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Co-Extrusion (CoEx) for Cost Reduction of Advanced High-Energy-and-Power Battery Electrode Manufacturing

Ranjeet B. Rao, Ph.D. (Principal Investigator)

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Contributors

PARC: Scott Solberg, Kathryn Murphy, Rahul Pandey

ORNL: Marissa Wood, Jianlin Li, Kelsey Grady, David Wood

Ford: Renata Arsenault, Kent Snyder, Chulheung Bae

Overview

Timeline

- Project start date:
  December 17, 2015
- Project end date:
  Aug 17, 2019
- Percent complete:
  80%

Barriers Addressed

- **Cost**: Current cost of Li-ion batteries is ~$200–$300/kWh, a factor of about two to three times too high on a kWh basis.
- **Performance**: High energy density battery systems to meet both volume and weight targets.

Budget

- Total project funding:
  DOE share: $2,999,115
  PARC share: $787,478
- FY 2018 Funding (DOE): $664,362
- FY 2019 Funding (DOE): $764,127

Partners

Project Lead

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Project Partners

Oak Ridge National Laboratory

Ford

Collaborations

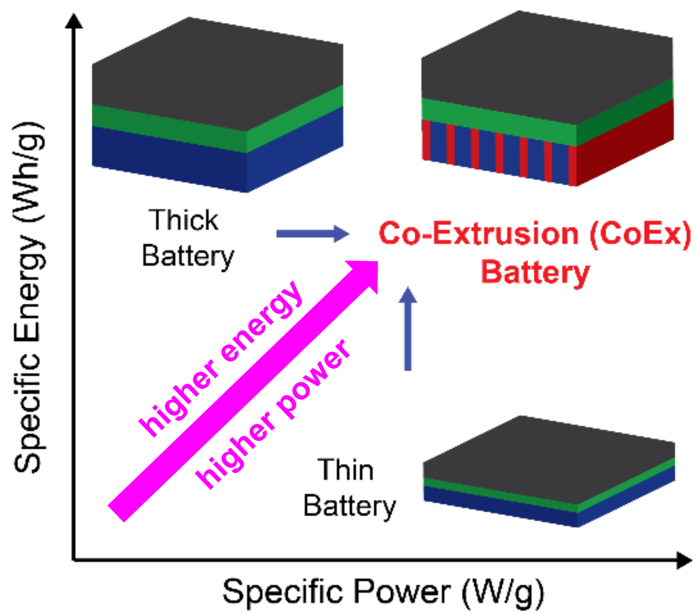
Navitas Systems

Argonne National Laboratory

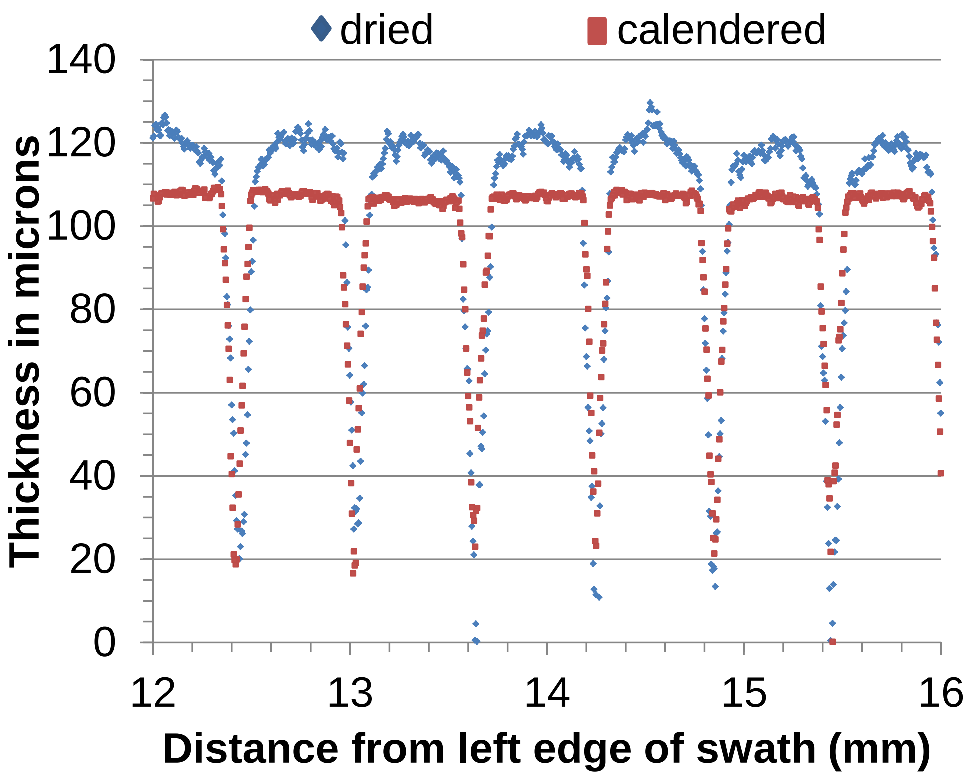
SLAC National Accelerator Laboratory

Relevance and Project Objectives

- Overall Project Objectives:
  - Demonstrate pilot scale, electric vehicle (EV)–relevant 14 Ampere hours (Ah) pouch cells using Co-extrusion (CoEx), addressing:
    - <u>Cost Barrier</u>: ≥30% reduction in $/kWh costs through thick structured high energy and power electrodes
    - <u>Performance Barrier</u>: Gravimetric energy density improvement of ≥ 20% relative to conventional electrodes of the same chemistry
- March 2018–March 2019 Objectives:
  - Scale up CoEx printhead to 90 mm width to enable printing of cathodes for 1 Ah pouch cells
  - Assemble CoEx cathodes and slot-die manufactured, thick matching anodes into 1 Ah pouch cells for electrochemical testing
  - Design and fabricate the printhead that will print CoEx cathode electrodes for large (14 Ah) pouch cells

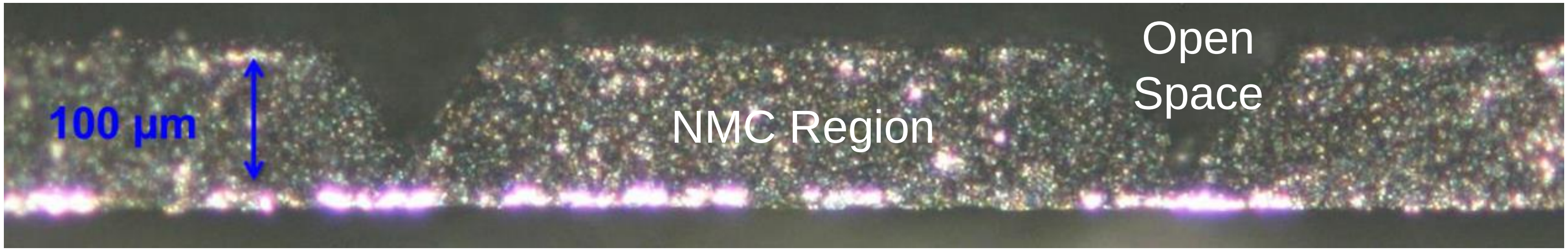


Approach: CoEx Structured Cathodes



CoEx printheads and slurry formulations can be used to create corrugated electrode structures, with periodic grooves that fill with electrolyte and provide fast ionic transport

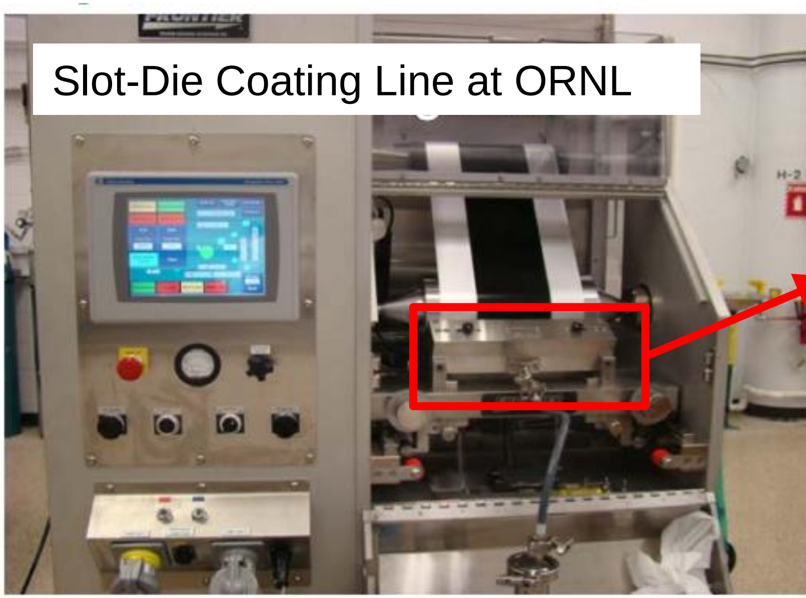
These grooves form during drying and maintain their shape during calendering process

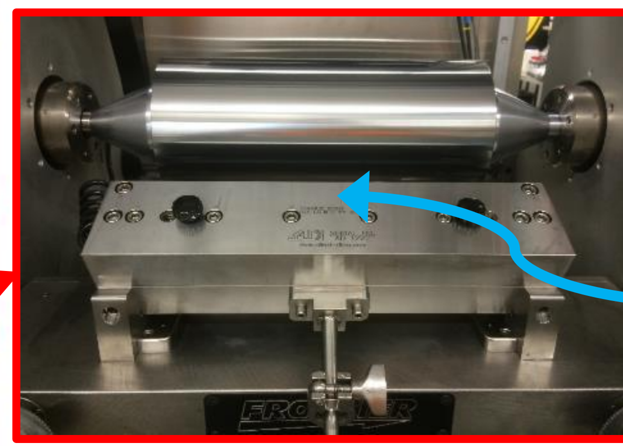


Current Collector

Approach and Strategy: ORNL BMF

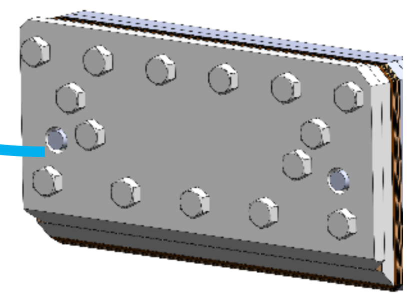
- End of Project Goals:
  - Integration of pouch cell scale CoEx printhead equipment at ORNL Battery Manufacturing Facility (BMF) and production of large format CoEx Cathodes
  - Development of thick matching anodes by ORNL using slot-die coating
  - Production and characterization of 14 Ah pouch cells
  - Develop a plan for commercialization of the CoEx technology with potential end-users and suppliers





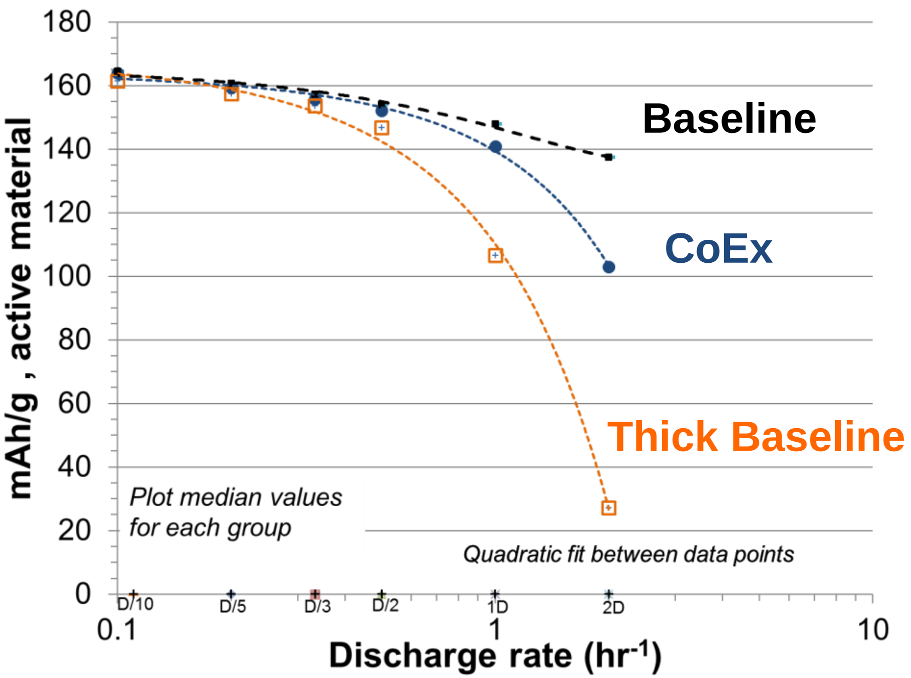
Slot-Die will be replaced with CoEx printhead & high pressure slurry dispensers

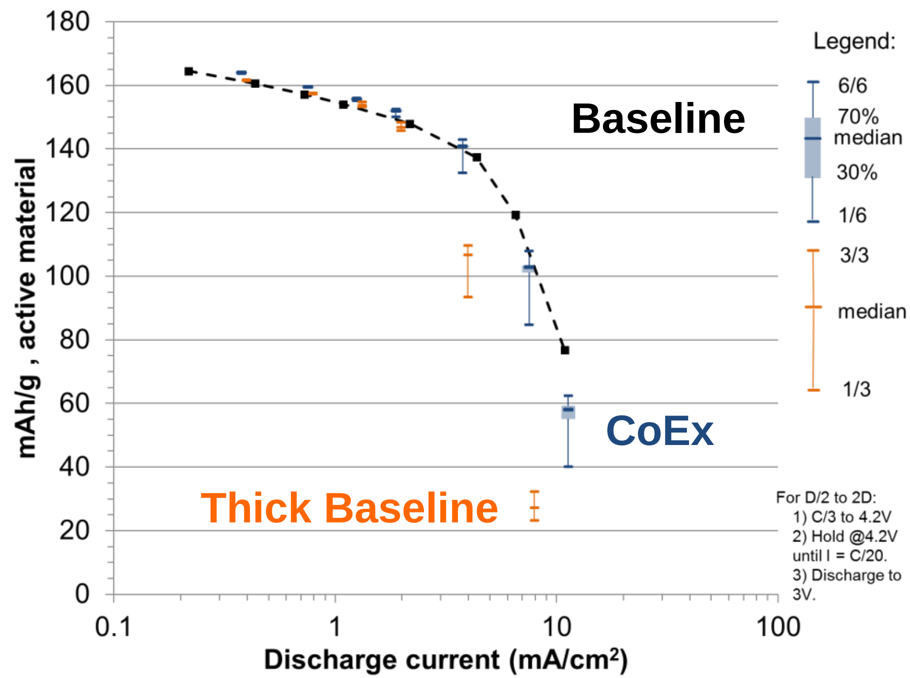
PARC CoEx printhead



Technical Accomplishments

1 Ah Pouch Cell Electrochemical Results





Pouch Cell	Cathode Loading (thickness)	Anode Loading (thickness)	# of Cathode Layers
Baseline	13.2 mg/cm^2 (55 µm)	6.9 mg/cm^2 (63 µm)	10
Thick Baseline	24.8 mg/cm^2 (106 µm)	12.3 mg/cm^2 (109 µm)	6
CoEx Cathode	**23.0 mg/cm^2 (111 µm)**	**12.3 mg/cm^2 (109 µm)**	**6**

CoEx Structuring Improves the Performance of Thick Electrodes

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Technical Accomplishments

1 Ah Pouch Cell Performance Comparison

Improvement of CoEx over baseline electrode

	CoEx Vs Baseline		
D-rate	mAh/g	Wh/ kg	Wh/ L
D/10	5%	6%	9%
D/5	5%	5%	8%
D/3	5%	4%	7%
D/2	4%	2%	5%
1D	0%	-4%	-2%
2D	-22%	**-29%**	**-24%**

Improvement of CoEx over thick homogeneous electrode

	CoEx vs Thick, Homogeneous		
D-rate	mAh/g	Wh/ kg	Wh/ L
D/10	-5%	-6%	-7%
D/5	-6%	-6%	-8%
D/3	-6%	-7%	-9%
D/2	-5%	-7%	-8%
1D	**15%**	11%	9%
2D	**169%**	**149%**	**145%**

	Thin Baseline	Thick Baseline	CoEx
Energy Output at D/2 (Wh)	3.47	3.77	3.52
$ Materials /kWh @ D/2	$129	$111	$116
% Improvement	-----	14%	11%
Energy Output at 1D (Wh)	3.30	2.82	3.13
$ Materials /kWh @ 1D	$136	$148	$130
% Improvement	-----	-9%	**4%**

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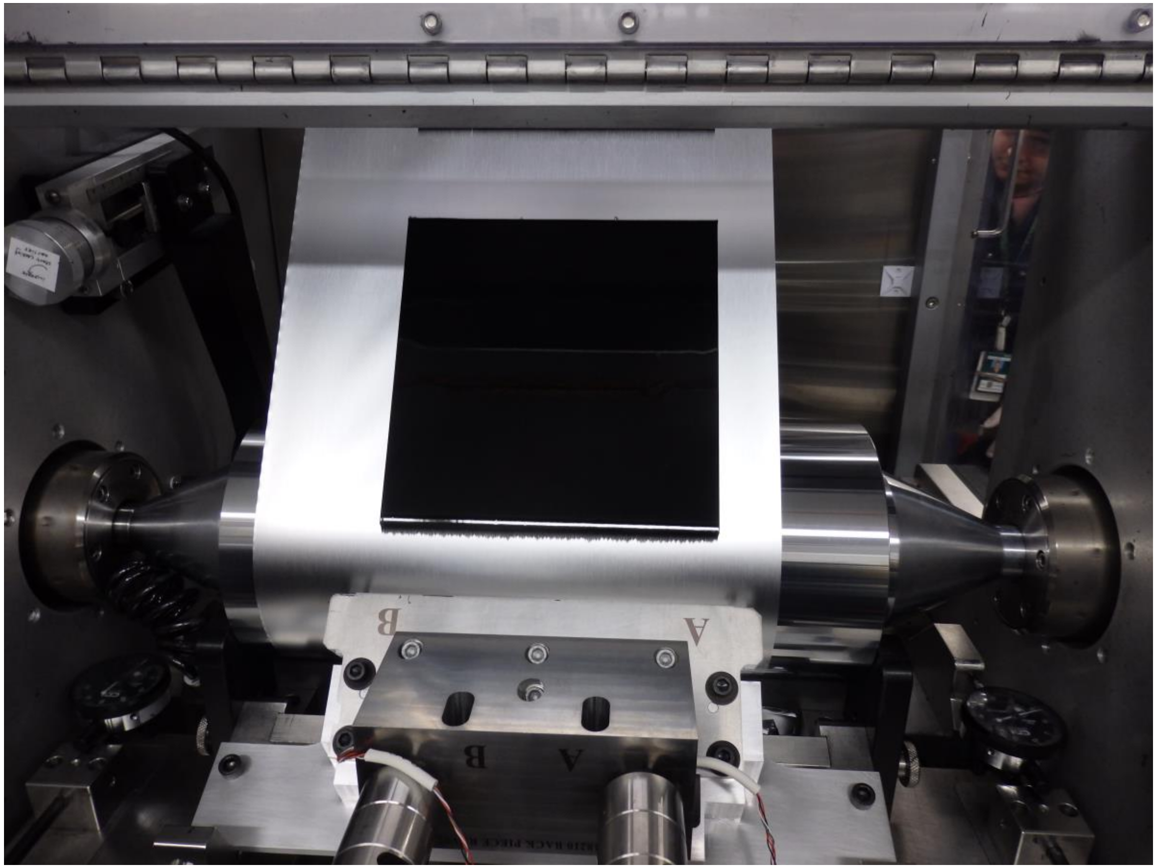
Integration With Web Coater at BMF



We have installed a CoEx printer on the web coater at ORNL's Battery Manufacturing Facility, demonstrating the ability to print 180 mm wide coatings

Collaboration and Coordination

Palo Alto Research Center (Prime)
Developing CoEx printhead hardware and print development. (Key Contributors: Ranjeet Rao (PI), Scott Solberg, Corie Cobb (now at UW), Kathryn Murphy, Rahul Pandey

Oak Ridge National Lab (Project Partner)
Developing the matching high capacity anode, providing materials guidance, 1-6 Ah pouch cell assembly, and BMF integration assistance for CoEx hardware (Key Contributors: Marissa Wood, Jianlin Li, Kelsey Grady, David Wood)

Ford Motor Company (Project Partner)
Providing guidance and recommendations on baseline electrode design, testing and cycling protocols, and market evaluation of CoEx technology (Key Contributors: Kent Snyder, Renata Arsenault, and Chulheung Bae

Navitas Systems (Collaboration)
Providing use of pouch cell assembly equipment for 14 Ah pouch cells in FY 2018 (Special Thanks to Chris Silkowski & Michael Wixom)

Argonne National Labs (Collaboration)
Providing guidance on best practices for coin cell assembly and half cell testing protocols (Special Thanks to Bryant Polzin & Daniel Abraham)

SLAC National Accelerator Laboratory (Collaboration)
Using synchrotron radiation source to perform microstructural analysis of CoEx electrodes (Special Thanks to Johanna Nelson Weker)

Proposed Future Research

- Complete remaining milestones
  - Printing of larger (180 mm wide) CoEx cathodes for 14 Ah pouch cells
  - Assembly and testing of CoEx and baseline pouch cells for rate performance, cycle life, and HPPC
- Produce more 1 Ah pouch cells for testing
  - Fast charge behavior of CoEx cells
  - Power enhancement at low loadings
  - Reduced CoEx structuring pitch

Any proposed future work is subject to change based on funding levels

Summary

- **Relevance**
  - Demonstrate pilot scale, electric vehicle (EV)–relevant, 14 Ampere hours (Ah) pouch cells via Co-Extrusion (CoEx), with goals of 30% reduction in cost and gravimetric energy density improvement of ≥ 20%
- **Approach**
  - Develop thick structured electrodes with CoEx to mitigate power and energy trade-offs in cathodes
  - Use advanced slot coating capabilities to develop a matching, thick, high capacity anode
  - Leverage ORNL's BMF to scale up CoEx production to produce 14 Ah pouch cells
- **Technical Accomplishments**
  - 1 Ah pouch cell testing shows that CoEx structuring improves the rate performance of thick cathode electrodes
  - CoEx pouch cells show up to 9% increase in volumetric energy density at D/10 discharge rate relative to the baseline electrode, and 9% increase in volumetric energy density at 1D discharge rate relative to a similarly loaded thick cathode electrode
  - CoEx pouch cells also show improvement on a $/kWh basis (material cost only), with an 11 and 4% improvement over the baseline at D/10 and 1D discharge, respectively
- **Future Work**
  - Demonstrate CoEx capability with web coating for larger format 14 Ah pouch cells
  - Further optimize

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Technical Back-Up Slides

Cost Comparison Values for 1 Ah Pouch Cells

	Thin Baseline	Thick Baseline	CoEx
NMC Cost	\$0.19	\$0.21	\$0.20
Graphite Cost	\$0.03	\$0.04	\$0.04
PVDF + ACB	\$0.01	\$0.01	\$0.01
Separator + Foils	\$0.16	\$0.11	\$0.11
Electrolyte	\$0.05	\$0.05	\$0.05
Total Cost	**\$0.45**	**\$0.42**	**\$0.41**

Energy Density Values for 1 Ah Pouch Cells

Discharge Rate	Gravimetric Energy Density (Wh/kg)			Volumetric Energy Density (Wh/L)			Gravimetric Power Density (W/kg)		
	Baseline	Thick Baseline	CoEx	Baseline	Thick Baseline	CoEx	Baseline	Thick Baseline	CoEx
D/10	140.06	158.00	148.82	374.61	439.90	407.86	14.01	14.88	15.80
D/5	136.61	153.34	143.73	365.40	426.93	393.91	27.32	28.75	30.67
D/3	133.42	149.86	138.90	356.87	417.25	380.66	44.47	46.30	49.95
D/2	130.37	142.96	133.55	348.70	398.03	365.99	65.19	66.77	71.48
1D	124.09	107.16	118.51	331.91	298.35	324.80	124.09	118.51	107.16
2D	113.12	32.11	79.94	302.56	89.39	219.09	226.24	159.88	64.21
3D	96.23	10.01	42.78	257.38	27.87	117.23	288.69	128.33	30.03