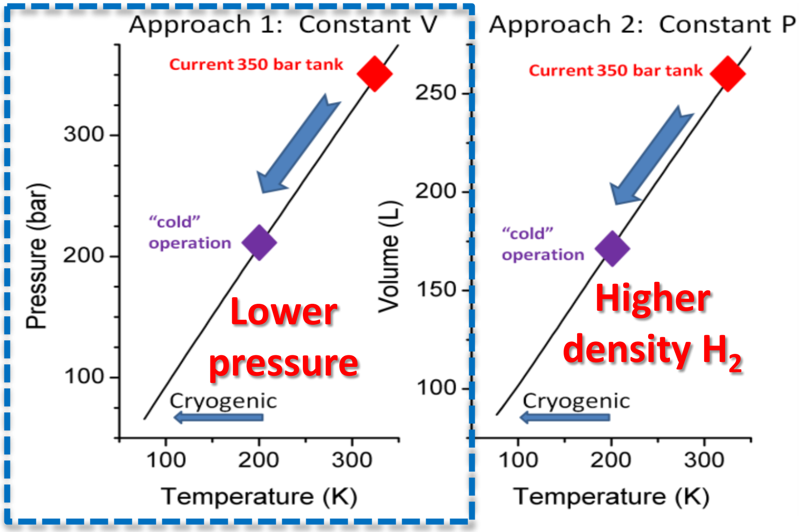
Type IV COPV Cold Gas Operation Challenges

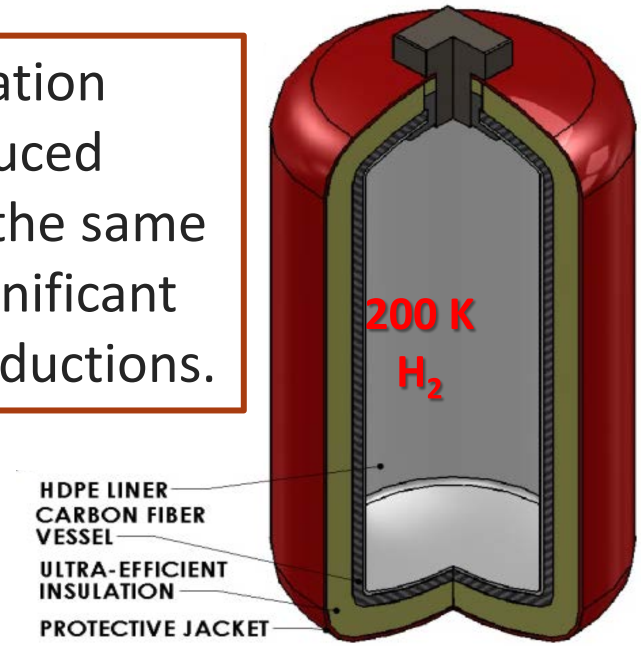
DAVID W. GOTTHOLD

Pacific Northwest National Laboratory

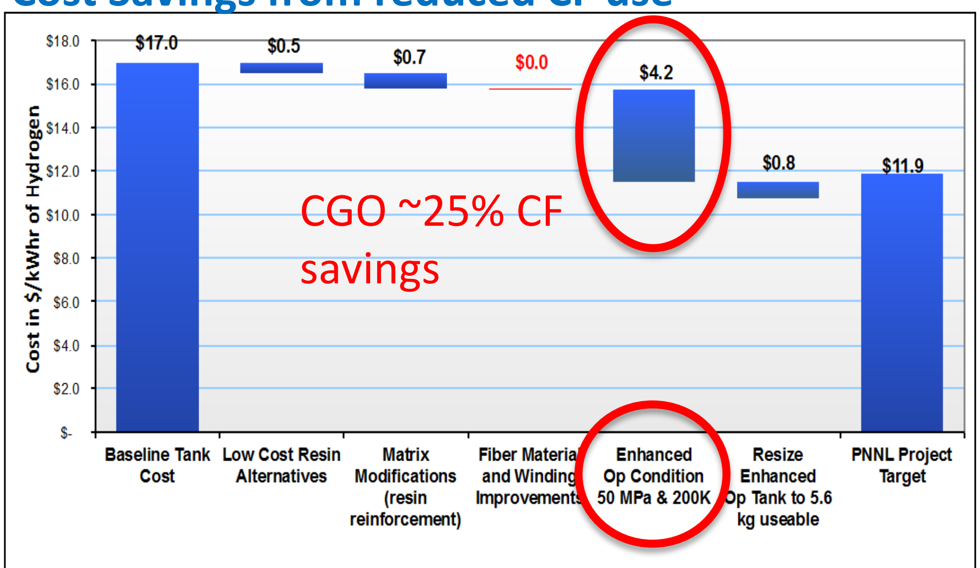
Cold Gas Motivation and Challenges



Cold gas operation allows for reduced pressures for the same volume for significant CF and cost reductions.



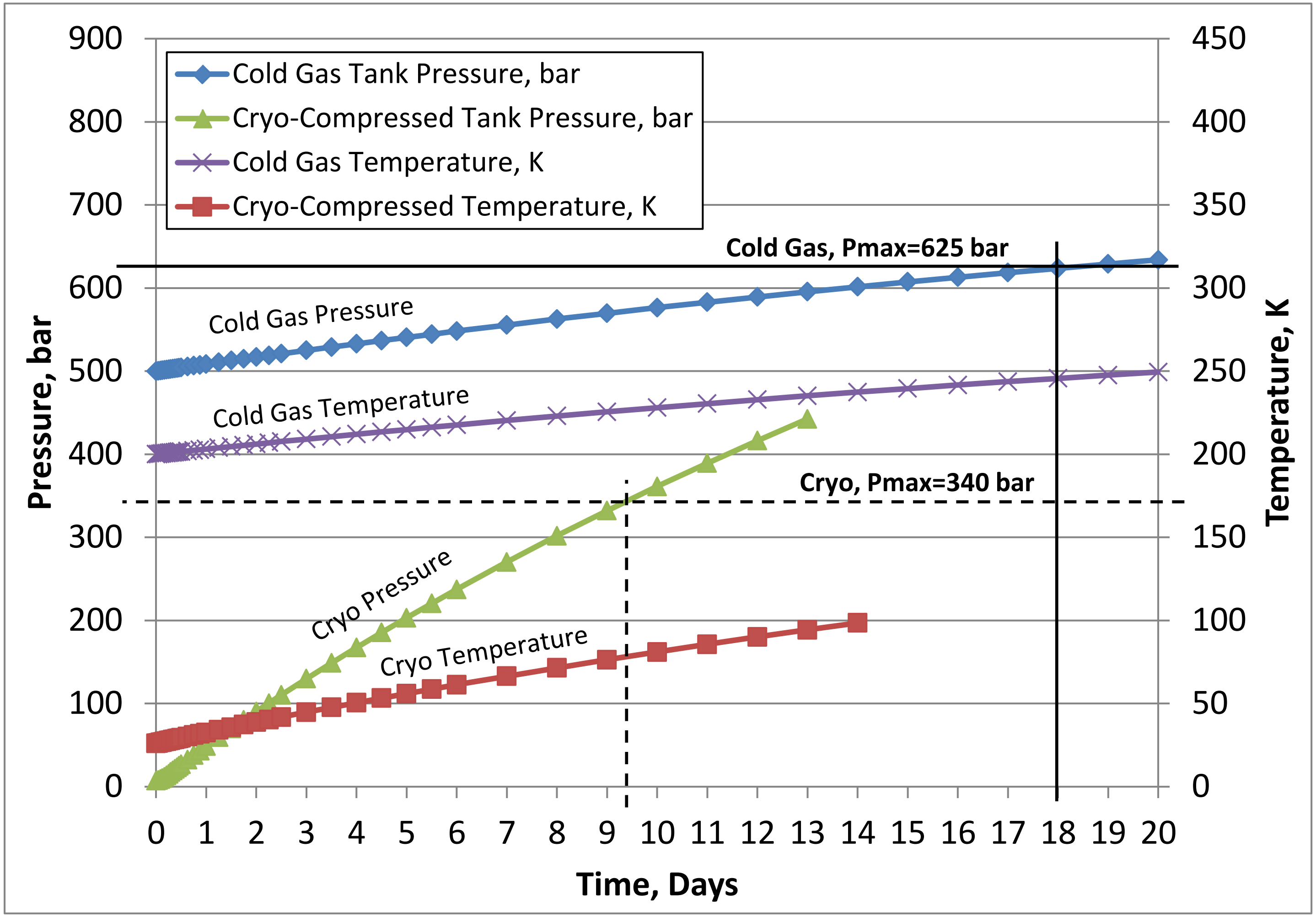
Cost Savings from reduced CF use



Materials properties change significantly at cold gas temperatures and must be studied.

Example: HDPE DBT ~ 200 K

Higher operating temperature improves dormancy for equivalent R-factor



Key Cold-Gas Challenges

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- Operation conditions near or below transition temperatures of many common polymers
  - HDPE DBT ~200K (set lower operating temperature)
- Thermal cycling across a wide temperature range
  - -73C to +60C
  - Temperature crosses condensation point
- Thermal expansion mismatch
  - Polymer-metal interface at boss
  - Liner/composite shrinkage

Low Temperature Materials Data

Use	Material	Reported Useful Temp Range, °C	T_g , °C	T_m , °C	Linear CTE, 10^{-5}/C
Valve Seals	Viton	-23 / +204	-20	260	8.3 – 10.5
	Nitrile Rubber (Buna-N)	-34 / +250		---------	11.2
	Teflon (PTFE)	-100 / +260	115	335	10
	EPR (ethylene-propylene-rubber)	-62 / +160	-60	---------	
	Fluorosilicone	-59 / +232	-50	---------	81 (low Temp)
	Silicone	-62 / +216	-50	---------	18 – 25.5
	Neoprene	-40 / +121	-43	---------	61 - 72
Valve Pistons	PEEK	/ +250	143	343-374	
Valve Seats	Nylatron	/ +105		260	6.3 – 10.6
	Vespel	-100 / +500	none observable	none observable	2.7 – 5.4
	PCTFE		45	215	7
Tanks: Resin	Epoxy				
	Vinylester				
Liner	HDPE		-110	130	12
	PPS (polyphenylene Sulphide)	/ +220		282	5
	Nylons		50	255	8-10

Low Temperature Materials Data

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Use	Material	Reported Useful Temp Range, °C	T_g , °C	T_m , °C	Linear CTE, 10^{-5}/C
Valve Seals	Viton	-23 / +204	-20	260	8.3 – 10.5
	Nitrile Rubber (Buna-N)	-34 / +250		---------	11.2
	Teflon (PTFE)	-100 / +260	115	335	10
	EPR (ethylene-propylene-rubber)	-62 / +160	-60	---------	
	Fluorosilicone	-59 / +232	-50	---------	81 (low Temp)
	Si				18 – 25.5
	N				61 - 72
Valve Pistons	P				
Valve Seats	N				6.3 – 10.6
	Vespel	-100 / +500	none observable	none observable	2.7 – 5.4
	PCTFE		45	215	7
Tanks: Resin	Epoxy				
	Vinylester				
Liner	HDPE		-110	130	12
	PPS (polyphenylene Sulphide)	/ +220		282	5
	Nylons		50	255	8-10

There is a lot of missing and incomplete data in the temperature ranges of interest

Cold Gas Capability at PNNL

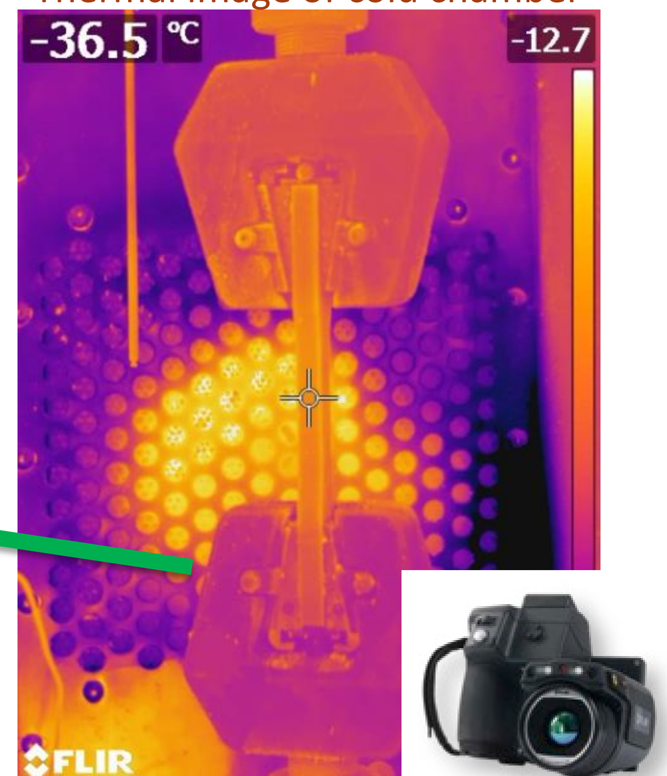
Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- To investigate materials compatibility at enhanced operating conditions of cold gas operation, PNNL has expanded our cold temperature capability
  - New mechanical test frame capable of -129 C up to 315 C for all materials
  - IR camera for thermal imaging and evaluation of advanced physical insulation for cold gas operation

Enhanced environmental chamber on test frame

Enhanced environmental chamber (inside)

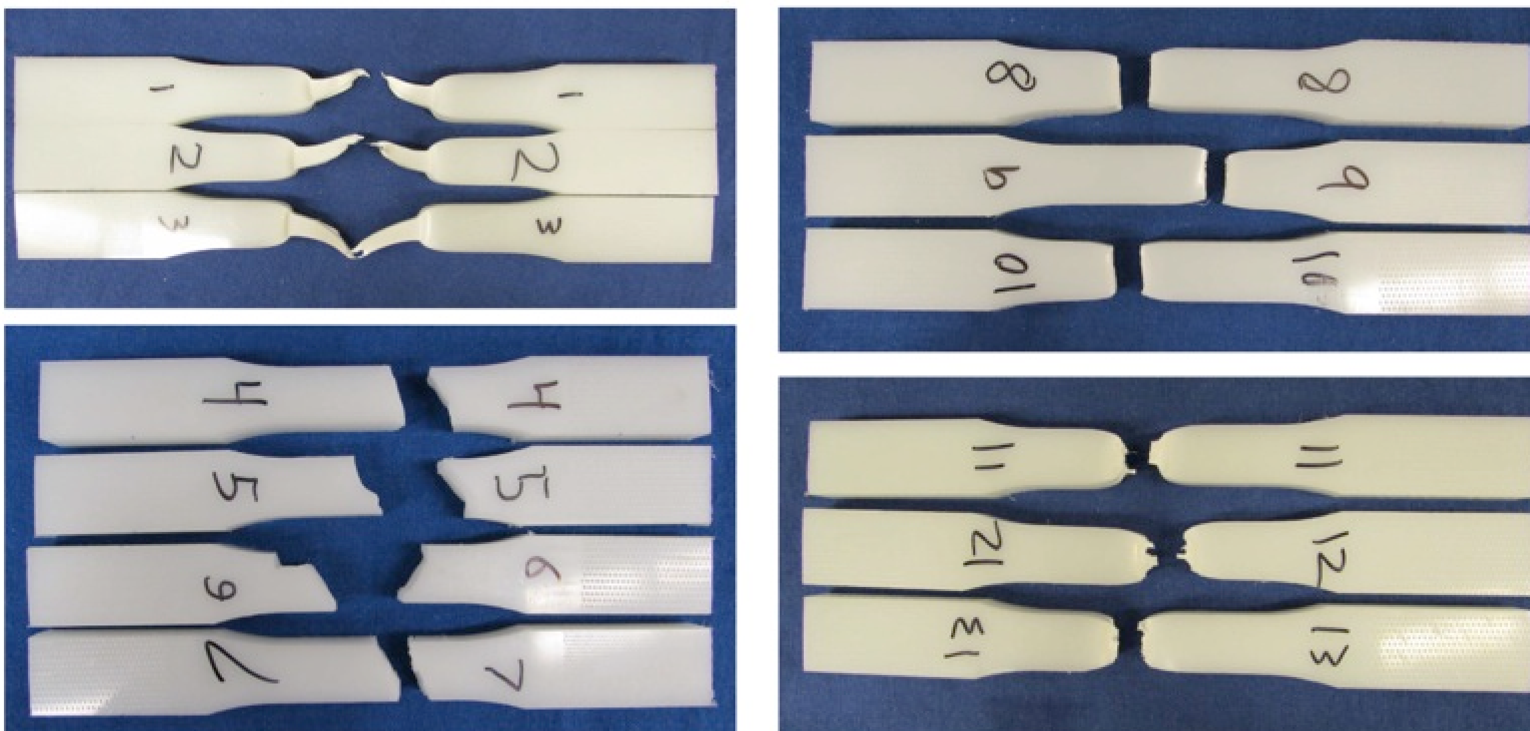
Thermal image of cold chamber



Preliminary polymer test results

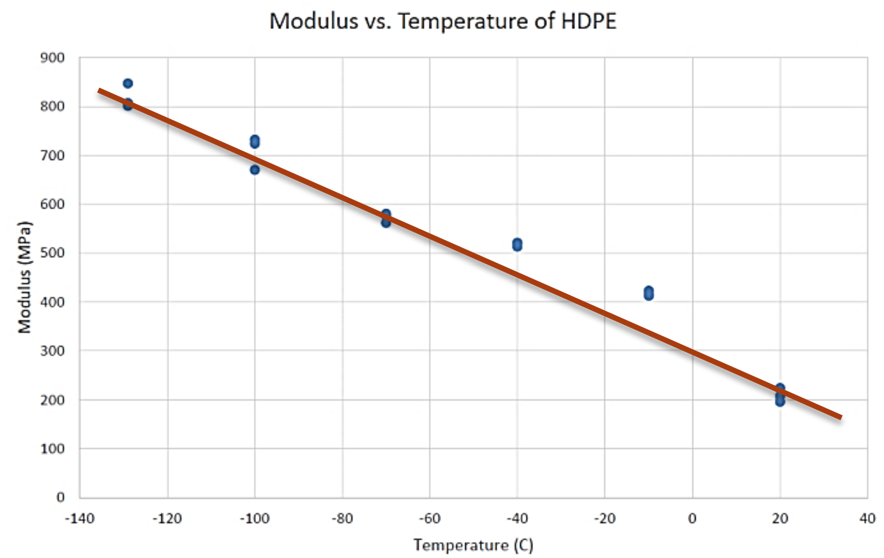
Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

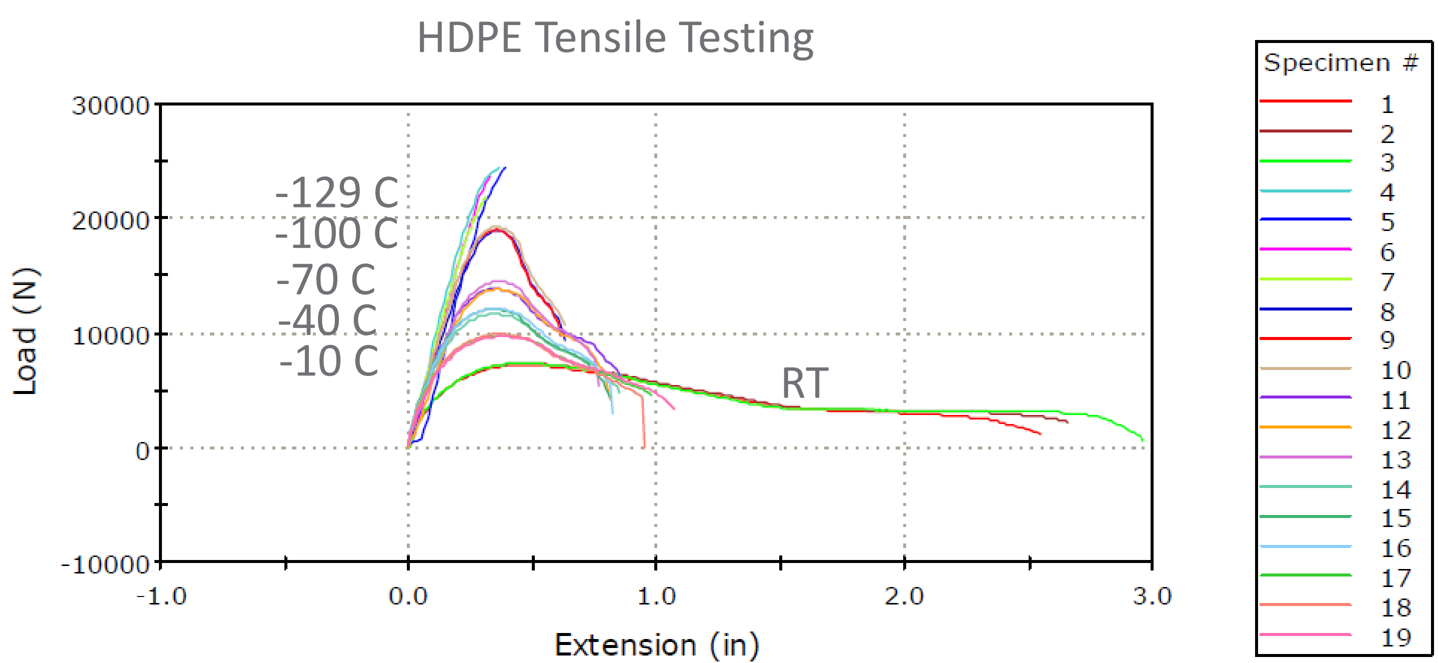
- PNNL started preliminary testing of baseline polymers from -129C to room temperature
- Preliminary data from HDPE, Teflon, and nylon in progress
- HDPE – clear ductile/brittle transition observed



Preliminary polymer test results

- HDPE modulus increases as temperature decrease
- Ductile/brittle transition occurs below -100 C
- Teflon and Nylon tests in progress, other materials to follow

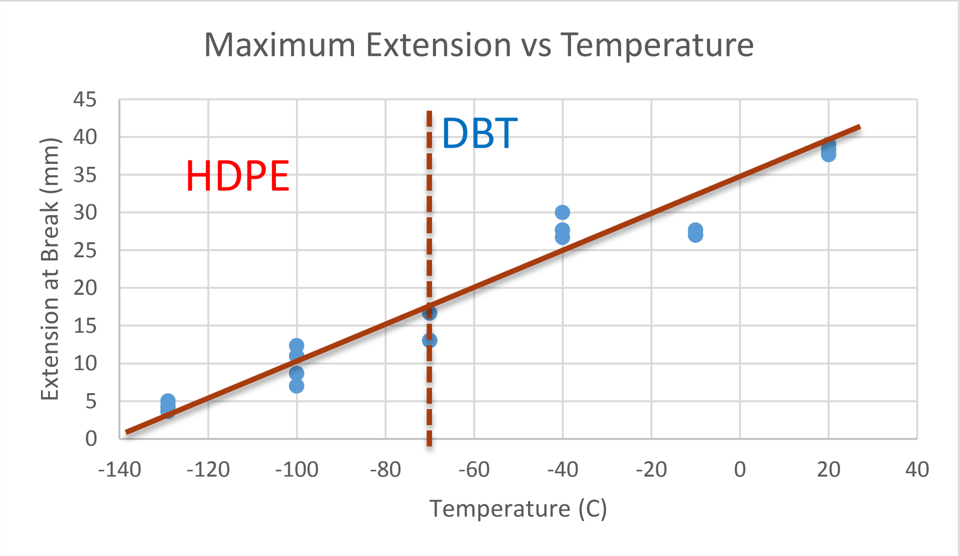


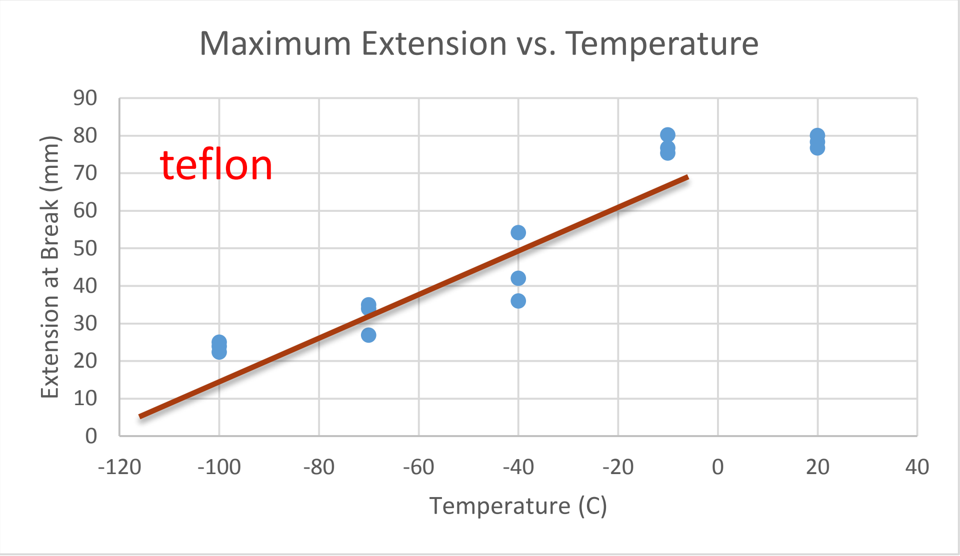


Example data for Cold Polymers

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

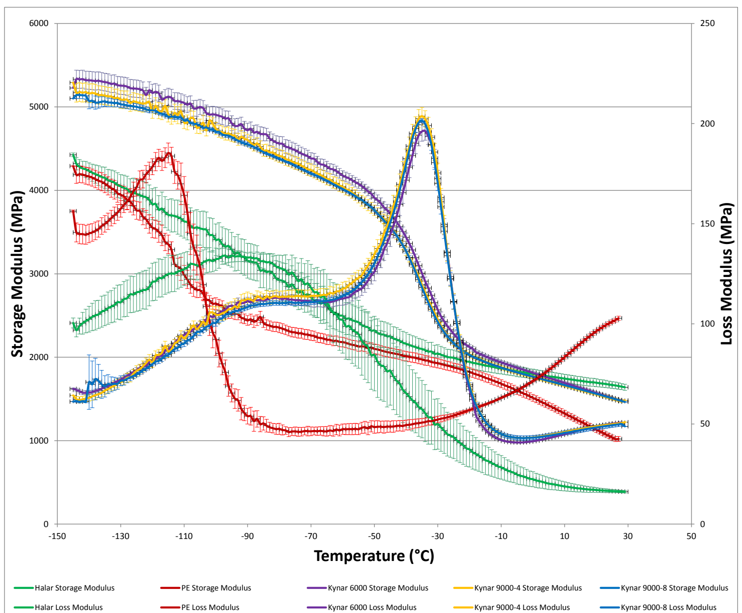
- In general, as temperature goes down:
  - Modulus increases
  - Strength increases (then decreases)
  - Strain to failure decreases
  - Transitions occur
- Ductile Brittle Transitions occur
  - Related to glass transition temp
  - Example HDPE ~ 200K



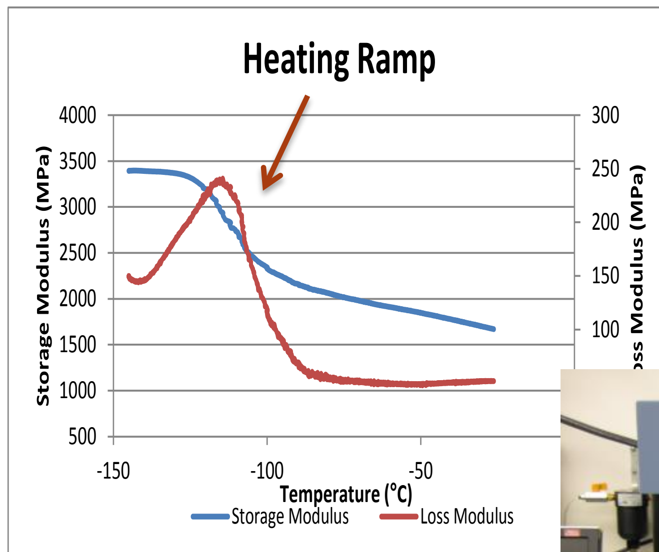


Additional test capabilities

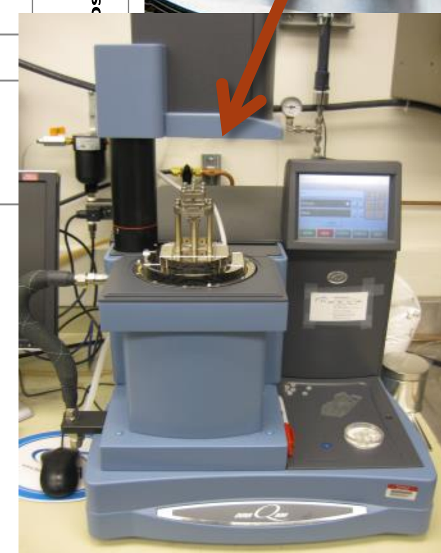
- In addition to cold gas mechanical testing, PNNL can test polymers with DMA at cold temperatures to investigate transition temperatures to determine potential material problems\
- -150 C to room temperature (and up to 650 C)



Previous DMA results for multiple polymers (loss and storage modulus)



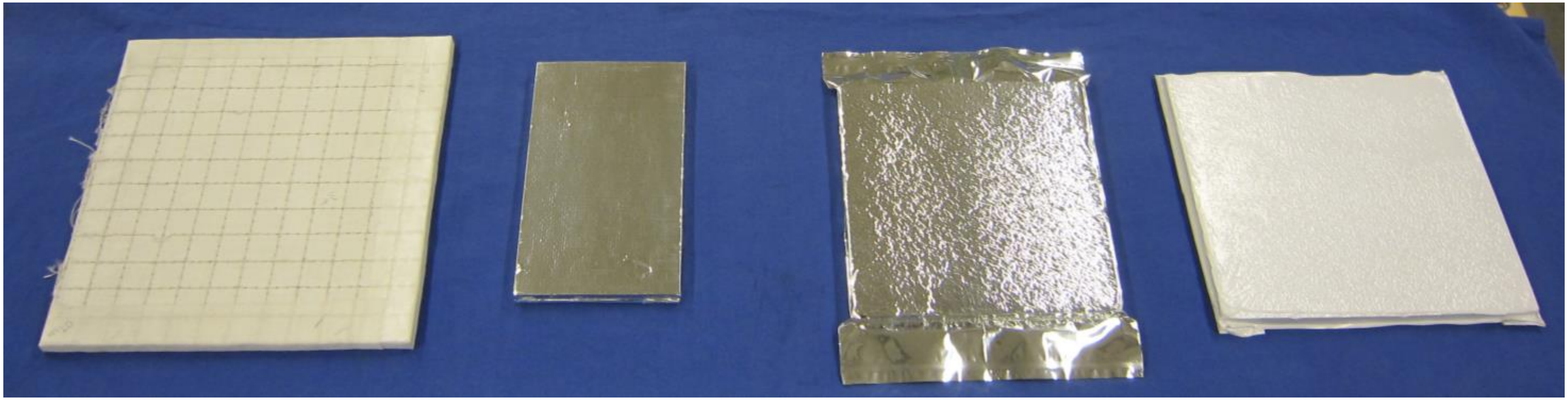
Previous DMA data for UHMWPE



Insulation for cold operation

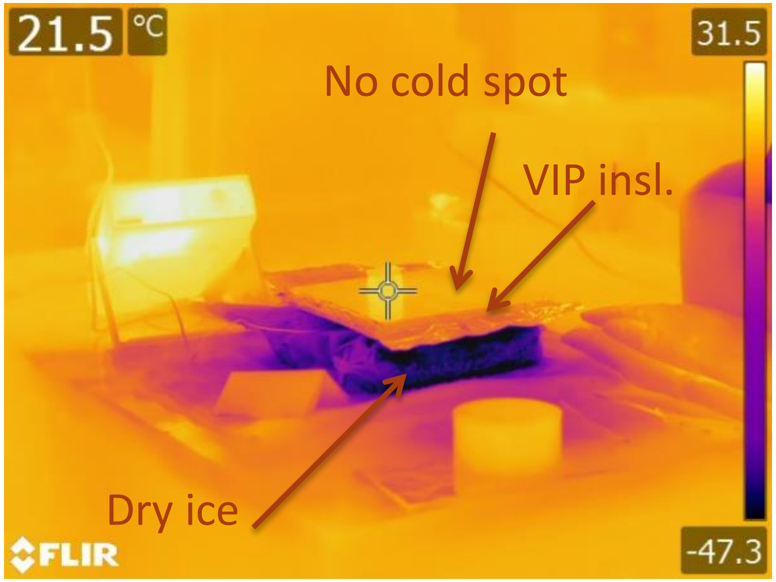
- Advanced physical insulation such as vacuum insulation panels (VIP) will likely be the only physical insulation capable of achieving required dormancy
- VIP material typically vacuum packaged fumed silica (FS) in stiff board-like configuration – most aluminized mylar packaging
- Quilted (non vacuum packaged, VP) material also available – would need to vacuum package after tank wrap

Quilted FS (not VP) VIP-AM (vendor 1) VIP-AM (vendor 2) VIP (vendor 2)

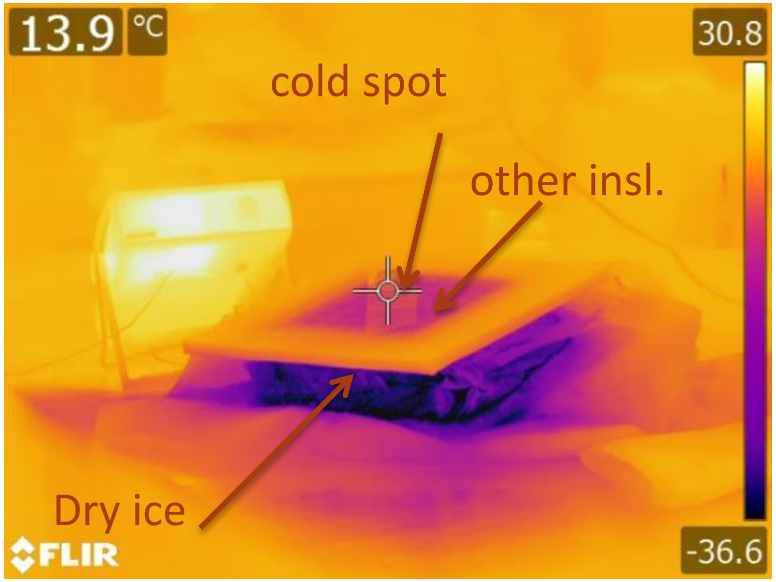


Thermal testing of insulation

- In process of designing test frame for thermal testing of different insulations and joining at enhanced operating conditions – evaluation with thermal imaging



VIP insulation – high performance



Other insulation – poor performance

Unknowns

- Fatigue and impact behavior both at low temperatures and after thermal cycling
- Scaling of materials testing from coupons to full tanks
- Effect of fill process on liner stability
- Vibration stability of advanced insulation

Collaborations

- Pacific Northwest National Laboratory: David Gotthold (PI), Ken Johnson, Kyle Alvine, Matt Westman
  - Project management, material and cost models, resin modifications
- Hexagon Lincoln: Norm Newhouse, Brian Yeggy, Alex Vaipan
  - Tank modeling, tank fabrication, tank and materials testing
- Ford Motor Company: Mike Veenstra, Dan Houston
  - Enhanced operating conditions, cost modeling, materials testing
- Toray Carbon America: Anand Rau*
  - Carbon fiber surface modification and testing
- AOC Resins: Thomas Steinhausler, Mike Dettre
  - Resin system design and materials testing