EPFL

ICCM 23
BELFAST 2021

LCA of Carbon fibers: an analysis of available data sets

V. Michaud, EPFL

J. Takahashi, Tokyo University

I. Verpoest, KU Leuven

École
polytechnique
fédérale
de Lausanne

PAN based carbon fibers- analysis of various data sets

Aims of this presentation:

- Present available data on LCI/LCA of carbon fibers, as found in literature and databases.
- Discuss potential reasons for the large differences.

Expected outcome :

- \- Reach a better understanding of the disparity in LCI/LCIA data for carbon fibers
- … and hopefully take a step towards a more “harmonized” data set for LCI/LCIA of carbon fibers

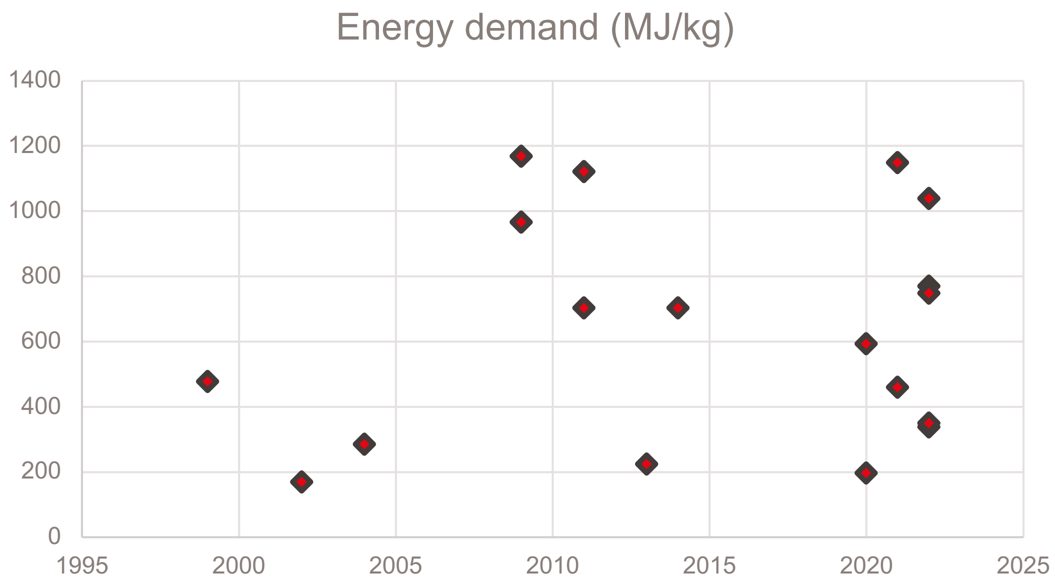
EPFL

LCA of carbon fibers – observation from users

	CO_2 footprint (kg CO_2 eq/kg)	Energy (MJ/kg)	Reference	Year
EUCIA old	39	771	1	2022
EUCIA new	49	1041	2	2022
JCMA (2009)	22.4	967	3	2009
Das	31	704	7	2011
Duflou	55.8	1169	8	2009
Witik	54.8	1122	9	2011
Romaniw		225	10	2013
IDEMAT	12.2	339	11	2006
JCMA (2022)	20	350.2	6	2022
Ghosh		461	12	2021
JEC observer		198-594	5	2020
Der		4436 +1150	13	2021
ADEME	41	750	4	2022
Aerocomposites		478	14	2009
Bell, Pickering		171	17	2002
METI		286	15	2004
Deng		704	16	2014

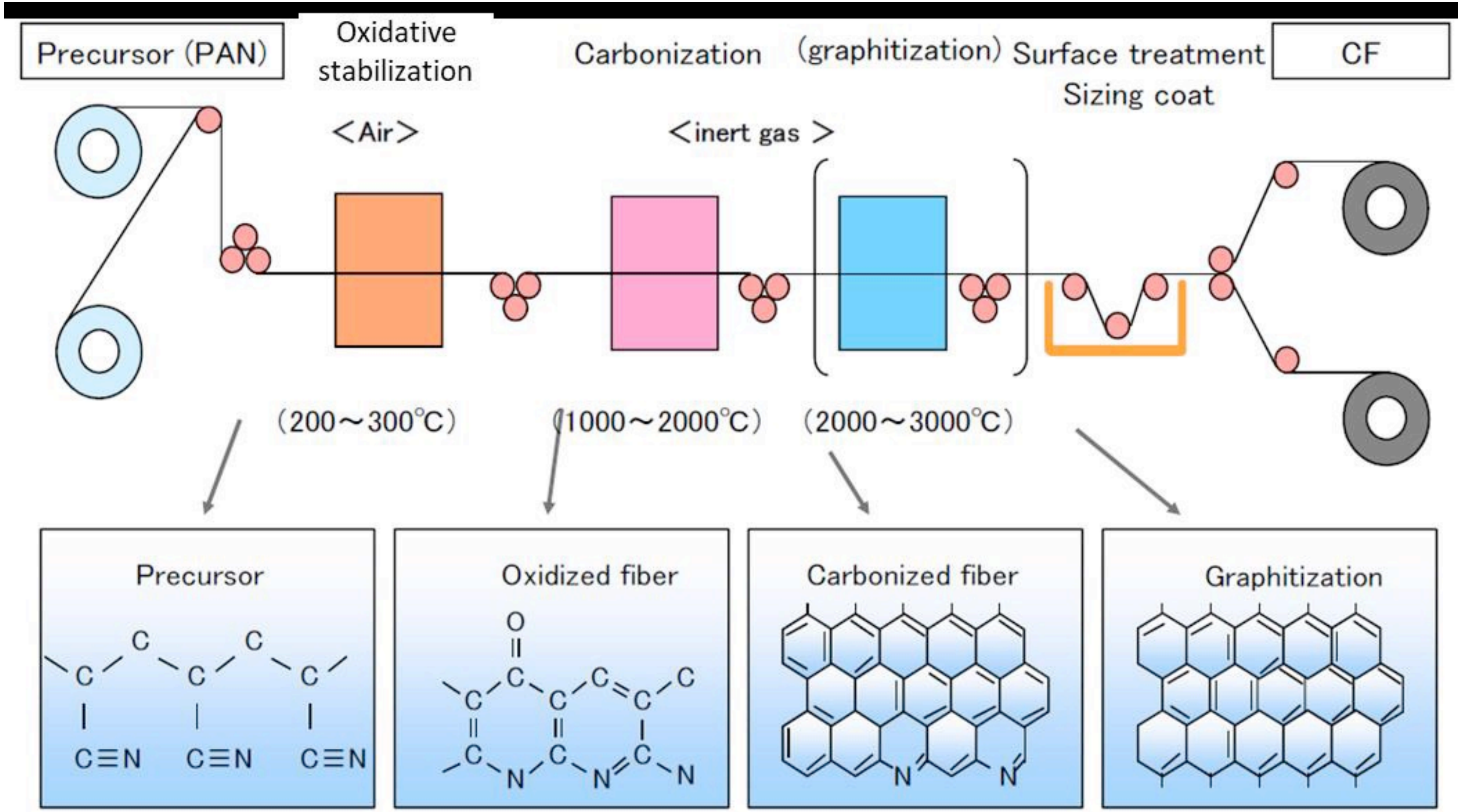
Non exhaustive summary of available data from literature or databases, for 1 kg of Carbon fiber (from PAN precursor) – References are given at the end of the presentation.

Energy demand reported towards publication date



Even in recent data sets, the variation in energy demand varies by a factor 6, which value should we use in the analysis of composite manufacturing?

Carbon fiber manufacturing



Source:Dave Warren, Oak Ridge National Laboratory, DOE Physical-Based Hydrogen Storage Workshop, August 24, 2016, at USCAR, Southfield, Michigan

LCA of carbon fiber production

V. Michaud

Carbon Fiber PRODUCT LCI as input to further LCIA of composite “life cycle”

LCI for 1 kg of Carbon Fiber

Raw materials

Heat provided by natural gas, fuel…

Electricity

Steam etc…

Any other input …

CF PRODUCTION

AN production

PAN polymerization & fiber

OXIDATION

CARBONISATION

SURFACE TREATMENT

COMPOSITE **PART MANUFACTURING**

COMPOSITE PART **USE PHASE**

COMPOSITE PART **RECYCLING**

LCA of carbon fibers – reasons for discrepancy

- Various assumptions in the manufacturing conditions, temperature, duration of each step, conversion rate from PAN to CF lead to different results.

- Various assumptions in the energy mix, the energy flow in the factory, system boundaries, type of process, geographical location, etc... due to lack of measured data and consensus in the calculation methodology.

- Data measured from lab-scale facilities may overestimate the impact, as these are not as efficient as industrial production which is confidential.

- Calculation methods may be different between researchers.

Indicators for Life Cycle Assessment

We focus here on **Cumulative Energy Demand (CED)**, for the production of 1kg of PAN based fiber (T300-700 type). This represents the total quantity of primary energy (renewable and non-renewable) used during the whole of a product's life cycle.

CED is useful as part of an LCA because it can function as a proxy for greenhouse gas emissions and other environmental impacts caused by energy use.

We focus also on the **comparison of two data sets** from JCMA and EUCIA which are industrial associations.

First data reported in 1999

- First data on "**environmental load of carbon fibre production**" by prof. Jun Takahashi, *in collaboration with Japanese carbon fiber manufacturing companies*
- Focused on **four major impact categories**:

	Energy (MJ/kg-CF)	CO_2 (kg/kg-CF)	SO_x (kg/kg-CF)	NO_x (kg/kg-CF)
First data in 1999	~~478.5~~	~~29.7~~	~~0.068~~	~~2.009~~
Recalculated data in 2004	~~285.9~~	~~20.5~~	~~0.02~~	~~0.146~~
Recalculated data in 2009	**286**	**22.4**	**0.019**	**0.121**

EPFL

European Composite industries association data on CF (2018)

Methods used:
1. Cumulative energy demand
2. Greenhouse Gas Protocol V1.01 / C02 eq (kg)
3. ILCD 2011 Midpoint+ V1.06 / EU27 2010, equal weighting

Eco footprint carbon fiber

CED 771 MJ/kg
GHG 38,9 kg CO2eq

AN				Conversion %	PAN				Conversion %	PAN input CF	CF				Delta PAN/CF	
Source...		Data	Unit		Source...		Data	Unit			Source...		Data	Unit	Data	Unit
Ecoinvent	CED	82,24264	MJ	N/A	ELCD	CED	115,3003	MJ	53%	217,55	Literature	CED	770,9	MJ	553,34	MJ
Ecoinvent	GHG	2,821385	kg	N/A	ELCD	GHG	5,683081	kg	53%	1,07E+01	Literature	GHG	38,9	kg	2,82E+01	kg

- First mention end 2018 *(@ Composites Europe - Novembre 8, 2018)*
- *Data on CED and GHG are much higher than Japanese data*
- According to the presentation (see also: Background report, Version 1.3, p.27-30, 16/10/2018)
  - Industry input seeked for, but not obtained
  - Eco invent & Literature Data
    - – KULeuven: Duflou JR, De Moor J, Verpoest I, Dewulf W. Environmental impact analysis of composite use in car manufacturing. Cirp Annals-ManufacturingTechnology. 2009;58(1):9-12 ... **However, only "ecopoint data" in this paper, no data on energy ,**
    - – ORNL: Das S. Life cycle assessment of carbon fiber-reinforced polymer composites. International Journal of Life Cycle Assessment 2011. p. 268-82.

European Composite industries association data on CF (2020)

V. Michaud

- 20 Febr 2020: "**EuCIA announces addition of new carbon fibre data to Eco Impact Calculator**" (**http://www.jeccomposites.com/knowledge/international-composites-news/eucia-announces-addition-new-carbon-fibre-data-eco-impact**)
  - *"In a recent cooperation, **experiment-based data** produced by the **Institut für Textiltechnik (ITA) of RWTH Aachen University, Germany**, and EuCIA's study were thoroughly reviewed and **EuCIA's initial LCA data** adjusted to reflect actual experience of the PAN to carbon fibre conversion efficiency. Both data sets, initial and new, are now available to Eco Calculator users."*

	Carbon footprint (kgCO2/kg CF)	Cumulative Energy Demand (MJ/kgCF)
Initial data (2018)	38.9	770.9
New data (2020)	**49.0**	**1040.9**

New data set from JCMA in 2022

V. Michaud

First presented by **prof. Jun Takahashi**, The University of Tokyo, Japan during ECCM20 (June 29, 2022)

Published *end October 2022 by* **The Japan Carbon Fiber Manufacturers Association** (JCMA)

https://www.carbonfiber.gr.jp/english/index.html or Lifecycle Assesment Model (carbonfiber.gr.jp)

CED: **350 MJ/kg-CF (including 32 MJ as feedstock energy)**

GHG: **19.8 kg-CO_2/kg-CF**

SOx: **0.016 kg-SO_x/kg-CF**

NOx: **0.035 kg-NO_x/kg-CF**

Comparison JCMA 2022/EUCIA 2020

- Similar approach (feedstock energy is included in both).
- **EUCIA** (998MJ more recent estimate, 2022) uses a mix of data based on
  - measurements in laboratories and pilot lines
  - theoretical estimations, data from validated but not transparent databases
  - available (literature) data

  … because they could not obtain data directly from carbon fibre manufacturers.

- **JCMA** (350 MJ) uses data aggregated from the 3 main CF manufacturers (Toray, Mitsubishi Chemical, Teijin), in 2017
  - measurements in factories during CF production of 6994 tons of CF
  - Aggregation to respect confidentiality, so not all data is clearly available.

Reasons for discrepancy (tentative)

Energy related to electricity use is very different, and should be clarified:

- **EUCIA**: electricity (Europe market) for oxidation/carbonization: 496MJ, and energy for production of PAN fiber is 323MJ (not sure if all is electricity!), leading to 500-800MJ, depending on the part of electricity in PAN production.
- **JCMA**: electricity for process is 92.7MJ (external and internally generated), the rest comes from fuel, natural gas, etc. Hence electricity represents only 25-30% of the energy use for making CF, and much more in EUCIA data.

Other difference: **economy of scale** is crucial, for example heat recuperation is very effective in large scale production facilities, whereas not done in pilot lines.

Preliminary conclusions

The differences between EUCIA and JCMA data sets is most probably due to large **differences in input data:**

- Industrial versus labscale and pilot plant data, and theoretical assumptions.

- Large difference in electricity consumption, possibly due to heat recuperation and energy efficiency increased in industrial versus lab-scale, and difficulty to compare datasets (separation of PAN production or not).

Preliminary conclusions

Still, there is an **urgent need** for

- **critically analysing all** published data
- creating a ‘**harmonised**’ CED/LCIA-data set , based on **industrial reality**
- performing a **sensitivity study** on the most important parameters (type of CF, type of precursor, used energy inputs, …)
- further broaden the discussion from **CED** to **all impact categories → full LCIA**
- Meetings are ongoing to better compare the datasets and understand these differences

Acknowledgements

Contributions from JCMA and EUCIA are warmly acknowledged, as well as discussions with many colleagues from academia and industry interested in assessing the environmental impact of composites.

Contacts:

ignaas.verpoest@kuleuven.be

veronique.michaud@epfl.ch

takahashi-jun@cfrtp.t.u-tokyo.ac.jp

EPFL

References

1- EUCIA database, Data from EU average, Cumulative Energy Demand https://ecocalculator.eucia.eu/Account/Login?ReturnUrl=%2F
2- EUCIA database, new assessment with EU average impact data, help from RTWH Aachen. Cumulative Energy Demand, https://ecocalculator.eucia.eu/Account/Login?ReturnUrl=%2F
3- The Japan Carbon Fiber Manufacturers Association (JCMA): http://www.carbonfiber.gr.jp accessed 2009 (cited by Witik, 2011).
4- IMPACTS database, ADEME. Midpoint category results. https://base-impacts.ademe.fr/
5- JEC Observer, 2020, data from School of Mechanical Engineering Birmingham (UK).
6- The Japan Carbon Fiber Manufacturers Association (JCMA):https://www.carbonfiber.gr.jp/english/tech/lci.html, accessed November 2022.
7- Das, S., Life cycle assessment of carbon fiber-reinforced polymer composites. The International Journal of Life Cycle Assessment, Volume: 16, Issue: 3, 2011: 268-282, feedstock energy counted in (fossil fuel energy if burnt instead of used for plastics)
8- Duflou, J. R., De Moor, J., Verpoest, I., Dewulf, W., Environmental impact analysis of composite use in car manufacturing. Manufacturing technology 2009; 58: 9-12.
9-Witik RA, Payet J, Michaud V, Ludwig C, Månson J-AE. Assessing the life cycle costs and environmental performance of lightweight materials in automobile applications. Composites Part A 2011; 42(11): 1694-1709.
10- Y.Romaniw, Tthe relationship between light-weighting with carbon fiber reinforced polymers and the life cycle environmental impacts of orbital launch rockets, PhD, Georgia Tech, 2013
11- IDEMAT, Remmerwaal, TU delftDelft, 2006
12- T.Ghosh, H. C. Kim, R. De Kleine , T. J. Wallington, B. R. Baksh, Life cycle energy and greenhouse gas emissions implications of using carbon fiber reinforced polymers in automotive components: Front subframe case study sustainable materials and technologies, 28 (2021) e00263.
13- A. Der, N. Dilger, A. Kaluza, C. Creighton, S. Kara, R. Varley, C. Herrmann, S. Thiede, Modelling and analysis of the energy intensity in polyacrylonitrile (PAN) precursor and carbon fibre manufacturing, Journal of Cleaner Production 303 (2021) 127105.
14- The society of Japanese Aerospace Companies, "An investigation report about inventory data construction of composite materials", 1999, pp. 30-43 (cited by Suzuki and Takahashi, The Ninth Japan International SAMPE symposium Nov.29 – Dec.2, 2005)
15- METI, Global warming program, "Report of Research and development on carbon fiber reinforced plastic for lightening automobiles", 2004, pp. 205-206 (cited by Suzuki and Takahashi, The Ninth Japan International SAMPE symposium Nov.29 – Dec.2, 2005).
16- Y.Deng, Life cycle assessment of bio-based fibre reinforced composites, PhD thesis, KU Leuven, 2014.
17- Bell, J. R., S. J. Pickering, H. Yip, and C. D. Rudd. "Environmental Aspects of the Use of Carbon Fibre Composite in Vehicles-Recycling and Life Cycle Analysis." End of Life Vehicle Disposal--Technical, Legislation, Economics (ELV 2002) (2002).
18- Sakamoto, K.; Kawajiri, K.;Hatori, H.; Tahara, K. Impact of the Manufacturing Processes of Aromatic-Polymer-Based Carbon Fiber on Life Cycle Greenhouse Gas Emissions. Sustainability 2022, 14, 3541. https://doi.org/10.3390/su14063541