INL Electrochemical Performance Testing

Lee Walker, Matt Shirk (PI), Eric Dufek, and Sergiy Sazhin

2018 Annual Merit Review and Peer Evaluation Meeting

Project ID: BAT202
Idaho National Laboratory

June 19, 2018

INL/MIS-17-41668

Overview

Timeline

- Established in 1985
- Activity On-going

Barriers

- Cost – System Cost
- Performance – Energy, Power
- Reliability and Ruggedness – Vibration
- Life – Performance over time and cycles

Budget

- FY 2017: $3.81 M
- FY 2018: $3.65 M

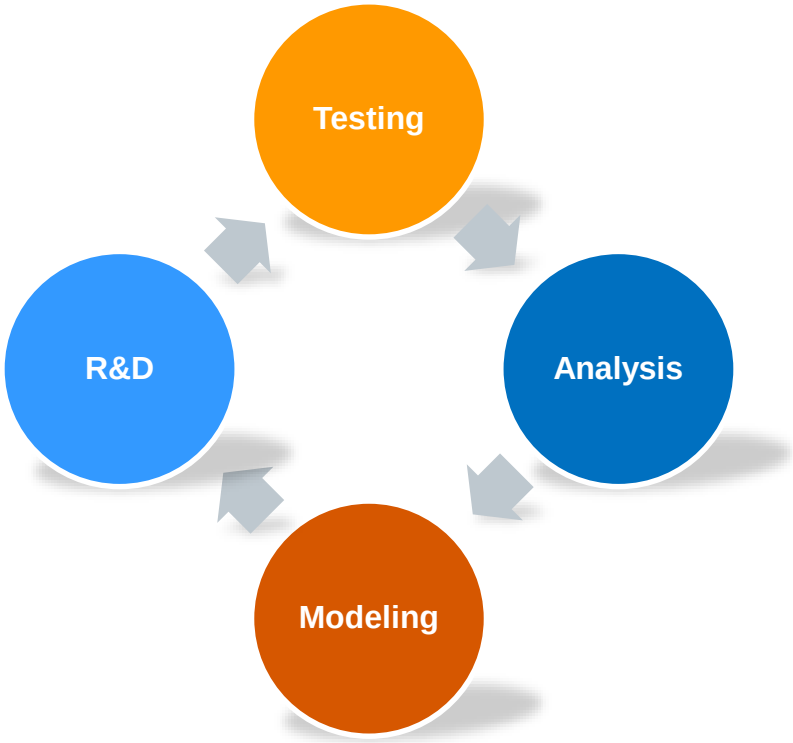
Partners

- U.S. Advanced Battery Consortium
  - FCA, Ford, General Motors
- U.S. DOE National Labs
  - ANL, SNL, NREL, ORNL
- Others
  - AVTA, DOT (NHTSA), Private Industry

Relevance

Technical Challenge

- Advanced battery chemistries intended for vehicles are being introduced to the automotive industry at an accelerated rate
  - DOE supported battery research spurs market changing innovation and INL supports the process
  - Transitioning chemistries from the lab to the consumer often fails due to inadequate testing early in the R&D cycle



Quality evaluation/validation/analysis is critical for adoption and success in the market

Relevance

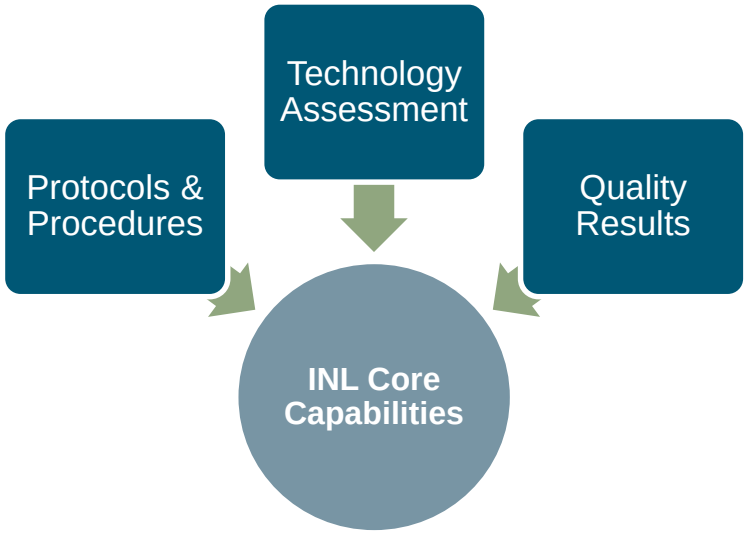
Objectives

Independent, science-based performance assessment of energy storage devices.

- Software analysis tools aid expert staff to analyze data and compile reports.
- Standards developed for data acquisition, analysis, quality, and management.

- **Protocols & Procedures**
  - Internationally referenced manuals for performance assessment
  - Lead National Laboratory for technical content and authorship with support from DOE and USABC.

- **Quality Results**
  - Flexible state-of-the-art energy storage test facility capable of supporting current and future development activities.
  - Rigorous NIST traceable calibration procedures for in depth uncertainty analysis
  - Temperature controlled testing for reliable and repeatable results.



Milestones

Fiscal Year	Date	Description	Status
2017	12/31/2016	Q1 Deliverables testing status report	Complete
2017	3/31/2017	Q2 Deliverables testing status report	Complete
2017	6/30/2017	Q3 Deliverables testing status report	Complete
2017	9/30/2017	Q4 Annual deliverables testing status report	Complete
2018	12/31/2017	Q1 Deliverables testing status report	Complete
2018	3/31/2018	Q2 Deliverables testing status report	Complete
2018	6/30/2018	Q3 Deliverables testing status report	On-track
2018	9/30/2018	Q4 Deliverables testing status report	On-track

Approach

- **INL Battery Test Center (BTC)**
  - Cell, Module, and Pack Performance and Life Assessment
  - Testing, Evaluation, Validation, and Verification
  - Data Quality Standards

- **Vehicle and Infrastructure Evaluation**
  - On-Road Demonstration and In-Lab Component Analysis
    - EV, PHEV, HEV & 12V S/S battery analysis
    - Infrastructure testing

INL Role: Research to support Testing, Evaluation, Validation and Verification

Technical Accomplishments/Progress

- INL Battery Test Center (BTC)
  - **756** test channels
    - 719 cell level
    - 32 module level
    - 5 pack level
  - >100 controllable thermal chambers
    - Capacity ranges from small to walk-in sizes
  - Non-Destructive Battery Evaluation Laboratory
    - Containment rooms
    - Vibration table

INL's Battery Test Center is DOE Core Capability for Electrochemical Performance Testing

Progress

Test Manuals

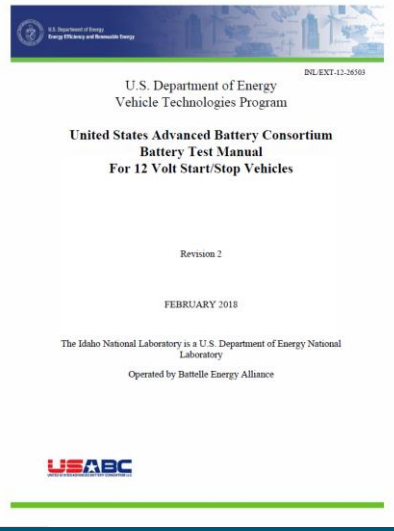
INL is the lead National Laboratory for technical content and authorship with support from DOE and USABC.

- New Manual Revision Developed and Published: Battery Test Manual for 12 Volt Start/Stop Vehicles
- New “Under Hood” High Survival Temperature Test Thermal Cycle
- Extended Cold Crank Test to determine operational region for cold crank operation

Test Energy Removed (Wh)	Test Temperature	-30°C				-25°C				-20°C				-15°C			
	Notional Pack Size (Ah)	40	44	48	52	40	44	48	52	40	44	48	52	40	44	48	52
	DOD at Target	71.4	64.9	59.5	54.9	71.4	64.9	59.5	54.9	71.4	64.9	59.5	54.9	71.4	64.9	59.5	54.9
	Pass/Fail (%)																
0																	
36																	
72																	
108																	
144																	
180																	
216																	
252																	
288																	
324																	
360																	

Pass by Measurement	
Pass by Assumption	
Fail by Measurement	
Fail by Assumption	

Figure E.1. Extended Cold Crank Test Matrix


INL/EXT-12-26503

U.S. Department of Energy
Vehicle Technologies Program

United States Advanced Battery Consortium
Battery Test Manual
For 12 Volt Start/Stop Vehicles

Revision 2

FEBRUARY 2018

The Idaho National Laboratory is a U.S. Department of Energy National Laboratory

Operated by Battelle Energy Alliance

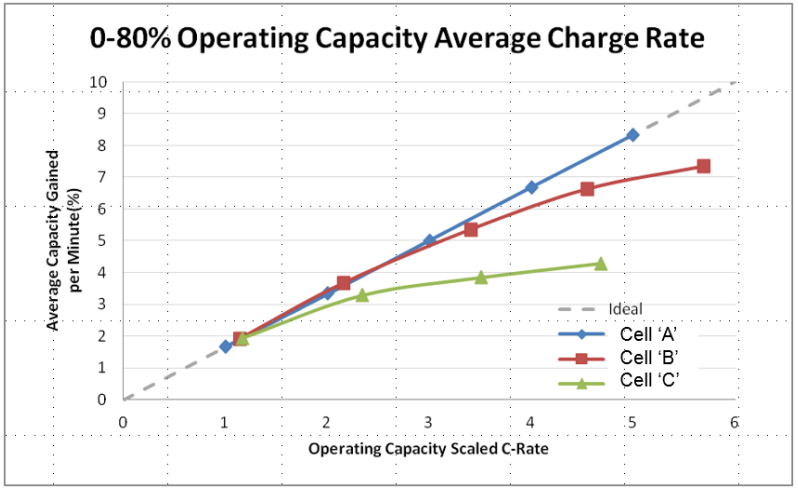
USABC

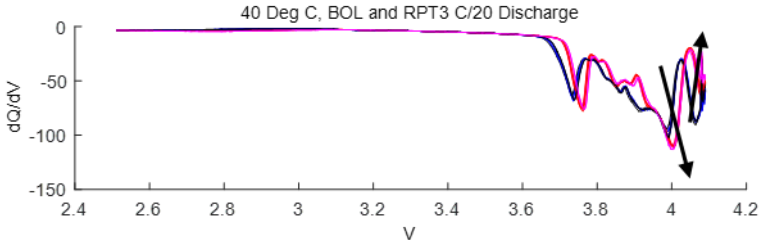
Manuals harmonized across programs to clarify testing and support similar analysis methods

Progress

Fast Charging Capability

- Various commercial technology cells are being benchmarked on their high-rate charge capability
- The implications of higher-than-standard fast charging are being evaluated
  - Cell design
    - Life
    - Safety
- Methods to investigate cell imbalance and lithium plating

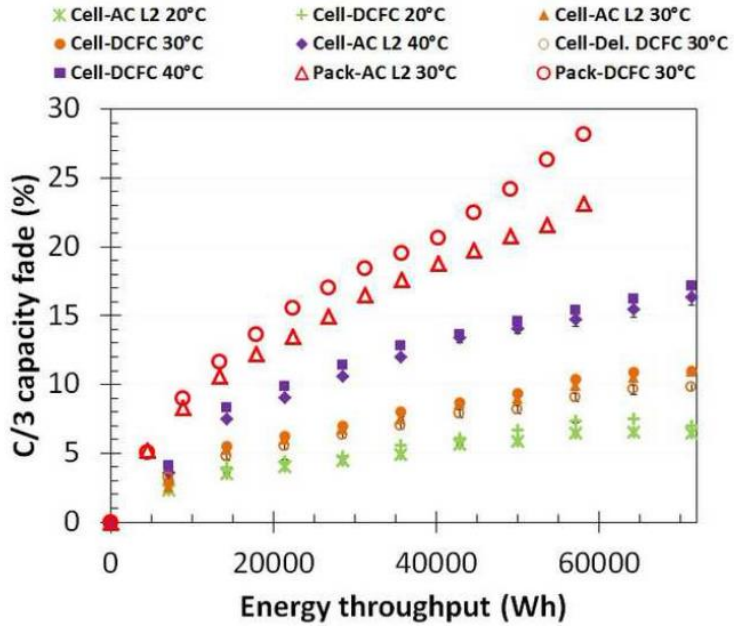


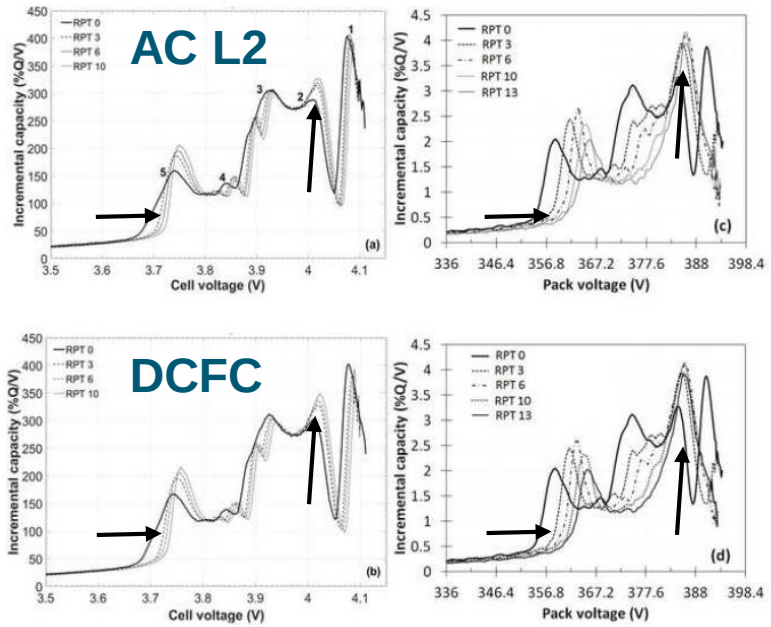


Extreme Fast Charging Imposes additional demands on cells

Progress

Fast charge implications: Pack and cell analysis





- Pack degradation cannot be directly inferred from cell evaluation.
- Fade modes readily identified and quantified - loss of lithium inventory and loss of active material (negative electrode)
- Lithium plating was not detected at any temperature

T. Tanim et. al, J. Power Sources, **2018**, 56-65

Cell design and management critical for XFC

Progress

INL-ANL Comparative Benchmarking

- INL and Argonne battery testing labs are working together with DOE to identify gaps in current test manuals and adopted practices
- Each lab is benchmarking a sample of identical cells in isolation
- Deviation in results will be analyzed for root causes and the gaps allowing such variation will be addressed

Continuous Process Improvement is key to Maintaining High Quality Data

Progress

USABC Testing in FY17 & FY18-to-date

Developer	Article Type	Number of Articles Tested	Capacity (Ah)	Application	Status
Leyden	Cell	9	1.7	EV	Complete
LG/CPI	Cell	12	1.4	EV	Complete
LG/CPI	Cell	12	12	12V S/S	Complete
LG/CPI	Cell	23	60	PHEV	Complete
LG/CPI	Module	1	36	12V S/S	Complete
LG/CPI	Cell	12	1.96	EV	Complete
NOHMS	Cell	15	2	PHEV	Complete
SAFT	Cell	3	13	12V S/S	Complete
NOHMS	Cell	18	10	PHEV	Complete
24M	Cell	3	6	EV	Complete
Envia	Cell	15	11	EV	Complete
NOHMS	Cell	18	1.5	PHEV	Complete
SAFT	Cell	13	12.5	HEV	Running
SAFT	Cell	15	1.5	12V S/S	Running
LG/CPI	Cell	15	12	12V S/S	Running
SAFT	Cell	15	1.5	12V S/S	Running
Amprius	Cell	24	10	EV	Running
LG/CPI	Cell	15	20	12V S/S	Running
LG/CPI	Module	4	40	12V S/S	Running
Farasis	Cell	5	30.5	EV	Running

The INL Battery Test Center evaluated 242 cells and 5 modules for USABC in FY17 and FY18-to-date.

Progress

Benchmark Testing in FY17 & FY18-to-date

Developer	Article Type	Number of Articles Tested	Capacity (Ah)	Application	Status
Hydroquebec	Cell	13	1	PHEV	Complete
LG Chem	Cell	3	1.5	48V	Complete
ORNL	Cell	6	1.4	EV	Complete
ORNL	Cell	6	1.4	EV	Complete
Toshiba	Cell	1	20	12V S/S	Complete
LG Chem	Cell	4	25.9	EV	Complete
EIG	Cell	20	5	12V S/S	Complete
Toshiba	Cell	3	20	EV	Running
Toshiba	Cell	12	20	12V S/S	Running
Toshiba	Cell	15	2.9	EV	Running
LG/CPI	Cell	10	25.6	PHEV	Running
ANL	Cell	15	0.019	EV	Running

The INL Battery Test Center evaluated 108 cells for Benchmark in FY17 and FY18-to-date.

Progress

DOE FOA-2011 Testing in FY17 & FY18-to-date

Developer	Article Type	Number of Articles Tested	Capacity (Ah)	Application	Status
Argonne/Miltec	Cell	8	0.1	PHEV	Complete
Applied Materials	Cell	15	0.042	EV	Complete

The INL Battery Test Center evaluated 23 cells for FOA-2011 in FY17 and FY18-to-date.

Progress

DOE ABR-IC³P Testing in FY17 & FY18-to-date

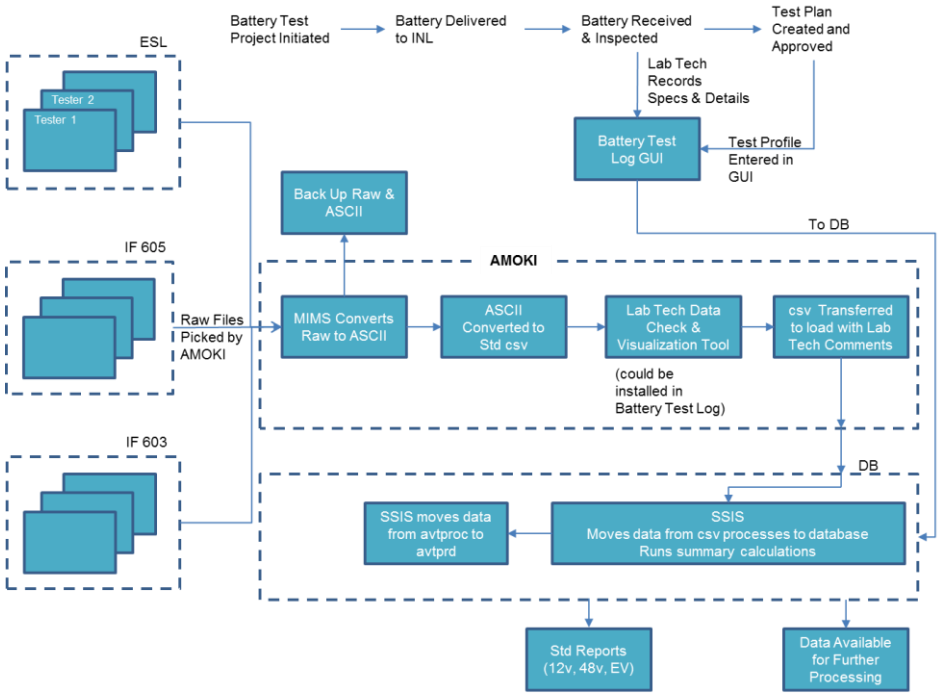
Developer	Article Type	Number of Articles Tested	Capacity (Ah)	Application	Status
ANL	Cell	9	0.25	PHEV	Complete
Penn State University	Cell	9	2	PHEV	Complete
ANL	Cell	12	0.447	PHEV	Complete
Envia	Cell	12	26	PHEV	Running
Penn State University	Cell	15	2	PHEV	Running
Farasis	Cell	12	0.81	EV	Running
Farasis	Cell	12	1.22	PHEV	Running

The INL Battery Test Center evaluated
81 cells for DOE ABR-IC³P in FY17 and FY18-to-date.

Progress

Testing Flow and Data Management Tools

- Data tools enable enhanced testing efficiency and performance tracking and reporting



Deliverable/Test tracking

Data Conversion

Data Processing

Analysis and Reporting

Database accelerates dissemination of R&D Results to stakeholders

Response to Previous Year Reviewers' Comments

- Reviewer Comment:
  - The reviewer remarked that INL maintains a state-of-the-art test facility, and that it is a good idea to think ahead about what new equipment will be needed to test future technologies. The reviewer also pointed out methods for measuring the swelling of Si containing cells under cycling, high current channels for the next generation of 12V cell testing, and combination vibration and cycling testing, possibly in a temperature controlled environment.
- Reviewer Comment:
  - The reviewer pointed out that INL is on the edge of needing more facilities and staff as the load of new materials and cells to test grows.
- Battery Test Center (BTC) Response:
  - INL Battery Test Center carefully builds capabilities to keep pace with the needs of DOE's Energy Storage program. Growth is balanced with anticipated budgets, and new techniques are constantly being evaluated and implemented to maximize the utility of the existing resources while remaining relevant. Tracking the stress and strain of cells is in fact an example of new test methods being developed at INL to better understand the implications of some new EV cell technologies. These methods, if useful, will be rolled into future manual revisions.

Collaboration & Coordination with Other Institutions

- INL and Argonne National Laboratory continue to enjoy a close testing partnership.
  - This collaboration reduces unnecessary duplication of resources and creates valuable overlap of capability where useful.
  - Both labs are conducting parallel experiments to identify and correct gaps in documented test methods that could lead to variation in results.
- INL supplies SNL with aged batteries with known-path histories for additional abuse testing.
- INL is very involved in several USABC activities and works closely with its partners.
  - Technical Advisory Committee (TAC), as well as the Test Methods & Definitions and Internal Short Circuit Work Groups.
- Expanded test capability creates additional opportunities for collaboration with other national labs (ANL, LBNL, SNL, NREL, ORNL), government agencies, and industry and academic institutions.

Remaining Challenges and Barriers

- Maintaining a flexible state-of-the-art energy storage device testing facility
  - Adapt to shifting targets and emerging technology
  - Continuously update/modify test protocols and analysis procedures
  - Equipment maintenance, repair, and upgrades
- Expanding lab capability for enhanced data assessment through additional equipment and expertise
- Strengthen and expand collaborative ties with existing Vehicle Technologies Office programs at INL, other National Laboratories, and industry.
- Strengthening relationships with developers to ensure testing conforms to the needs of unique technologies while maintaining compatibility with USABC procedures and Vehicle OEM needs.

Proposed Future Research

- USABC testing deliverables
  - Continue testing and analysis for existing deliverables
  - Provide deeper understanding of failure modes and mechanisms, particularly for emerging materials
- Update and Refresh test manuals
  - EV & 12V S/S
- Expand lab capabilities
  - Continue building non-destructive evaluation facilities and expertise
  - Additional laboratory support for industry and universities
  - Further develop and refine data management systems
- Expand ties with VTO vehicle and infrastructure research activities to keep abreast of technology trends and needs
- Enhance understanding of energy storage for first responders and regulators

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

Summary

- The INL Battery Test Center is the lead DOE laboratory for advanced automotive battery performance testing.
  - 20,000 square feet of lab space with 752 test channels for advanced energy storage testing.
- INL is continuing to support DOE and USABC with science-based performance testing and assessment of candidate battery technologies for various vehicle platform applications.
  - Rigorous NIST traceable calibration procedures provide for in depth uncertainty analysis.
- INL has strong capabilities in advanced battery diagnostics and prognostics for improved state-of-health assessment.
  - On-going research activities in collaboration with DOE, NHTSA, and SNL.

The INL Battery Test Center (BTC) evaluated 454 cells and 5 modules for a total of 458 articles in FY17 and FY18-to-date

Technical Backup Slides

Equipment

Tester Make	Tester Capability	# of Testers	# of Channels
Maccor	0-5V, +/- 5A	3	160
Maccor	0-10V, +/- 12.5A	3	72
Maccor	0-5V, +/- 25A	2	48
Maccor	0-5V, +/- 30A	1	96
Maccor	0-5V, +/- 50A	2	72
Maccor	0-5V, +/- 60A	6	144
Maccor	0-7V, +/- 90A	2	48
Maccor	0-5V, +/- 100A	1	8
Maccor	0-5V, +/- 180A	1	8
Maccor	0-5V, +/- 250A	6	47
Maccor	0-7V, +/- 250A	1	8
Maccor	0-7V, +/- 300A	1	8
PEC	0-50V, +/- 80A	1	12
Maccor	0-55V, +/- 220A	2	8
Maccor	0-65V, +/- 250A	1	4
Maccor	0-60V, +/- 275A	1	4
Bitrode	0-60V, +/- 500A	1	4
Bitrode	0-500V, +/- 350A	3	3
Bitrode	0-1000V, +/- 500A	2	2
Total Count of Testers and Channels		**40**	**756**