Small Carbon Quantum Dots, Large Photosynthesis Enhancement🌲

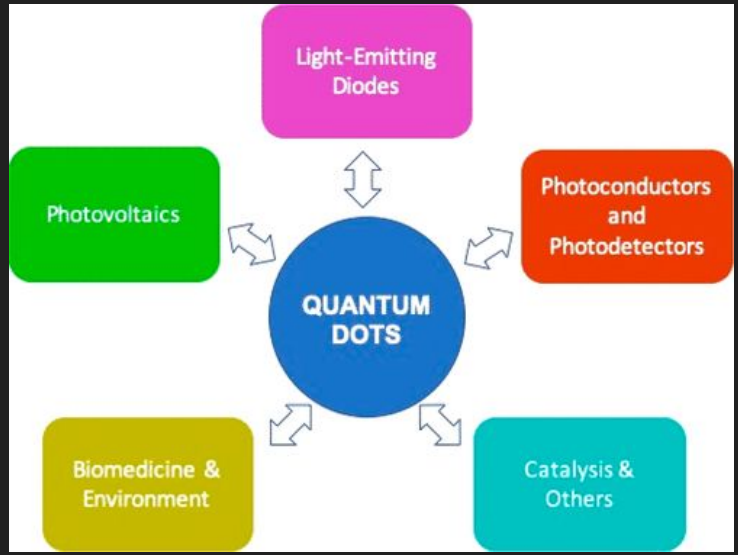
Group 5: Forbes, D., Gibson, J., Gliozzi, J. Gold, M. Harris, I.

🌲Y. Gong and J. Zhao, Small Carbon Quantum Dots, Large Photosynthesis Enhancement, J. Agric. Food Chem. 66, 9159 (2018).

Introduction

The Case for Rare-Earth doped Carbon Quantum Dots (RE-CQDs)

- Argument for further investigation into RE-CQDs and photosynthesis enhancement
- Why photosynthesis enhancement?
- RE-CQDs could lead to nanofertilizers and new class of synthetic materials that can “grow.”



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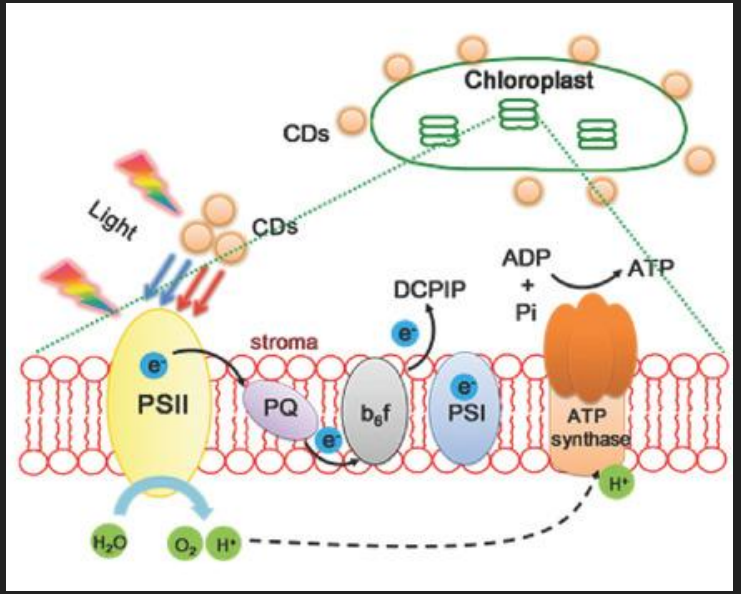
Previous Work with Photosynthesis Enhancement and RE-CQDs

- The authors present other groups' research as support:
  - CQDs bind with isolated chloroplast (2014)
  - Rare-earth elements augment photosynthesis (2001)
  - RE-CQDs have desirable properties

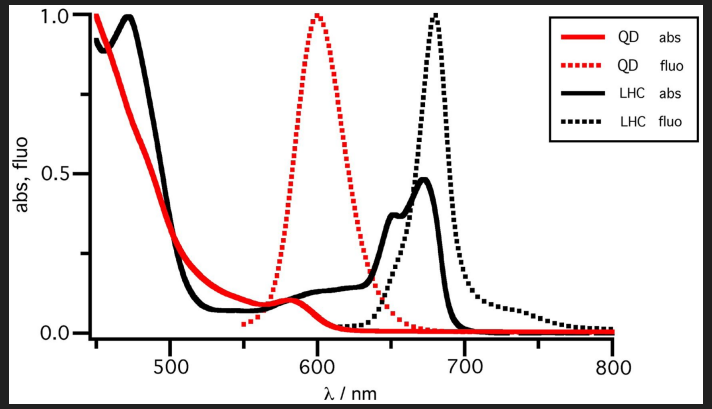


Advanced Functional Materials. Li. W et al. (2018)

Background and Results

Quantum dots (QD) for nonradiative energy transfer

- CdSe QD as energy donors to LHC-IIb[1]
  - Fluorescence resonance energy transfer (FRET).
  - Helps fill the ‘green gap’
- 3x increase in excitations in LHCs vs. control[2]
- Maximum enhancement:[3]
  - Molar ratio LHCII:QD of 2.7:1.
- More recently w/ Si-based QD[4]



[1]

Issues:

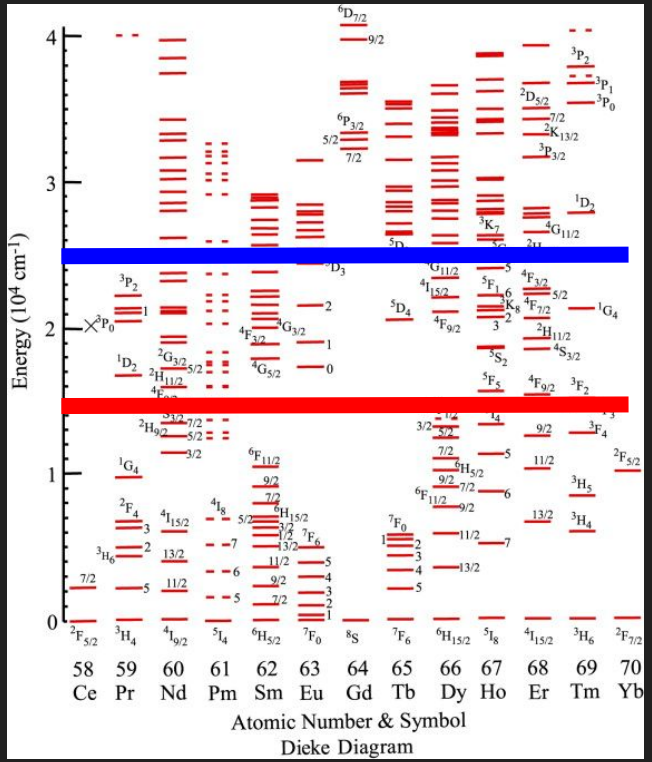
1. Cytotoxicity.
2. Mechanism isn’t fully understood.

Solution to 1:
Carbon Quantum Dots (CQDs)

[1] Erker, W., et al. *J. Lumin* (2010).
[2] Nabiev, I., et al. *Agnew. Chem.* (2010).
[3] Liu, X., et al. *Shengwu Wuli Xuebao* (2013).
[4] Li, Y., et al. *Nanoscale* (2020).

Rare-earth (RE) elements and quantum efficiency

- RE doped into solids → long lived, optical transitions
- Complete $5s^2 5p^6$ orbitals shield the outermost $4f^{\,n}$ orbital from external fields.
- RE solid state devices:
  - optoelectronics, signal processing
  - quantum memory, quantum networking
- Ongoing work at UIUC!!! Goldschmidt group[5]



[6]

[5] Dutta, S., et al. *Nano Lett.* (2020).
[6] Ogasawara, K., et al. *Rare Earths* (2007).

Direct impact of REs on photosynthesis *in vivo*

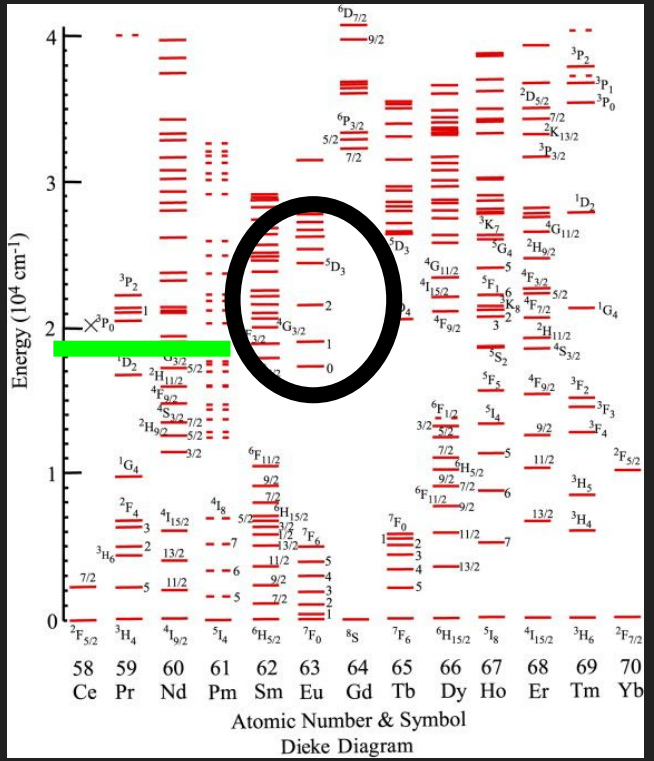
- Tobacco seedlings[7]
  - Accelerated photosynthesis → stimulated seedling growth
  - Optimum concentration due to toxicity
- Green Algae[8]
  - Low intensity: 300% increase in photosynthetic rate → 36% enhancement in growth
  - Found an overall increase in chlorophyll.
- Corn[9] and many other agricultural goods, dating back to the 60s.[10]

[7] Chen, W. J., et al. *Biol. Trace Elem. Res.* (2001).
[8] Řezanka, T., et al., *Photosynth Res* (2016).
[9] Cui, W., et al. *J. Rare Earths* (2019).
[10] Kotelnikova, A., et al. *Environ. Saf.* (2020).

RE-CQDs for improved photosynthesis

- Proposed work: Eu doped CQDs
  - Transitions in the green (speculative)
  - Chelation of Eu-CQDs demonstrated[11]

- Eu CQDs for Hg detection in water[12]
  - Dual fluorescence
  - Cool but not really relevant



[11] Zhang, T., et al. *RSC Adv.* (2016).
[12] Gan, Z., et al., *B Chem*. (2021).

Argument Analysis

Argument Structure

- The conclusion is a hypothesis motivating future experiments
- Motivation:
  - Prior studies showing how carbon nanotubes improve photosynthesis
  - Semiconductor CQDs improved energy transfer in light harvesting complexes, but are toxic
- Narrowing the range of CQDs:
  - Many prior studies of heteroatoms (lattice substitutes)
  - Few on CQDs doped with rare-earth chelates
  - Rare-earths by themselves increase photosynthesis
  - Europium CQDs promising

Critique of Argument Validity

- Logical flow of motivating RE-CQDs and narrowing down to Eu is valid
- Citations of detailed experimental papers
- I would add citations for two claims:
  - One mentions author but does not include citation
  - Another makes claim about prior studies of RE but does not cite studies

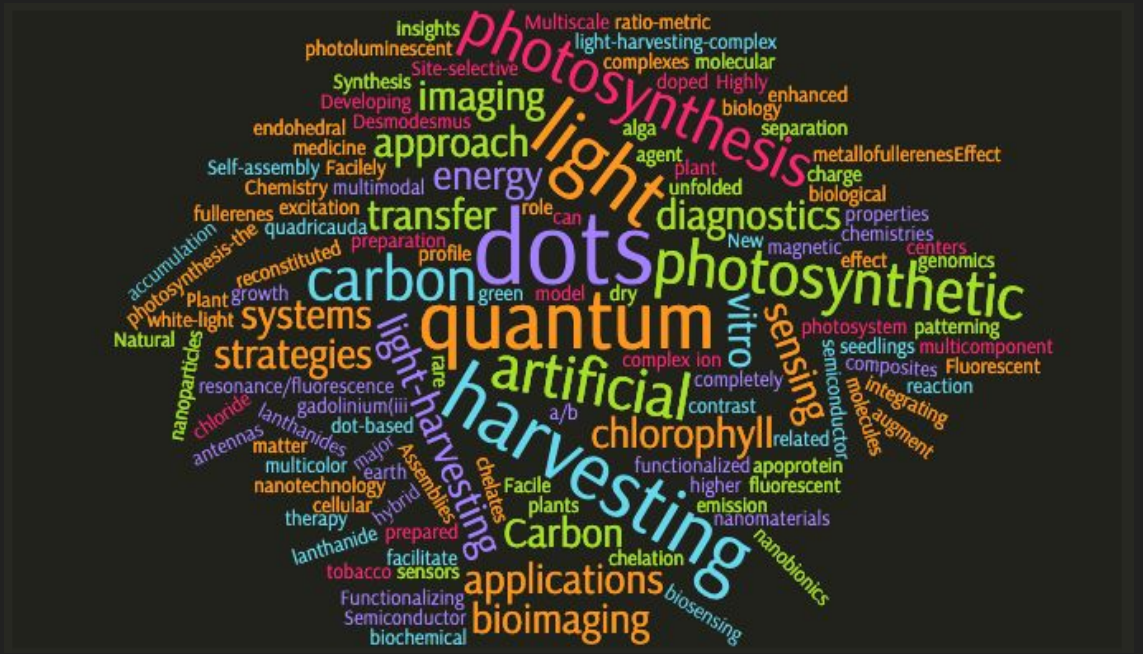
Critique of Argument Validity, cont.

- Needs discussion of CQD's themselves
  - Can at least reference literature

Citation Analysis

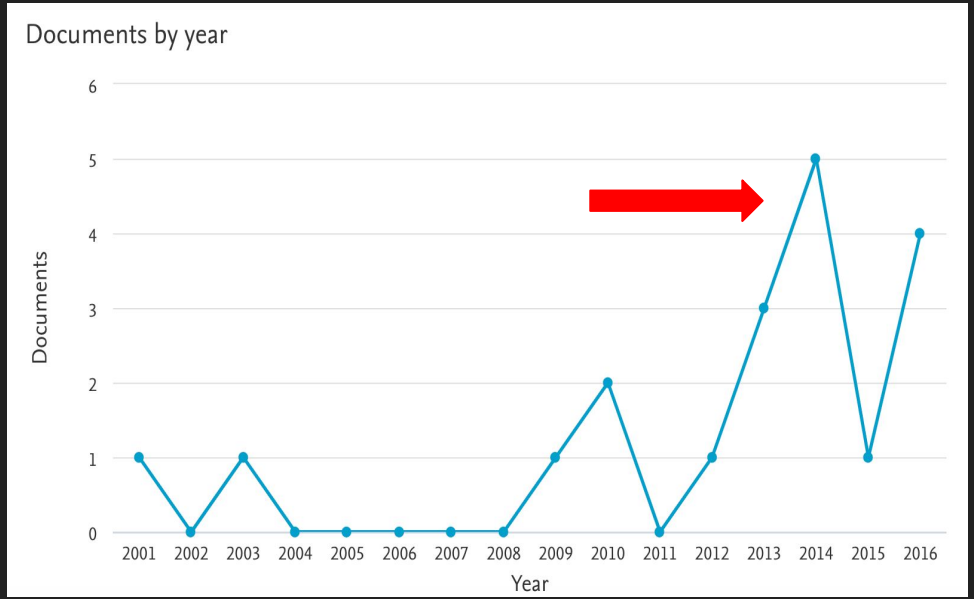
Citation Analysis: Pre-Paper

- Interdisciplinary Field: 17 total references



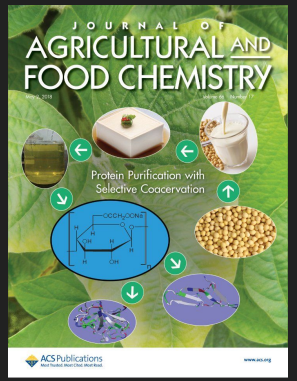
Citation Analysis: Pre-Paper

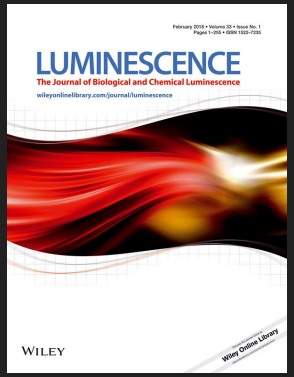
- Interdisciplinary Field: 17 total references
- Activity clustered around last 10 years

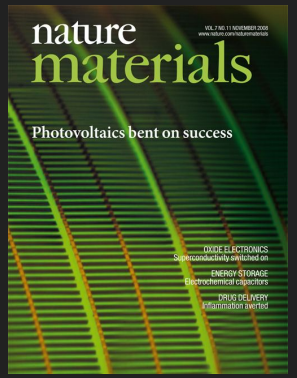


Citation Analysis: Pre-Paper

- Interdisciplinary Field: 17 total references
- Activity clustered around last 5 years
- Variety of Journals

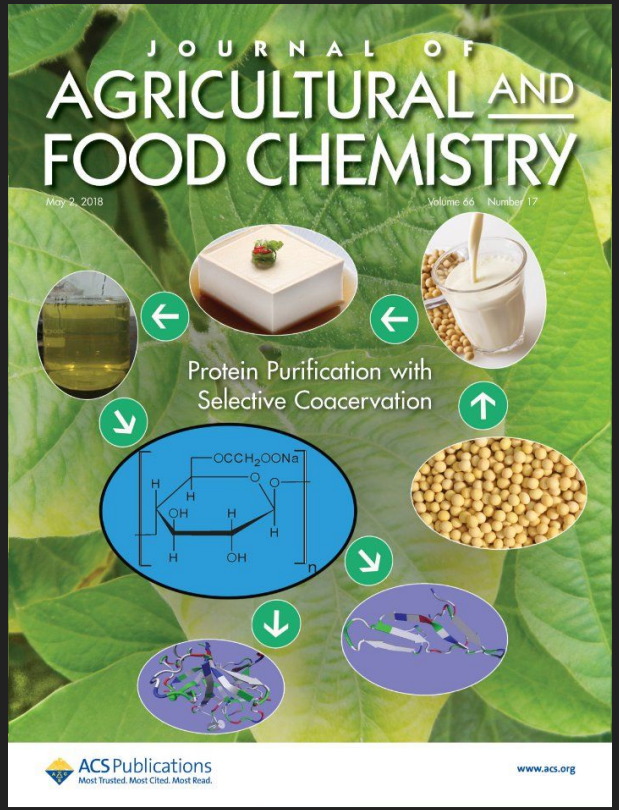






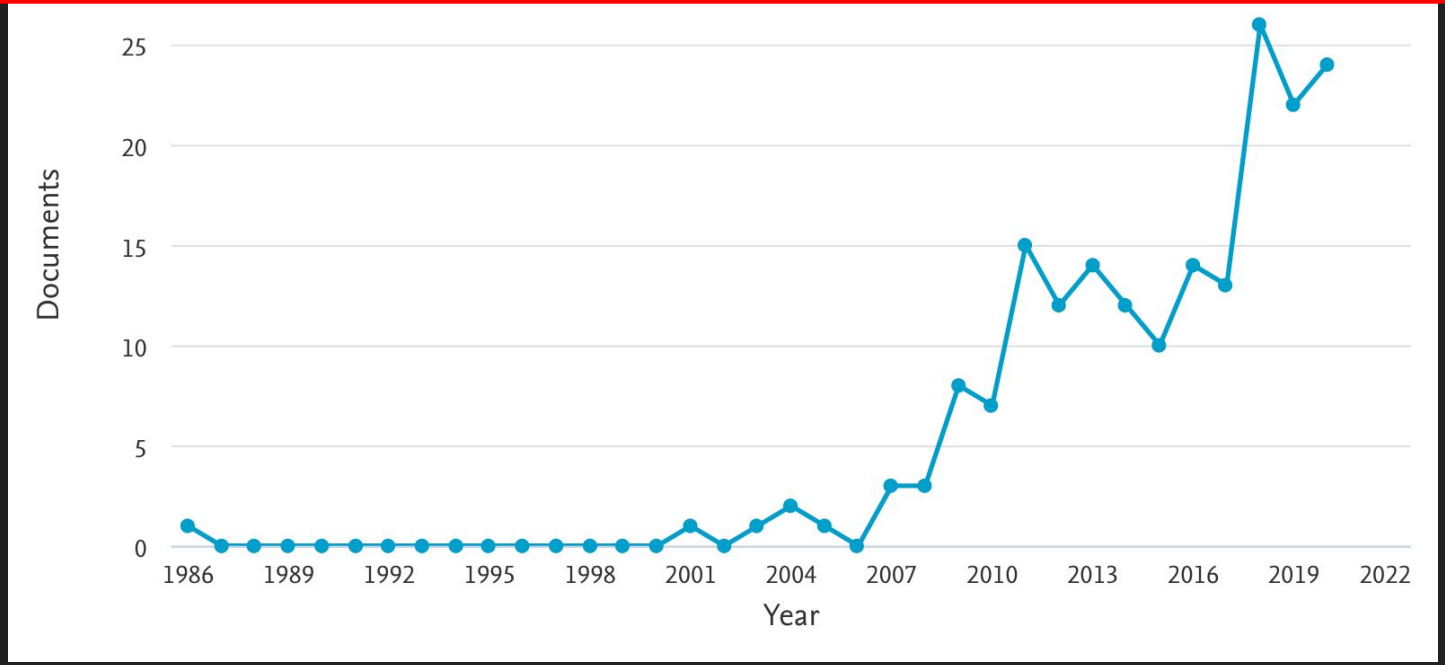
Citation Analysis: Post-Paper

- Few citations: 7-9
  - Relatively recent paper (published 2018)
  - Survey-style, No novel results
  - Niche intersection of fields
  - Authors early in career or unestablished
- Small but growing topic



Citation Analysis: Post-Paper

TITLE-ABS-KEY (quantum AND dot AND photosynthesis)



Conclusions

Main Takeaway from article

- QDs connect to plants' LHC and aid in energy transfer
- Doping QDs with carbon to make CQDs is more plant-friendly
- CQDs doped with rare earth elements (RE-CQDs) make photosynthesis even more efficient due to elements' properties

What's Next in this new field?

- Europium doped CQDs are stable and have high fluorescence quantum efficiency
- These QDs have emission peaks that overlap with what is available to chloroplasts and could hence use chloroplasts as energy donors
- The effect of RE-CQDs on plant photosynthetic physiology and biochemistry must also be studied

What is possible with these next steps?

- We could develop a better understanding of this technology's effect on the environment
- Seeing how RE-CQDs work with chloroplasts could lead to developing synthetic materials with natural growing and repairing capabilities
- This type of research could guide us towards more eco-friendly sources of obtaining energy!

Questions