Low Viscosity Epoxy for Ultra-High Solids Maintenance & Protective Coatings

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Outline

- Challenges of high solids epoxy coatings
- Levers controlling viscosity of epoxy coatings
- Physical properties of low viscosity epoxy (DLVE) and standard liquid epoxies
- Performance of coatings from DLVE and standard liquid epoxies
- Technical summary
- Benefits DLVE

Low Viscosity Epoxy Resins for Overcoming Challenges with High Solids Coatings

Dow has developed a family of low viscosity resins for high solids coatings.

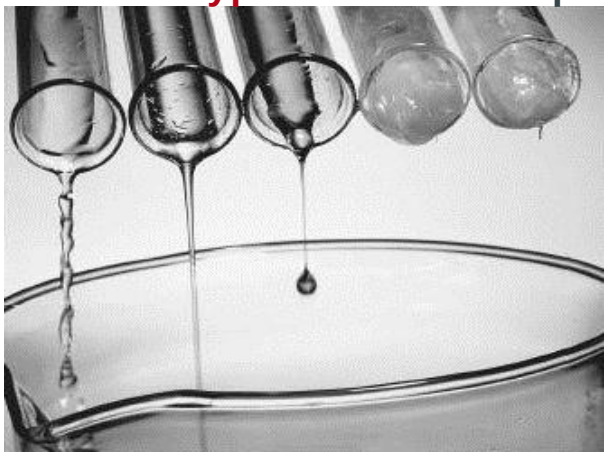
Currently available ultra-high solids coatings based on standard epoxy resins can suffer from a number of drawbacks:

- High viscosity
- Poor spray application qualities
- Reduced corrosion resistance

Novel low viscosity epoxy:

- Features low viscosity vs. Bis-A and Bis-F liquid epoxy resins
- Enables ultra high solids systems (> 90% volume solids)
- Improves sprayability and appearance
- Offers excellent corrosion resistance

LVE Prototypes **Semi-Solid Epoxy**



Levers Controlling Viscosity

- Levers for controlling formulation viscosity
- Low viscosity is important to enable spray application

Epoxy	Pigment
• Low viscosity epoxies enable low viscosity paints • Reactive diluents reduce viscosity but can affect the performance • Solvents reduce viscosity but increase VOC and reduce volume solids	• Pigment volume concentration (PVC) has a high impact on paint viscosity at a given solids level • Not all pigments are equal: Size, shape, and oil absorption play a role in viscosity • Dispersants affect viscosity
Hardener	**Volume Solids**
• Low viscosity hardeners enable low viscosity paints • Chemical identity and AHEW and stoichiometry	• High volume solids will result in high viscosity coatings • The higher the volume solids, the lower the VOC

Comparison of DLVE to Standard Liquid Epoxy / Epoxy Diluent Blends

DLVE demonstrates significantly lower viscosity vs. standard epoxy resins, and similar viscosity to conventional diluent-modified epoxy resins.

Property[1]	SER in Solvent	BADGE	BFDGE	BADGE + AGERD	DLVE 18	DLVE 19
Description	Solid 1-Type Epoxy resin, 75% solids in xylene	Liquid Bisphenol A Diglycidyl Ether	Liquid Bisphenol F Diglycidly Ether	Liquid Bisphenol A Diglycidyl Ether + AGE Reactive Diluent[3]	Modified resin + novel cycloaliphatic polyglycidyl ether	Modified resin + novel cycloaliphatic polyglycidyl ether
Epoxide Equivalent Weight, EEW, (g/eq)	430 - 480 (on resin solids)	182 - 192	167 - 174	195 - 204	165 - 180	190 - 205
Viscosity[2] @25ºC, (cP)	16,000	13,000	3,900	750	850 - 1,250	4,500 - 5,300

[1]Typical Properties not to be construed as specifications
[2]Viscosity tested with TA Instruments AR-2000 Rheometer, 5 sec^{-1} shear rate
[3]C12 – 14 alkyl glycidyl ether (AGE)

Temperature Effect on Viscosity of DLVE 18 vs. Alternative Resins

Lower viscosity at low temperatures can be a potential advantage in spray applied cold weather applications.

Temperature (ºC)	Viscosity of BADGE[1] (cP)	Viscosity of BFDGE[2] (cP)	Viscosity of DLVE 18 (cP)	Viscosity Reduction (%) of DLVE 18 vs. BADGE	Viscosity Reduction (%) of DLVE 18 vs. BFDGE
20	28,930	7,177	1,326	95	82
23	18,190	5,223	1,034	94	80
25	13,380	3,820	866.5	94	77
50	488.3	196.8	103.8	79	47

Viscosity tested with TA Instruments AR-2000 Rheometer, 5 sec^{-1}

[1]Liquid Bisphenol A Diglycidly Ether
[2]Liquid Bisphenol F Diglycidly Ether

Starting Point Formulation for High Solids Coating

DLVE 18 90% Volume Solids, 25% PVC

Material Name	Kilograms	Liters
Part A		
Grind		
Low Viscosity Epoxy (DLVE 18)	86.00	75.95
Xylene solvent	5.07	5.88
Wetting & dispersing agent	0.49	0.52
Defoamer	0.20	0.20
Wollastonite filler	59.75	20.60
Strontium zinc phosphosilicate anti-corrosive pigment	17.56	5.83
Barium sulfate extender pigment	25.89	6.31
Red iron oxide pigment	25.86	4.94
Propylene glycol methyl ether acetate solvent	0.53	0.55
Grind Sub-total	221.34	120.78
Grind above in order on Cowles, check Hegman Grind rating		
Let Down		
Methyl isobutyl ketone solvent	0.86	1.07
Propylene glycol methyl ether acetate solvent	0.71	0.73
Xylene solvent	6.73	7.80
Part B: Curing Agent		
Mannich Base (D.E.H.™ 615)	37.47	37.10
Totals	267.11	167.49
Volume Solids	**90%**	
VOC (g/L)	**85 g/L**	
PVC	**25%**	

Coating Performance Comparison

LVE demonstrates:

- Sprayable viscosity vs. LERs
- Faster dry time, increased hardness, and improved chemical resistance vs. Bis A epoxy with AGE diluent
- Anti-corrosive primer formulation: 90% solids; 25% PVC; Mannich base hardener

Epoxy Resin	SER (CONTROL)	BADGE	BFDGE	BADGE + AGE RD	DLVE 18
Hardener	Polyamide	Mannich Base	Mannich Base	Mannich Base	Mannich Base
Volume solids (%)	**52%**	90%	90%	90%	90%
VOC (g/L)	**418**	85	85	85	85
Viscosity (KU), 25°C	88	**> 140 (Brookfield Viscosity = 5220 cP)**	**> 140 (Brookfield Viscosity = 4880 cP)**	99	**102**
Amenable to airless spray application?	Yes (only due to low volume solids)	No	No	Yes	Yes
Pot-Life (hr)	> 4	0.5 - 1.0	0.25 - 0.5	0.5 - 1.0	0.5
Dry-to-touch time (hr), 25°C	2.5	1.3	1.5	2	1.9
Tack-free time (hr), 25°C	3.5	1.9	1.9	2.9	2.9
Dry-hard time (hr), 25°C	8.5	2.4	2.2	4.1	3.4
Dry-through time (hr), 25°C	**14**	3.4	3.2	**12.2**	**7.0**
Konig hardness (sec), 7d	91	171	169	**111**	**144**
Impact resistance (in•lb)[1]	**40**	10	10	20	10
Chemical resistance[2]	8.6	9.0	8.5	**8.3**	**8.9**
Corrosion resistance: Scribe creep (mm) after 1,500 hr cyclic prohesion	1	3	2	4	**1**

[1]Direct impact resistance (ASTM D2794) *[2]Average score (out of 10 max) for multiple chemicals*

Corrosion Performance Comparison

Coating from DLVE 18 demonstrates combination of high corrosion resistance AND low formulation viscosity (90% volume solids, 25% PVC)

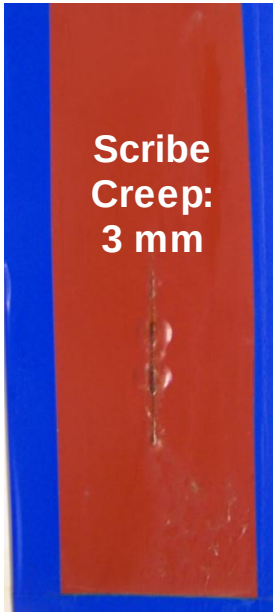
- Benchmark: SER cured with polyamide (52% volume solids)
- All other: Liquid epoxy resins cured with Mannich base (90% volume solids)
- 1,500 hours results per ASTM G85, 100 micron coating on blasted steel

SER

BADGE
2K Viscosity > 140

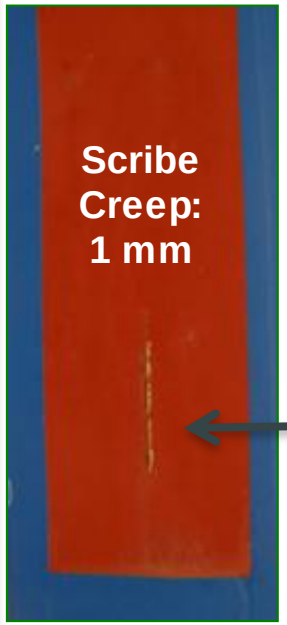
BFDGE
2K Viscosity > 140

Viscosity Too High for Spray Application



BADGE + AGE RD
2K Vicosity: 100 KU

DLVE 18
2K Viscosity: 102 KU



Easy spray application: Low viscosity and high solids

Good corrosion resistance: Less scribe creep and blistering

DLVE vs. Diluent Modified Epoxy – Corrosion Resistance

DLVE 18 coating demonstrates improved corrosion resistance compared to coatings from commonly used diluent-modified epoxy systems:

- Anti-corrosive primer formulation: 90% volume solids; 25% PVC; Mannich base hardener
- Single coat (~75 micron) applied via drawdown direct to 16 gauge blasted hot rolled steel
- 2,000 hours test duration as per ASTM G85

BADGE + CGE

BADGE + AGE

BADGE + BDDGE

BADGE + HDDGE

DLVE 18

CGE = Cresol glycidyl ether
AGE = C12-14 Alkyl glycidyl ether
BDDGE = Butanediol diglycidyl ether
HDDGE = Hexanediol diglycidyl ether

Airless Spray Results: DLVE vs. Bis-F Epoxy

LVE coating formulation demonstrates improved sprayability.

- 90% volume solids, 25% PVC formulation cured with phenalkamine
- Talc and silica based formulation (no zinc phosphate anti-corrosive pigment)

Bisphenol-F Epoxy

Poor Appearance

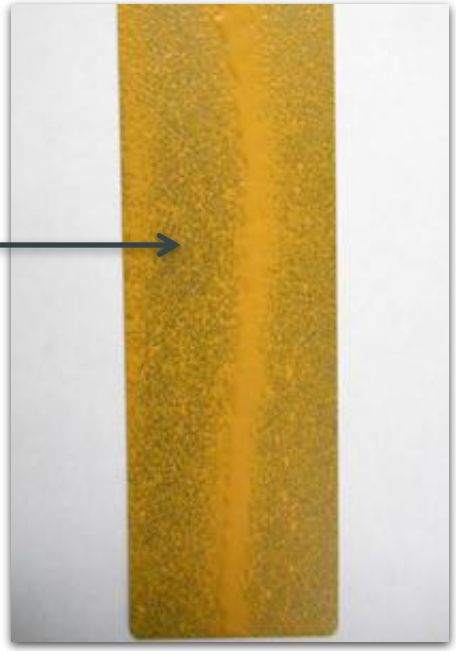
- Poor droplet break-up
- Higher viscosity
  ICI Viscosity = 2070 cP
  KU Viscosity = 129 KU

Low Viscosity Epoxy DLVE 18

Good Appearance

- Improved droplet-break-up
- Lower viscosity
  ICI Viscosity = 1258 cP
  KU Viscosity = 104 KU

Poor appearance and coverage



Improved appearance
Gloss :
20° - 86
60° - 100
85° - 100

*Sprayed using Graco XD Force Cordless Airless Sprayer, with 0.017 ” tip.

DOW

DLVE Airless Spray Results: Video Comparison

Low viscosity epoxy demonstrates improved sprayability and coating appearance

- Enables improved droplet break-up and improved spray fan pattern
- At all spray conditions (pressure, tip size), Bisphenol-F Epoxy formulation could not be sprayed with good appearance

Bisphenol-F Epoxy

Poor Appearance

Click on Black Box above to start video
(auto full screen mode)

Low Viscosity Epoxy DLVE 18

Improved Appearance

Click on Black Box above to start video
(auto full screen mode)

Corrosion Performance Spray Applied

Strong corrosion resistance of spray-applied coating based on DLVE 18:

- 90% vs. 25% PVC
- Phenalkamine cure, and no anti-corrosive pigment
- Single coat (~75 microns) applied via airless spray direct to metal
- Bonderite 1,000 phosphate-treated, cold-rolled steel panel
- 1,500 hours of salt spray testing

Chemical Resistance: DLVE 18 vs. Solid and Fatty Acid Epoxy Resins

DLVE 18 has comparable chemical resistance performance to standard epoxies.

Chemical	1-Type Solid Epoxy	Fatty Acid Epoxy	DLVE 18
SOLVENTS:			
Methyl ethyl ketone	9	7	8
VM&P naphtha	10	8	10
Ethanol (50%)	9	7	8
Isopropanol	9	7	8
ACIDS & BASES:			
Hydrochloric acid (10%)	7	6	7
Sulfuric acid (10%)	6	6	5
Ammonium hydroxide (28%)	8	7	8
Sodium hydroxide (15%)	10	8	9
CLEANERS & AUTO FLUIDS:			
Formula 409 cleaner	9	7	9
Pine Sol cleaner	6	7	9
Motor oil (10W30)	10	9	10
Brake fluid	10	8	8
AVERAGE SCORE:	8.6	7.3	8.3

Water Resistance: DLVE 18 vs. Bis-A LER and Semi-Solid Epoxy Resins

DLVE 18 demonstrates improved water resistance, color retention and resistance to whitening vs. standard epoxy resins.

- 33% PVC coating cured with modified cycloaliphatic amine hardener (1:1 stoichiometry)
- Single coat (80-100 micron) applied via drawdown direct to metal (16 gauge blasted hot rolled steel)
- 1,000 hours Cleveland humidity test duration as per ASTM D2247

Performance Comparison: DLVE 18 vs. Commercial Epoxy Coating

DLVE 18 demonstrates:

- Comparable viscosity, and impact and chemical resistance
- Faster drying times and better hardness development
- Shorter pot-life

System	Commercial Paint	DLVE 18 + D.E.H.™ 615	
Volume solids (%)	85	85	
VOC (g/L)	180	122	
Viscosity (KU), 25°C	104	106	
Pot-life (hr) based on 20 KU increase in viscosity	2.5	0.5	
Dry-hard time (hr), 25°C	9.5	3.5	
Dry-through time (hr), 25°C	17.5	5.5	
Konig hardness (sec), 1d	18	55	
Konig hardness (sec), 7d	105.5	158	
Impact resistance (in·lb)[1]	10	20	
Chemical resistance[2]	9.6	9.0	

[1]Direct impact resistance (ASTM D2794) *[2]Average score (out of 10 max) for multiple chemicals*

Corrosion Resistance: DLVE 18 vs. Commercial Epoxy Coating

DLVE 18 demonstrates improved corrosion resistance compared to commercial coating.

Commercial Paint

DLVE 18

Single coat (~125 micron) applied via drawdown direct to metal (16 gauge blasted hot rolled steel) 2,000 hours test duration as per ASTM B117.

DLVE 18 Formulation for Tank Lining Application

- Volume solids: 100%
- PVC: 13%
- Initial viscosity = 94 KU

DLVE 18 & D.E.H.™ 584		
Material Name	**Kilograms**	**Liters**
Part A		
Grind		
DLVE 18	100.00	88.40
Omyacarb 5	35.60	13.17
Ti-Pure R-706	32.40	8.10
Aerosil 200	0.25	0.11
Bentone SD-2	2.08	1.29
Grind above in order on Cowles, check Hegman, then reduce speed and add Part B		
Grind Sub-total	170.33	111.07
Part B		
D.E.H. 584	50.87	53.55
Total	221.20	164.62

XCM 18 Tank Lining Coating Performance

Epoxy	DLVE 18	
Hardener	D.E.H.™ 584	Mannich Base D.E.H.™ 615
Initial viscosity (KU)	94.0	116.4
Pot-life (hours)	1.5	~ 15 min[1]
Dry speed (hours)		
Dry to touch	13.4	1.0
Tack free	18.6	1.8
Dry hard	19.8	2.0
Dry through	>22	3.0
7 day pencil hardness	3H	~3H
7 day impact resistance (in lbs)		
Direct impact	~4	~4
Reverse impact	<4	<4

[1]*Time to start gel.*

DLVE 18 Tank Lining Coating Performance

Using 100% volume solids formulation, DLVE 18 demonstrated advantages over D.E.R.™324 on gasoline and toluene immersion resistance, when D.E.H.™ 584 or D.E.H.™ 615 were used as hardeners.

	Gasoline 1 week	Toluene 6 weeks	60°C Water 6 weeks
D.E.R.™ 324 (Control)			
DLVE 18	D.E.H.™ 584	D.E.H.™ 615	D.E.H.™ 584

- 1-coat drawdown on both top and bottom of blasted steel panel. Edge of each panel was sealed by Environlite 405HT.
- Dry film thickness was ~ 20-25 mil.
- Immersion in different chemicals for extended period of time.

DLVE 18 Formulation for Primer Application

- Volume solids: 90%
- PVC: 25%
- VOC: 85 g/L
- Initial viscosity = 102.6 KU

DLVE 18 & D.E.H.™ 615		
Material Name	Kilograms	Liters
Part A		
Grind		
DLVE 18	86.00	75.95
Xylene	5.07	5.88
BYK 104S	0.49	0.52
BYK 501	0.20	0.20
Wollastocoat 10 ES	59.75	20.60
Halox SZP-391	17.56	5.83
Blanc Fixe N	25.89	6.31
Red iron oxide	25.86	4.94
PM acetate	0.53	0.55
Grind Sub-total	221.34	120.78
Grind above in order on Cowles, check Hegman		
Let Down		
MIBK	0.86	1.07
PM acetate	0.71	0.73
Xylene	6.73	7.80
Part B		
D.E.H.™ 615	37.47	37.10
Totals	267.11	167.49

DLVE 18 Based Primer Coating Performance

At 25% PVC, using current formulation:
- DLVE 18 can achieve 90% volume solids with sprayable viscosity

Formulation optimization can further increase volume solids:
- PVC: 25%
- Volume solids: 90% or 95%
- Hardener: D.E.H.™ 615

Epoxy	DLVE 18	
Curing agent	D.E.H.™ 615	
Volume solids %	90%	95%
VOC (g/L)	84	41
KU viscosity (KU)		
Initial	102.6	134.5
Pot life (hrs)	0.5	0.25 - 0.5
Dry speed (hrs)		
Dry to touch	1.9	1.5
Tack free	2.9	2.2
Dry hard	3.4	2.9
Dry through	7.0	4.9

Oil and Gas Market
PEMEX Norm 053

Product Specified in Pemex Norm053	% Volume Solids	Anchored Profile [microns]	# Coats	DFT / Coat [microns]	Total DFT [microns]	Application Method	Use
RA-26 - Epoxy Top Coat 2K	70	no	1	125 - 150	375	Conventional spray or airless	To protect process equipment in chemical plants, refineries and petrochemical installations to exposure to marine ambient with high humidity and sea water, gases derivates of sulfur, alkalis and acids.
RP-13 Epoxy Coating 100% Solids	100	50 - 75	2	250 - 300	500 - 600	Conventional spray or airless	To protect the interior of process equipment at elevated temperatures of 95 ºC, separators to transport crude oil and water. To coat interiors of storage tanks and recipients to store diesel and glycols.

PEMEX Norms tendency: Increase solids by volume to >95%

Low Viscosity Epoxy Resin DLVE 19
2K Epoxy White Primer 33.0% PVC – 96% Volume Solids

Material Name	Kilograms	Liters
Part A		
Grind		
Low Viscosity Epoxy (DLVE 19)	27.20	23.97
Byk 9076	0..65	0.62
Byk 501	0.05	0.06
Wollastocoat 10ES	27.91	9.63
Halox SZP-391	8.62	2.86
Blanc Fixe Micro	12.56	2.85
Ti-Pure R-706	10.40	2.60
Pregeled to high speed velocity before to add		
Bentone SD-2	0.24	0.15
Total Grind	87.64	42.74
Part B: Curing Agent		
Polyamide	12.36	12.36
Totals	**100.0**	**55.10**
Volume Solids	**96.0%**	
VOC (g/L)	**55 g/L**	
Density (Kg/lt)	**1.8147**	
PVC	**33.0%**	

Coating Performance Comparison DLVE 19
Formulation Type RP13 with DLVE 19 to meet PEMEX 053

Epoxy Resin	Commercial Product RA26	DLVE 19	DLVE 19 + Acelerator
Hardener	Polyamide	Polyamide	Polyamide
Volume solids (%)	95	99.9	99.9
VOC (g/L)	120	55	55
% PVC	33	32.8	32.8
Viscosity (KU), 25°C	110	96	96
Pot-life (hr)	> 4	>4	>4
Set dry time (hr), 25°C ASTM D1640	1.18	2.40	2.10
Dry to touch (hr), 25°C ASTM D1640	3.18	3.50	3.25
Dry-through time (hr), 25°C ASTM D1640	3.50	4.20	4.0
Sag resistance ASTM D4400	No sags	No sags	No sags
Adherence ASTM D3359 – 24 hr dried to ambient -25° C	2B	1B	2B
Adherence ASTM D3359 – 20 days dried to ambient - 25° C	4B	5B	5B
Hardness ASTM D3363-5; 3mils DFT/over glass, to 24 hr dry ambient – 25° C	2H	2H	3H
Hardness ASTM D3363-5; 3 mils DFT/over glass, to 20 days dry ambient – 25° C	6H	6H	6H
Flexibility ASTM D522 – ¾"	Pass	Pass	Pass
Reverse impact resistance ASTM D2794 to 14 days	8	12	12
Direct impact resistance ASTM D2794 to 14 days	40	50	50
Corrosion resistance to 1500 hr ASTMB117 Corrosion rust grade ASTM D610 to 1200 hr	8	10	10
Blistering ASTM D714 to 1200 hr	Without blistering	Without blistering	Without blistering

Technical Summary: Low Viscosity Epoxy (LVE)

- LVE is recommended for high solids epoxy systems requiring spray application, good anticorrosive performance and low VOC
- LVE enables the airless spray application of 90% volume solids formulations with excellent appearance and a good array of final coating properties, particularly corrosion resistance and water resistance

Performance vs. Benchmarks	LVE Performance Summary in Formulated Coatings
vs. Standard BADGE	• Much Lower Viscosity • Lower VOC • Higher Solids • Similar Corrosion Resistance • Increased application space (sprayability) • Improved water resistance
vs. Standard BADGE + Diluent	• Improved performance at similar VOC • Improved corrosion and chemical resistance • Higher hardness • Faster cure
vs. BFDGE	• Lower viscosity • Lower VOC • Higher Solids • Similar performance demonstrated • Increased application space (sprayability)

Benefits of Low Viscosity Epoxy

Formulating coatings with new LVE enables practical high solids primers with an excellent balance of performance, environmental friendliness and cost.

Cost/Productivity

- Easier and lower total systems cost:
  - Via conversion of low solids (50%) to ultra-high solids (≥90%) formulations
- Higher pigment loadings for lower cost formulations
- Higher film thickness in single coat to minimize labor cost
- Increased productivity due to fewer coats needed

Performance

- Improved performance vs. existing diluent-modified epoxies used in ultra-high solids (≥90%) formulations:
  - Corrosion resistance
  - Faster dry time
  - Increased hardness
  - Improved performance vs. commercial standards

EH&S

- Reduced exposure to VOC (volatile organic compounds) to improve EH&S
- Reduction of solid waste since less paint containers are used
- Meet future VOC regulations

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Our Family of Low Viscosity Resins

Grade	EEW (gr/eq)	Viscosity @ 25 °C (mPa.s.)	Viscosity @ 50 °C (mPa.s.)	Availability by Region
DLVE 18	165 - 180	850 - 1250	n/a	LA, EMEAI, NAA, APAC
DLVE 19	195 - 205	4,500 - 5,300	n/a	
DLVE 52	170 - 185	500 - 700	n/a	
DLVNE 59	164 - 172	3,700 - 4,300	300 - 350	
DLVNE 60	169 - 175	78,000 - 82,000	2,600 - 3,000	
DLVNE 61	162 - 170	9,500 - 10,500	650 - 750	

Thank You

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