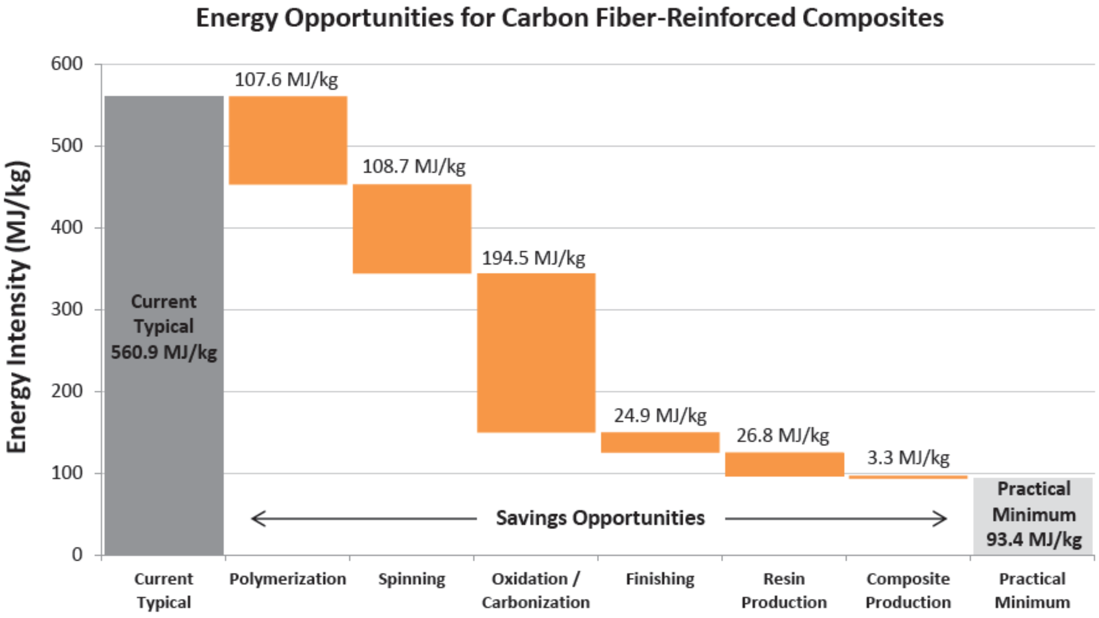


Figure 3 (5)

The challenges associated with composites manufacturing processes and their limitations in meeting the **energy efficiency** goals in key energy applications are presented. For automotive applications, the processes and the associated material systems need to be developed with a capability to produce 100,000 parts per year, requiring cycle times of less than three minutes for carbon fiber reinforced materials, and less than five minutes for glass fiber reinforced materials. Comparable goals for wind blade production are 10,000 units per year with automated material deposition rates of 1500 kg/hr. A goal for the use of composites in compressed gas cylinders is a manufacturing process capable of producing 500,000 units per year with the finished part cost in the $10–15/kg range. Typical cycle times for various molding processes are shown in Table 1. (5)

Table Comparison of the Most Commonly Used Composite Molding Processes[98]

Molding Process	Advantages	Disadvantages	Cycle Time
Pre-preg	Good resin/fiber control	Labor intensive for large complex parts	5–10 hrs
Preforming	Good moldability with complicated shapes and the elimination of trimming operation	Cost effective only for large, complicated shape parts; large scrap generated when fiber mats used	45–75 secs (Compform process) 4–5 mins (vacuum forming)
Resin Transfer Molding (RTM)	Inside and outside finish possible with thickness control, more complex parts possible with vacuum assisted	Low viscosity resin necessary; voids formation possible without vacuum assist	45–75 secs (Compform process) 4–5 mins (vacuum forming)
Liquid Compression Molding	Favored method for mass production with high fiber volumes	Expensive set-up cost for low production	1–2 mins
Sheet Molding Compound (SMC)	Cost effective for production volume 10K–80K/year.	Minimum weight savings potential	50–100 secs
Resin Injection Molding (RIM)	Low-cost tooling; prototypes can be made with soft tools	Difficult to control the process	1–2 mins
Bulk Molding Compound (BMC)	Low-cost base material	Low fiber content; randomly oriented; low structural quality; poor surface finish	30–60 secs
Extrusion Compression Molding	Fully automated; variety of polymers and fibers can be used with fiber volumes up to 60% by weight	Not for surface finish parts without paint film or similar process	3–6 mins
Structural Reaction Injection Molding	Low tooling cost; good surface finish capability	Difficult to control the process, particularly with low viscosity resins and longer cure cycle times.	4 mins for thermosetting resins; a few seconds for thermoplastic matrices
Carbon Fiber Reinforced Thermoplastics (CFRTP)	Easily recycled; fast consolidation	High viscosity which forces users to utilize equipment involving high temperature (200–400 °C)	1 min

Table 1 (5)

The energy intensity of various manufacturing techniques is another consideration driving improvements in composite manufacturing methods.

A comparison of the energy intensities of the current state-of-the-art methods is shown in Figure 4 (5). The high energy intensity of autoclave based processes has driven the current increased focus on processes such as resin transfer molding and out-of-autoclave (OOA) curing of thermosets. Curing refers to the cross-linking of polymer chains in the resin with the matrix, resulting in a hardened finished part.

Many methods can be used for curing including the use of heat, chemical additives, or electron beams. OOA pre-pregs can be cured at lower pressures and temperatures (vacuum pressure vs. a typical autoclave pressure of 586 kPa, and cure at 93°C or 121°C vs. a traditional 177°C autoclave cure). Out-of-autoclave pre-pregs have also recently been effectively used for tooling manufacturing. Using OOA technology, integrated stiffeners in large composite structures can be co-cured in a single cycle, simplifying a process that is typically very complex and expensive. Further, coefficient of thermal expansion (CTE) mismatches between tool and part play a smaller role at lower temperatures and are therefore more easily managed. As a result, OOA pre-pregs are a potential solution for part cracking caused by cure-temperature differentials and could help achieve faster, more agile manufacturing.

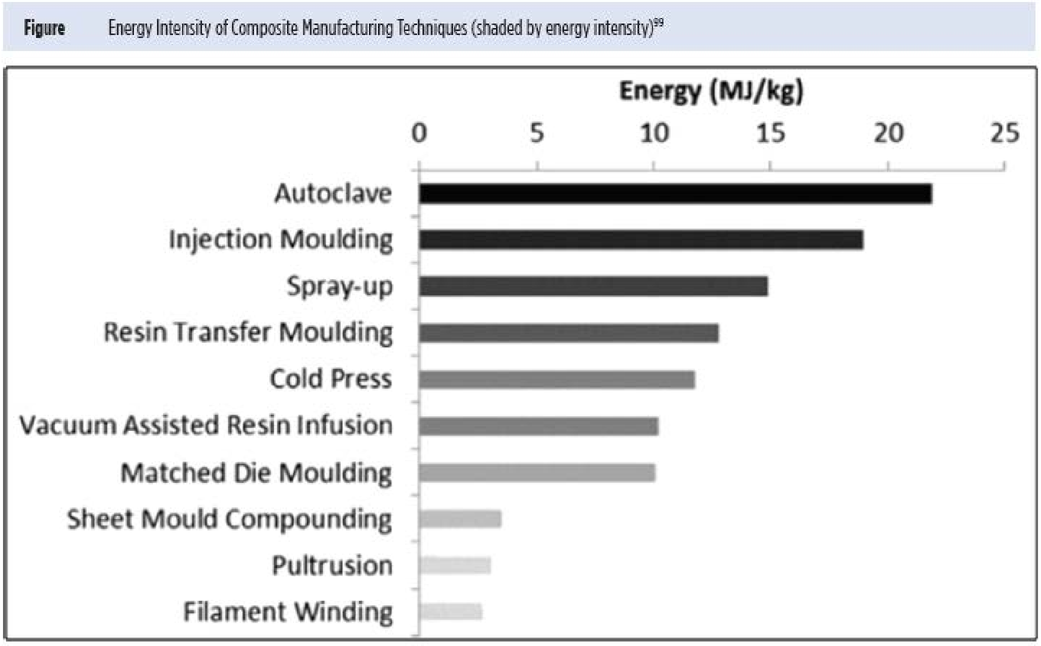


Figure 4. Energy intensity of composite manufacturing techniques (Song et al., 2009). (5)

4. Conclusion, advances energy technology's needs & suggestions:

The use of composites can lead to increased energy productivity due to improvements in life cycle energy and domestic production of clean energy products.

Use of composites can also support a reduction in the cost of energy from large-scale wind and other potential renewable sources (geothermal, solar) and help move the country toward doubling renewable power generation by 2030(5). Further, increased deployment of composites in transportation applications can support national goals to improve energy security by reducing the weight and increasing the efficiency of vehicles and by helping enable the use of new fuel sources such as hydrogen in the transportation sector, thus diversifying our fuel sources.

To enable these objectives, *the following advances in composites technology are needed:* (5)

1. *Reduce **life cycle energy** use and associated greenhouse gas emissions for supported composites R&D efforts;*
2. Reduce production cost of finished carbon fiber composites for targeted applications by 50% over ten years;
3. *Reduce the **embodied energy** (and associated greenhouse gas emissions) of carbon fiber composites by 75% in ten years;*

4. Improve recyclability of composites >95% in ten years by both improved process development and design criteria and that the recycled materials would meet application design specifications.

According to Final Report, COMPOSITES: CALCULATING THEIR EMBODIED ENERGY (7), The results of cradle-to-grave process of this project suggested that:

- Material stage: Composite products have significantly lower embodied energy during their material stage the traditional product. This is large due to the traditional materials require a relatively high amount of energy during their extraction process.
- Manufacturing process (process): Most of the composite products have higher embodied energy than the traditional products during the manufacturing process stage.
- *Usage stage: Composite products perform considerably better than the traditional products at this stage due to their light-weight and corrosive resistance properties which save the fuel consumption.*
- End-of-Life stage: Despite many advantages, composite products have the shortcoming at the end-of-life stage where the composite products are currently 100% landfill but the traditional product such as steel and aluminium is 65 to 70% recyclable. *Therefore, further challenge is to improve the recyclability of the composite products.* This is not only for improving the embodied energy efficiency but also to improving the competitiveness in the international market where the recycling rate is one of the main requirements for the exporting products into countries such as Europe commission and Japan.

Ultimately on the basis of the scopes and assumptions of this analysis (7), it was found that composite products are estimated to perform better than the traditional products in terms of their embodied energy that incurred during their life cycle stages. At the material stage, they perform the best. Their outstanding natures such as the strength and lightness are genuinely an advance on the traditional materials in this modern era.

Also many recommendations were proposed: (7)

- The *energy efficiency* during the manufacturing, installation, usage and maintenance processes can be further investigated to improve their environmental performance. This can be achieved by measuring or monitoring the energy consumption during the operation of these activities. Subsequently, the Life Cycle Assessment can be performed to improve their performance.
- Improving the recyclability of composite products can be a future challenge for the composites industry. This will not only help in improving the embodied energy efficiency of the composite products but also their competitiveness in the international market.

5. Energy efficiency policy background in Denmark:

Denmark has years of experience in sustainable energy transition. The Danish experiences in promoting energy efficiency and renewable energy could be relevant to countries that wish to make their energy systems more sustainable and less dependent on fossil fuels.

Firmly rooted in measures adopted by a broad parliamentary majority Denmark has agreed to a 2020 target entailing: (9)

- 35 % renewable energy in final energy consumption.
- 12 % reduction in gross energy comsumption compared to 2006.

- Minimum 34 % reduction in greenhouse gas emissions (GHG) compared to 1990.

This is in line with the Danish Government's long term target of making Denmark self-reliance on renewable energy in 2050.

Danish experiences Denmark (8) has achieved remarkable results in energy efficiency performance for households, industry and energy production, and is today a leader in the field within the EU and OECD. Energy consumption in buildings has been reduced by 45% per square meter during the past 40 years. Industrial energy intensity has improved by more than 2% per annum the past 10 years. According to a recent study, *energy efficiency gains have improved cost competitiveness in the Danish manufacturing sector by 9%.*

Denmark's success stems from a wide range of policies and measures, including (8):

- long-term prioritization of efficiency measures in energy production and end-use consumption.
- effective use of waste heat, including combined heat and power-generation.
- agreed savings obligation schemes for utilities.
- wide-spread implementation of energy management systems.
- ambitious building standards, including standardization of installations and equipment.
- increasing energy consciousness and altering consumer behavior via direct engagement of stakeholders, labelling, information campaigns and consultancy services.

International engagement Danish experiences on promoting energy efficiency are integrated in government-to-government energy cooperation with emerging economies (including China, Mexico, South Africa, Vietnam, Ukraine, Turkey and Indonesia.
The cooperation related to energy efficiency includes: (8)

- Energy efficiency in buildings, including energy performance standards for new buildings, installations and appliances, awareness and cost-of-energy scenario analysis.
- Industrial energy efficiency, including energy management, waste heat recovery and eco-standards on equipment and components, utilities' savings obligation.

Denmark also focuses on multilateral engagement in and support to:

- The IEA's E4-program focusing on *energy efficiency analysis* and policy advice in four major emerging economies. Synergies with the E4-program are increasingly integrated in the bilateral energy cooperation, e.g. in developing an EE roadmap in South Africa.
- The Clean Energy Ministerial (CEM) and its work streams promoting energy efficiency.
- The SE4All EE Hub (Copenhagen Centre on Energy Efficiency) and its associated energy efficiency Accelerator Platform.

In addition, Denmark gives priority to financing measures for energy efficiency through:

- Development and implementation of the Energy Savings Insurance instrument (ESI) in collaboration with the Inter-American Development Bank (IDB) and the Global Innovation Lab for Climate Finance in the Latin-American region.
- The Green Investment Facility (GIF) intends to assist small and medium sized enterprises (SMEs) in reducing their energy consumption in support of Vietnam's low carbon transition.

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