

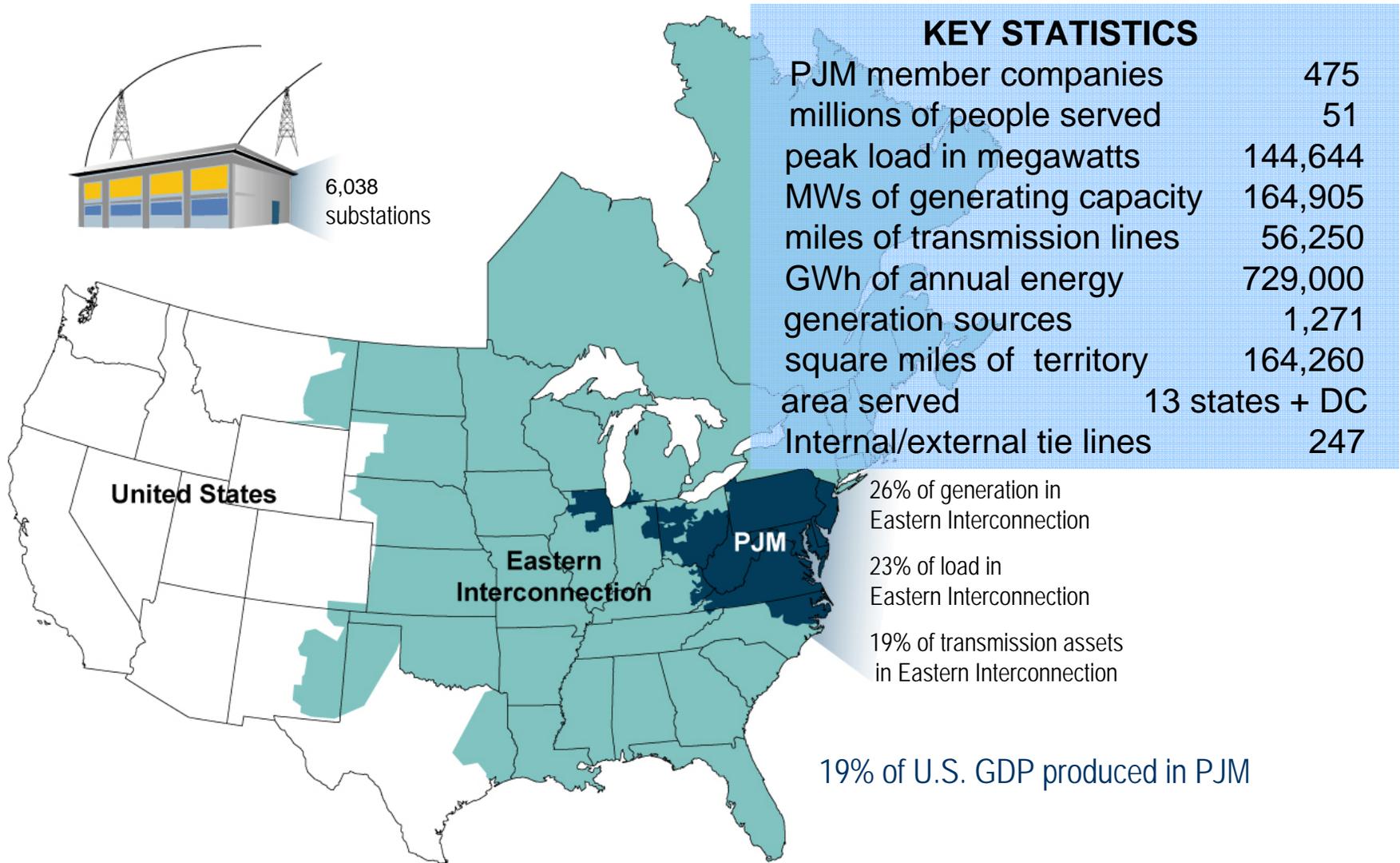
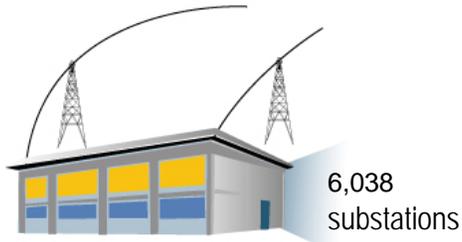
# New Technology at PJM

Carnegie Mellon  
Electricity Industry Center

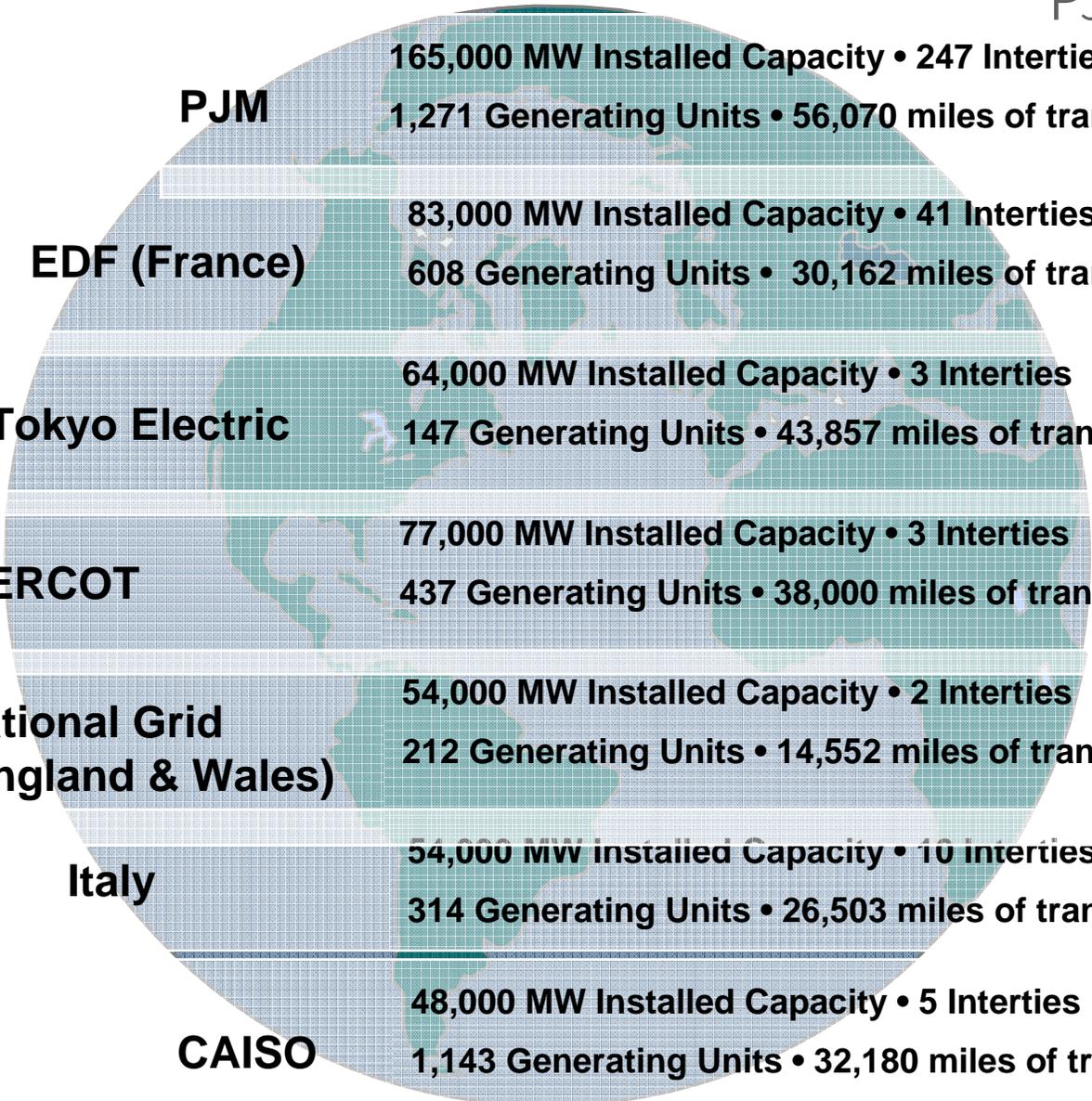
February 27, 2007

Ken Huber

# PJM as Part of the Eastern Interconnection

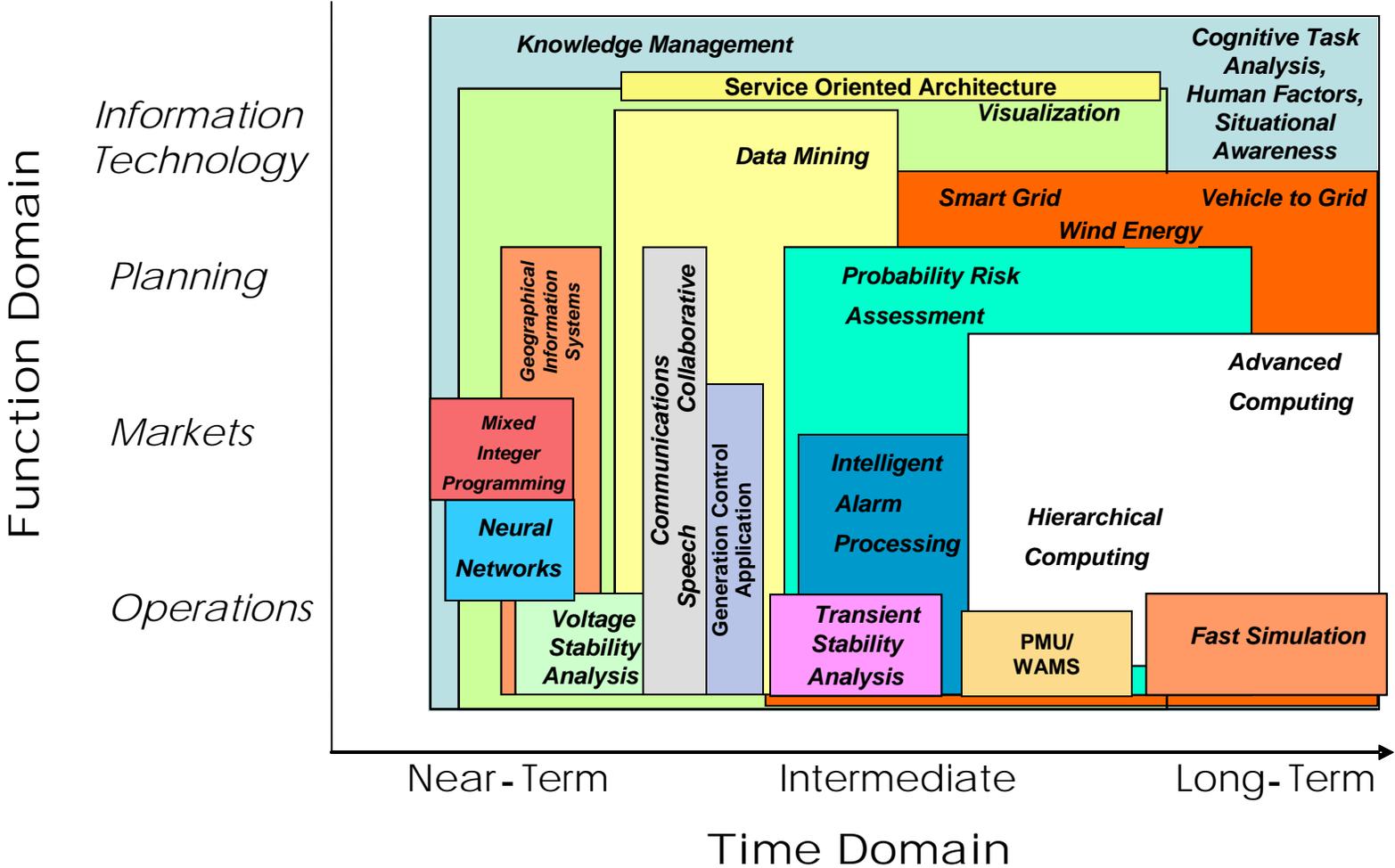


# PJM in the World

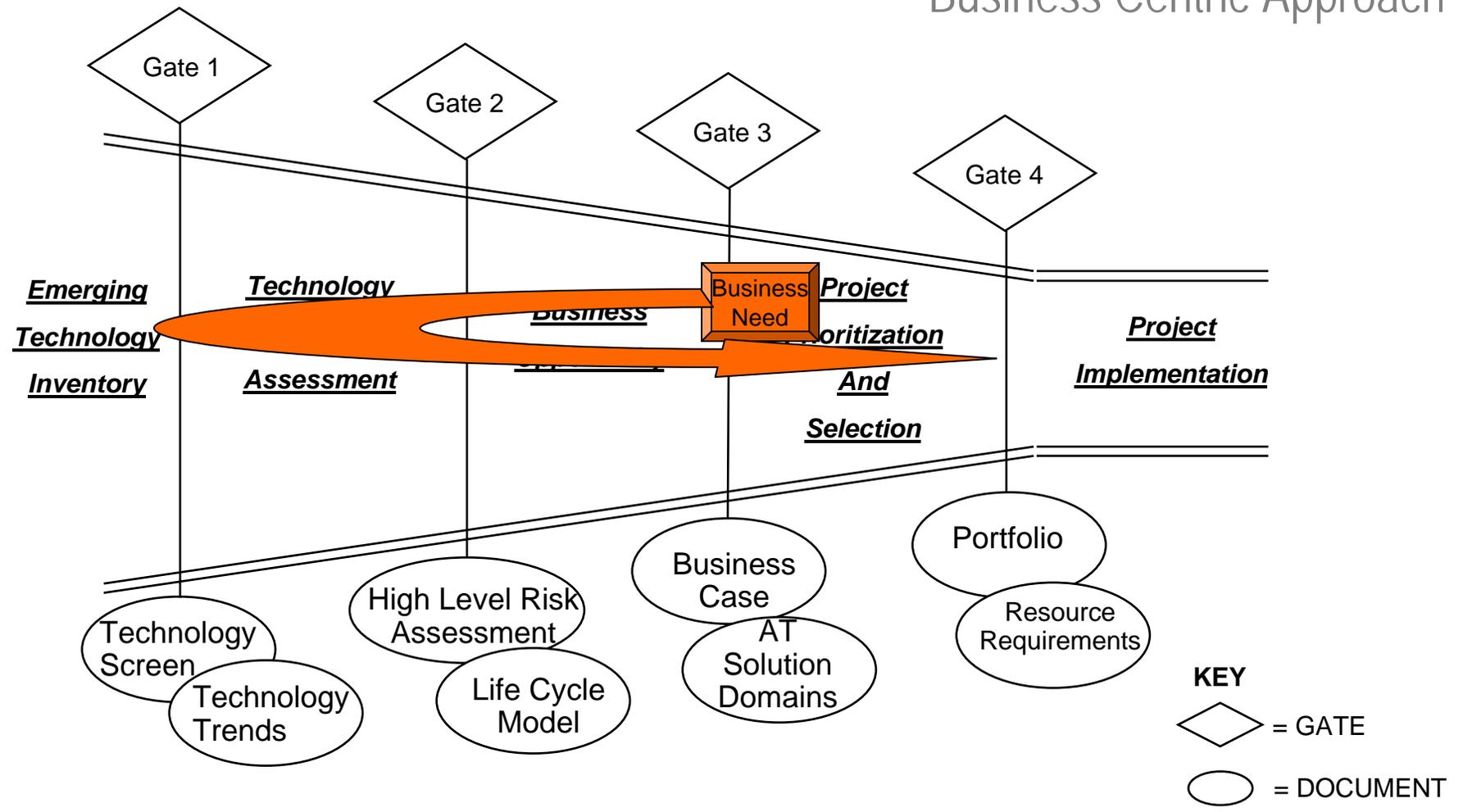


<b>PJM</b>	<b>165,000 MW Installed Capacity • 247 Interties</b> <b>1,271 Generating Units • 56,070 miles of transmission</b>
<b>EDF (France)</b>	<b>83,000 MW Installed Capacity • 41 Interties</b> <b>608 Generating Units • 30,162 miles of transmission</b>
<b>Tokyo Electric</b>	<b>64,000 MW Installed Capacity • 3 Interties</b> <b>147 Generating Units • 43,857 miles of transmission</b>
<b>ERCOT</b>	<b>77,000 MW Installed Capacity • 3 Interties</b> <b>437 Generating Units • 38,000 miles of transmission</b>
<b>National Grid (England &amp; Wales)</b>	<b>54,000 MW Installed Capacity • 2 Interties</b> <b>212 Generating Units • 14,552 miles of transmission</b>
<b>Italy</b>	<b>54,000 MW Installed Capacity • 10 Interties</b> <b>314 Generating Units • 26,503 miles of transmission</b>
<b>CAISO</b>	<b>48,000 MW Installed Capacity • 5 Interties</b> <b>1,143 Generating Units • 32,180 miles of transmission</b>

# Advanced Technology Initiatives

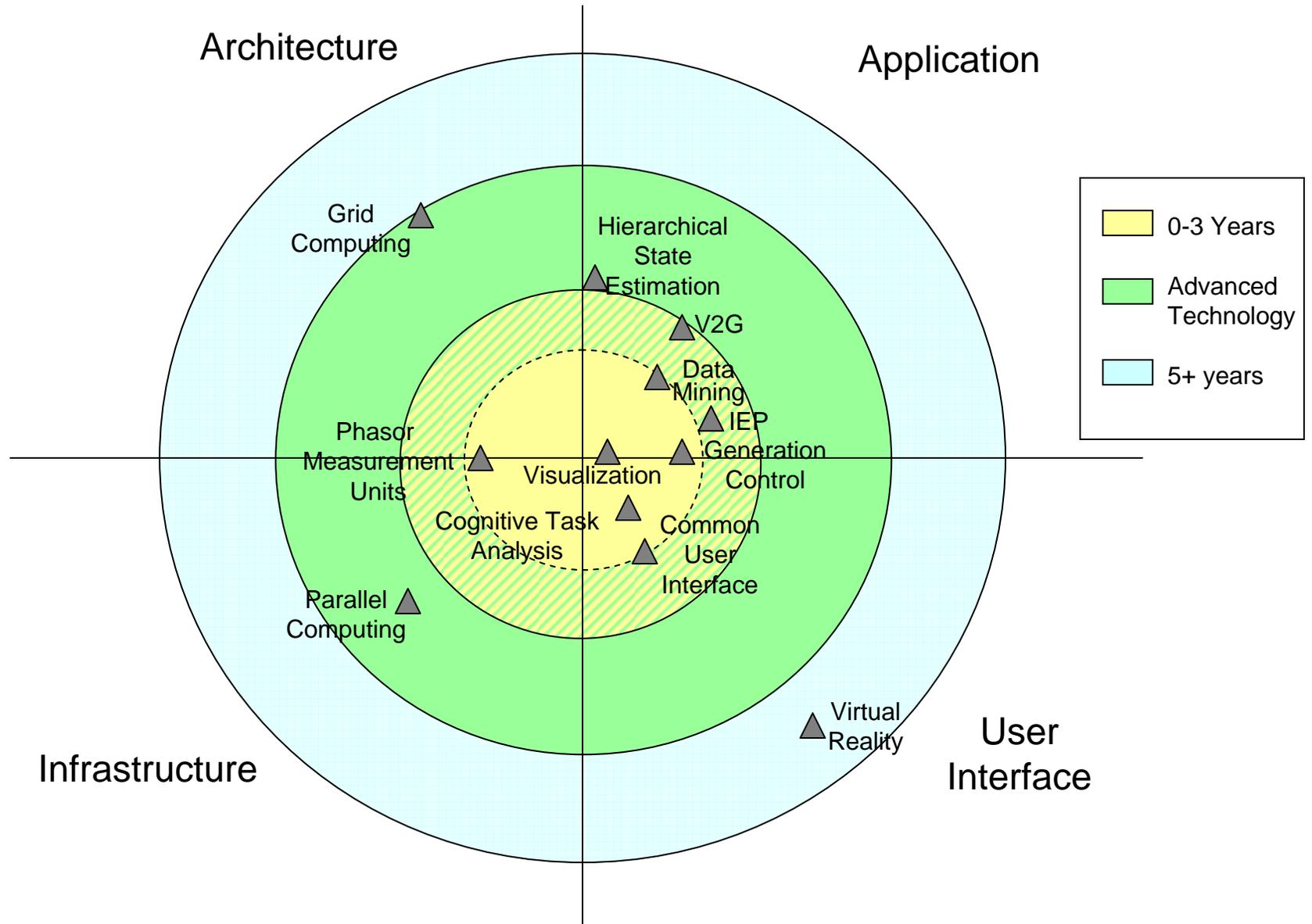


# Analysis of Emerging Technology Innovation Funnel Business Centric Approach

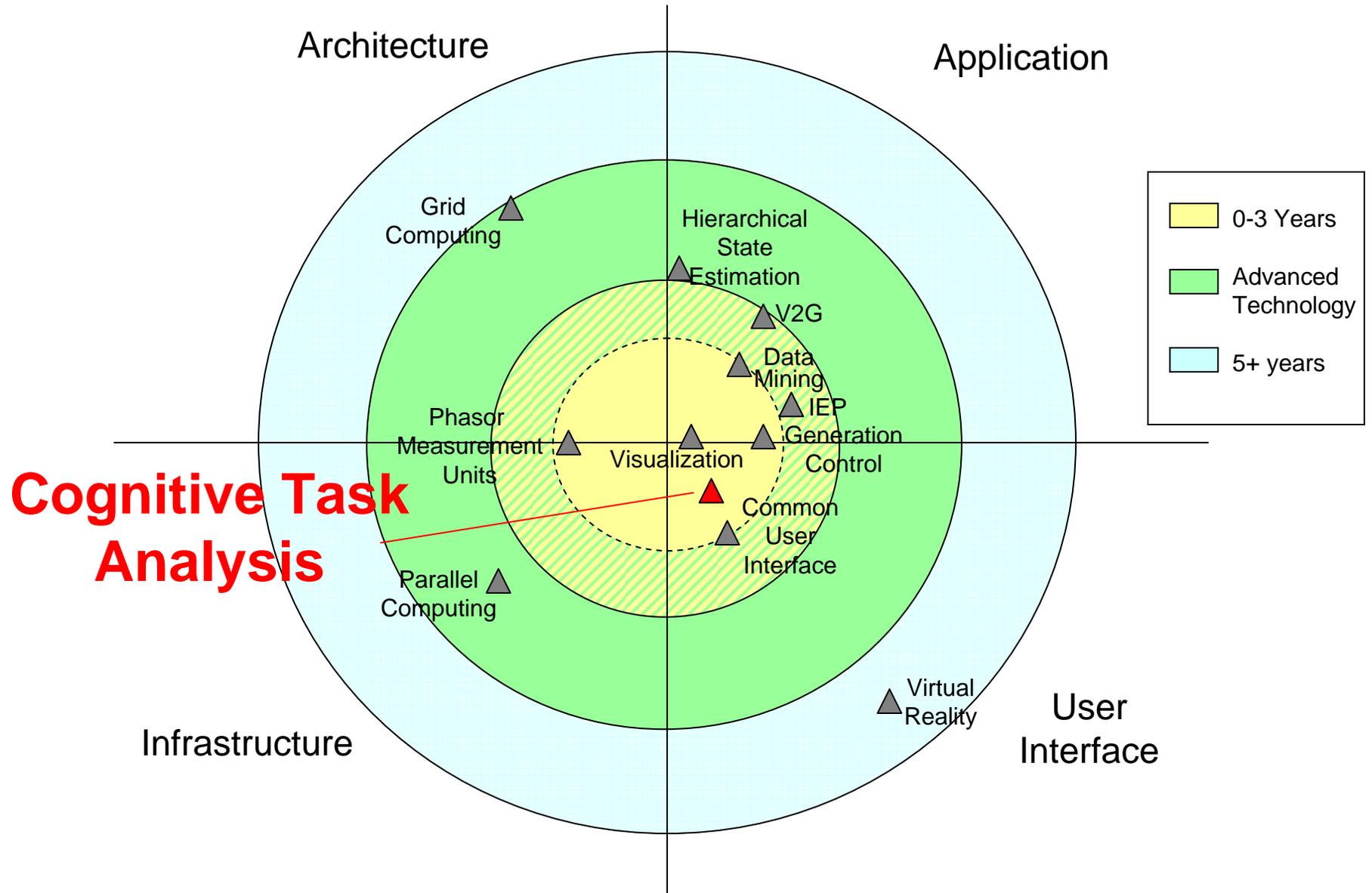


# Analysis of Emerging Technology

## Current Advanced Technology Focus



# Analysis of Emerging Technology Current Advanced Technology Focus



- Aging Workforce – Retirements
- Increased scope and configuration
  - Loss of “Tribal Knowledge”
- Pressures to reduce operating costs
- Design by engineers

# UDS Inputs: User Interface

RT Generation UDS

Case: 520070511202503  
 Interval: 11-MAY-2007 16:43  
 SE Time: 11-MAY-2007 16:23

Time: 14-MAY-2007 11:01:22  
 OverGen: 268.6  
 EES ImpCur: -2697  
 Load Cur Imp: 79946  
 Cur Dyn: -2371.7  
 -1105

Control Zone

Name	Forecast	Net Imp	Dyn	Init Gen	Loss Mw	Fix Ct
RTO	93352	-2698	-1356	97852	0	
PJM	38366	1711	-154	36982	0	
AEP	18648	-3668	-679	23039	0	
AP	6132	-671	0	6759	0	
DAY	2553	2086	-676	1147	0	
DOM	13433	690	121	12549	0	
DUQ	2024	-232	0	2254	0	
CE	12196	-2614	32	15122	0	

Parameters

Look Ahead	Sys Tran		Case Sys Tran	
	18	18	18	18
Min Run Time	60	60	60	60
Startup Time	36	30	30	30

Ignore Load Bias in Constraints:

Zone	Fixed Steam	Case 1		Case 0		Case 2		Current	
		DeltaGn	DeltaMw	DeltaGn	DeltaMw	DeltaGn	DeltaMw	Mw	Rate
PS	<input type="checkbox"/>	-303	69.3	-267	78.8	-174	91.6	1	50.2
PE	<input type="checkbox"/>	-85	71	-85	82.1	-92	96.2	15	50.2
PL	<input type="checkbox"/>	19	61.3	45	67.8	7	75.2	0	50.2
BC	<input type="checkbox"/>	54	260.1	102	280.9	102	515.1	27	50.2
JC	<input type="checkbox"/>	-18	66	0	73.5	0	83.5	0	50.2
ME	<input type="checkbox"/>	-27	54.2	1	61.9	78	72.9	-14	50.2
PN	<input type="checkbox"/>	5	57.2	5	59.4	5	47.5	-26	50.2
PEP	<input type="checkbox"/>	14	245.8	14	272	14	481	23	50.2
AE	<input type="checkbox"/>	2	70	2	81.1	2	92.9	2	50.2
DPL	<input type="checkbox"/>	0	71.5	0	82.9	0	97	0	50.2
COMED	<input type="checkbox"/>	-591	87.6	-313	92.2	164	116.5	9	51.3
DAY	<input type="checkbox"/>	-4	86	-4	90.2	-4	112.4	-7	50.2
AEP	<input type="checkbox"/>	-314	85.2	-75	89.4	-38	110.7	74	50.2
AP	<input type="checkbox"/>	219	46.1	44	44.5	-166	8.3	-5	50.2
DUQ	<input type="checkbox"/>	1	61.5	1	62.6	1	48	4	50.2
KEY/CON	<input type="checkbox"/>	7	59.3	7	63.2	7	47.8	0	50.2
DOM	<input type="checkbox"/>	72	233.7	72	262.1	144	458	-118	50.2

Virtual Trans: Total Loss Mw: 0

Exceptions: << All >>

Include SP Local Reduction:

Unit	T#	Zone	Co	Mw	Initial Mw	Delta Mw	Marg Cost	SP Reduce	Cost-Capped	DMT 99	Ramp Restrict	De-select
BC WAGN 1 CT	63	BC	BC	12	0	12		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
BC RIV 7 CT	62	BC	BC	19	0	19		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
BC RIV 8 CT	62	BC	BC	19	0	19		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
BC PHIL 3 CT	63	BC	BC	13	0	13		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
BC PHIL 4 CT	63	BC	BC	13	0	13		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
ME ORRT 1 CT	65	ME	RESI	19	0	19		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
ME HUNT 1 CT	65	ME	RESI	19	0	19		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
ME TOLN 1 CT	64	ME	RESI	0	0	0		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
ME TOLN 2 CT	64	ME	RESI	21	0	21		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
PS ESSX 121 CT		PS	PS	0	40	-40		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
PS ESSX 122 CT		PS	PS	0	19	-19		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
PS ESSX 123 CT		PS	PS	0	39	-39		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
PS ESSX 124 CT		PS	PS	0	20	-20		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Constraints

FG ID	Daily Num	Monitored Element	< M2M Link >	Contingent Element	UDS Flow Bind	M2M Gate	SP Activate	Local	Rating %	Case Rating	SE Flow	SE %	UDS Flow	UDS %	Limit	Marginal Value	Bind ing	Current Binding
	65	MIDLJCT 5 BANK XFORMER	H	Middletown Junc #2 and Hunterstown # 4	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	150	90	135	118	129	112	115	-1447	<input checked="" type="checkbox"/>	<input type="checkbox"/>
	60	KERRDAM-BEECHDP 22C	A	90 LINE: CAROLINA-KERR DAM & Carolina S	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		95	125	102	116	95	123	-1185	<input checked="" type="checkbox"/>	<input type="checkbox"/>
1701	63	MTSTORM-PRUNTYTO	B		<input type="checkbox"/>	I	<input type="checkbox"/>	<input type="checkbox"/>	98	93	2704	96	2624	93	2822	-446	<input checked="" type="checkbox"/>	<input type="checkbox"/>
	64	BRUNNERI-YORKANA 1055	A	Conastone-Peach Bottem (5012) 500 kV line	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	98	88	612	95	569	88	647	-393	<input checked="" type="checkbox"/>	<input type="checkbox"/>
	62	GRACETON-RAPHAERD 2313	B	BRIGHTON-CONASTONE 500KV	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	98	90	656	98	601	90	668	-297	<input checked="" type="checkbox"/>	<input type="checkbox"/>

# Event Summary

## OPERATION EVENT SUMMARY

```

12/17/07 08:05:12 500 KV MEADOWBR 500 KV BUS A KVB = 5.0 (***** 0.0)+
12/17/07 08:05:12 SA:ELKTONDP 115 KV D KV(VEMIN=105)L/O 272 LINE: DOOMS-GROTTOES RELIEVED
12/17/07 08:05:12 500 KV MEADOWBR 500 KV BUS A KVB = 5.1 (***** 5.0)+ RELIEVED
12/17/07 08:05:12 SA:ROXBURY-SHADEGAP KR 1075 MVA(STE = 167)L/O Conastone-Peach Bottem (5012) 500 RELIEVED
12/17/07 08:03:39 PJM EES SCHEDULE FAILURE ABNORMAL STATE OFF (NORMALLY OFF )
12/17/07 08:03:27 PJM EES SCHEDULE FAILURE ABNORMAL STATE ON (NORMALLY OFF )
12/17/07 08:02:51 500 KV VALLEY4 500 KV 17E KV_ = 504.2 (***** 505.0)
12/17/07 08:02:51 500 KV MEADOWBR 500 KV BUS A KVB = 5.1 (***** 5.0)+
12/17/07 08:02:51 500 KV MEADOWBR 500 KV BUS A KVB = 3.3 (***** 0.0)+ RELIEVED
12/17/07 07:56:47 SA:ELKTONDP 115 KV D =105.0 KV(VEMIN=105)L/O 272 LINE: DOOMS-GROTTOES
12/17/07 07:56:47 500 KV VALLEY4 500 KV 17E KV_ = 504.8 (***** 505.0) RELIEVED
12/17/07 07:55:19 PJM ACE LIMIT VIOLATION = -953.7 (NORMAL 1000) RELIEVED
12/17/07 07:55:02 SYSTEM SECURITY ALERT AP SOUTH TRANS FROM TT ARE 4353 MW EXCEEDING 4305 MW LIMIT
12/17/07 07:54:51 500 KV VALLEY4 500 KV 17E KV_ = 504.8 (***** 505.0)
12/17/07 07:54:51 500 KV MEADOWBR 500 KV BUS A KVB = 493.1 (***** 500.0)
12/17/07 07:54:51 SA:CONASTON-PEACHBOT 5012 =2802 MVA(STE =2598)L/O BEDINGTON BLACKOAK LINE
12/17/07 07:54:51 SA:ROXBURY-SHADEGAP KR 1075 = 173 MVA(STE = 167)L/O Conastone-Peach Bottem (5012) 500
12/17/07 07:54:51 SA:JACK ME-TMI 1051 = 723 MVA(STE = 675)L/O Conastone-Peach Bottem (5012) 500
12/17/07 07:54:51 SA:ELKTONDP 115 KV D KV(VEMIN=105)L/O 272 LINE: DOOMS-GROTTOES RELIEVED
12/17/07 07:53:22 25 KV CALVERTC GEN 01 GEN_MW changes from 878.4 to 0.0 (change limit= 200.0)
12/17/07 07:53:22 PJM ACE LIMIT VIOLATION = -1294 (NORMAL 1000)
12/17/07 07:53:21 PJM GT OPTIMIZE ACE TRIP ABNORMAL STATE ON (NORMALLY OFF )
12/17/07 07:53:21 MU: 25 KV CALVERTC GEN 01 GEN UNIT OUT OF SERVICE
12/17/07 07:53:21 MU: 500 KV CALVERTC 1GEN XF XFORMER OUT OF SERVICE
12/17/07 07:53:20 500 KV CALVERTC 1 GEN ATB STATUS CHANGED TO OPEN (NORMALLY CLOSED )
12/17/07 07:53:18 500 KV LINE BUR-POS ENDA_MW changes from -5.2 to -266.0 (change limit= 100.0)
12/17/07 07:53:18 500 KV LINE BRI-DOU ENDA_MW changes from -468.7 to -575.2 (change limit= 100.0)
12/17/07 07:53:18 500 KV LINE BRA-RAM ENDA_MW changes from 402.5 to 263.5 (change limit= 100.0)
12/17/07 07:53:15 500 KV CALVERTC 5051/1GEN ATB STATUS CHANGED TO OPEN (NORMALLY CLOSED )
12/17/07 07:52:58 SA:ELKTONDP 115 KV D =105.0 KV(VEMIN=105)L/O 272 LINE: DOOMS-GROTTOES
12/17/07 07:51:52 SA:ELKTONDP 115 KV D KV(VEMIN=105)L/O 272 LINE: DOOMS-GROTTOES RELIEVED
12/17/07 07:51:52 SA:BLAIRSVE NO.1 TX XFORMER MVA(STE = 195)L/O KEYSTONE-SHELOCTA-HOMER CITY 230 RELIEVED
12/17/07 07:51:52 SA:ROXBURY-SHADEGAP KR 1075 MVA(STE = 167)L/O Conastone-Peach Bottem (5012) 500 RELIEVED
12/17/07 07:51:52 SA:JACK ME-TMI 1051 MVA(STE = 675)L/O Conastone-Peach Bottem (5012) 500 RELIEVED

```

# Situational Awareness?

1: DTS - Training/RealTime - GMS RTO Overview

Display View Overlay Tools Help

### PJM RTO Overview

Gen Alarm	Crit Alarm	GTO Ctrl	DispLambd	Man ED	PJM Null	HydroGen	R M	CompOver	LFC	AGC
Em Sched	Pools	Tie Status	E Ties	W Ties	Econ Disp	Sig Flow	Reg Over	Tuning	Spin	Dynamics

CPS2 771 req -411 UDS ON GTO ON Master ON

Details

	RTO	PJM	AP	DUQ	AEP	DAY	CE	DOM
ACE	172	-11	45	-1	10	2	32	96
Manual Add	0	0	0	0	0	0	0	0
Reg Sig AUTO	-759	-338	-13	0	-256	0	-95	-57
CReg			-37	0	1	-10	-73	-89
TReg	914	364	29	0	256	0	95	170
DMT Reg	1067	233	79	0	256	0	129	370
Net Actual	-2736	-2	1011	-956	-842	592	-4902	2363
Net Schedule	-3078	-126	1017	-957	-955	594	-4932	2281
ACTIVE GT			1023	-957	-1249	125	-4970	2383
Manual GT			1023	-957	-1249	125	-4970	2383
GTO Mode			MAST	MAST	MAST	MAST	MAST	MAST
Tie Error (FTL)	-341	-124	7	-1	-113	2	-30	-82
Frequency		60.036	60.036	60.036	60.036	60.036	60.036	60.036
Bias MW/.1Hz	1370	299	101	0	329	0	166	475
Freq Error (FF)	514	112	38	0	123	0	62	178
Load	90748	36227	6197	1699	19464	2271	11363	13528
Steam	91188	33544	5072	2655	20289	1679	16112	10280
CT	471	181	105	0	0	0	153	32
Hydro	2074	1194	9	0	17	0	0	854
Total Net Gen	93735	36479	5186	2655	20306	1679	16265	11166
Economic Gen	96142	37401	5308	2664	20938	1587	16758	11487
Steam Deviation	-1635	-725	-109	-9	-376	92	-306	-201
Cost		123.6	114.1	114.6	109.8	113.1	110.0	117.8

**Dynamic Schedules**  
+ in; - out

RTO 892

**Reserve Sharing**  
+ in; - out

Mid-Atl off 0  
ECAR off 0  
MAIN off 0  
VACAR off 0

**Freq SCHEDULE**  
complete 60.036 hz  
deviation 0.037 hz  
error 0.037 hz  
desired 60.000 hz  
schedule 60.000 hz

**RTO SCHEDULE**  
Source EES

06:05 -3970 MW  
06:10 -3970 MW  
06:20 -4361 MW  
Schedule -3970 MW

**Bath County**

AP Share 0  
DOM Share 840

**RTO Pool Totals**

	Sched	MW	MVar
ALTE	-32	-246	34
ALEX	0		
ALTW	-493	-335	13
ALWX	0		
AMIL	6	-864	207
CIN	847	1135	-715
CWLP	0	-145	0
FE	-67	1047	-277
IPL	-50	553	-139
MECS	-210	-1455	105
NIPS	-300	-66	-128
WEC	-50	905	-26
WECX	0		
MISO	-321	548	
CPL	-162	584	-9
CPLW	-100	-178	25
DUKE	396	-560	192
EKPC	-466	-108	-30
LGEE	0	132	-7
MEC	-493	-998	-2
NEPT	-660	-675	0
NYPP	-1456	-680	37
OVEC	815	-509	237
TVA	-472	-273	204
CSW	-21		
Total	-3078	-2736	

<< RAISE RTO Manual Regulation = 0 MW LOWER >> Auto Manual

Cancel Execute DataEntry Recall

Dec 17 2007 06:05:51

# Good Human Factors?

3: OTS - Training/ - RTO Critical

Display View Overlay Tools Help

**EAST** **WEST** RTO Critical Information Display **RTO Over** **kV Trend**

Actual	EES	Deltas		PRE CONTINGENCY			POST CONTINGENCY		
	06:15	06:30		OPB LIMITS	AVAIL TRANS ROOM		OPB LIMITS	AVAIL TRANS ROOM	
CPLE	-162	0	0	<b>EAST</b>			<b>50045005</b>		
CPLW	-100	0	0	Adj. Op. Pt	6512		Adj. Op. Pt	3941	
DUKE	440	65	46	Transfers	4784 C		Transfers	3869	
EKPC	-466	0	0	Adj. Lim w/M	6855	2071	Adj. Lim w/M	4148	279
LGEE	0	0	0	Transfer Limit	7105	2321	Transfer Limit	4398	529
MEC	-483	15	-25	Rec Limit	6056		Rec Limit	4448	
NEPT	-660	0	0	<b>CENTRAL</b>			<b>CENTRAL</b>		
NYPP	-1456	0	0	Adj. Op. Pt	4292		Adj. Op. Pt	4228	
OVEC	815	0	0	Transfers	2407 C		Transfers	2453	
TVA	-472	0	0	Adj. Lim w/M	4518	2111	Adj. Lim w/M	4450	1997
MISO	-1583	-314	485	Transfer Limit	4768	2361	Transfer Limit	4700	2247
TOTAL	-4127	-234	506	Rec Limit	3589		Rec Limit	3585	
				<b>WEST</b>			<b>WEST</b>		
				Adj. Op. Pt	5104		Adj. Op. Pt	4331	
				Transfers	4209 C		Transfers	4174	
				Adj. Lim w/M	5373	1164	Adj. Lim w/M	4559	385
				Transfer Limit	5623	1414	Transfer Limit	4809	635
				Rec Limit	5192		Rec Limit	5081	
				<b>BED-BLA</b>			<b>BED-BLA</b>		
				Adj. Op. Pt	2043		Adj. Op. Pt	2357	
				Transfers	2019 C		Transfers	2790 H	
				Transfer Limit	2151	132	Transfer Limit	2455	-335
				Rec Limit	2023		Rec Limit	3099	
				<b>APSOUTH</b>			<b>APSOUTH</b>		
				Adj. Op. Pt	3002		Adj. Op. Pt	3761	
				Transfers	3253 C		Transfers	4082 H	
				Transfer Limit	3160	-94	Transfer Limit	3918	-164
				Rec Limit	3457		Rec Limit	4274	
				<b>KMF</b>			<b>KMF</b>		
				Adj. Op. Pt	500		Adj. Op. Pt	765	
				Transfers	495		Transfers	630	
				Transfer Limit	526	31	Transfer Limit	805	175
				Rec Limit	623		Rec Limit	804	

NOTE:  
Transfers based on STATE ESTIMATOR.  
Monitor Telemetered flow on NULL DISPLAY  
if STATE ESTIMATOR FAILS.

**Control / OPB Lim**

**W Control / OPB Lim**

**EXEC** UPDATE East/Cent/West/5004/5 Limits

**EXEC** UPDATE BGE/PEP Limits

**EXEC** UPDATE Bed-BlA / AP South Limits

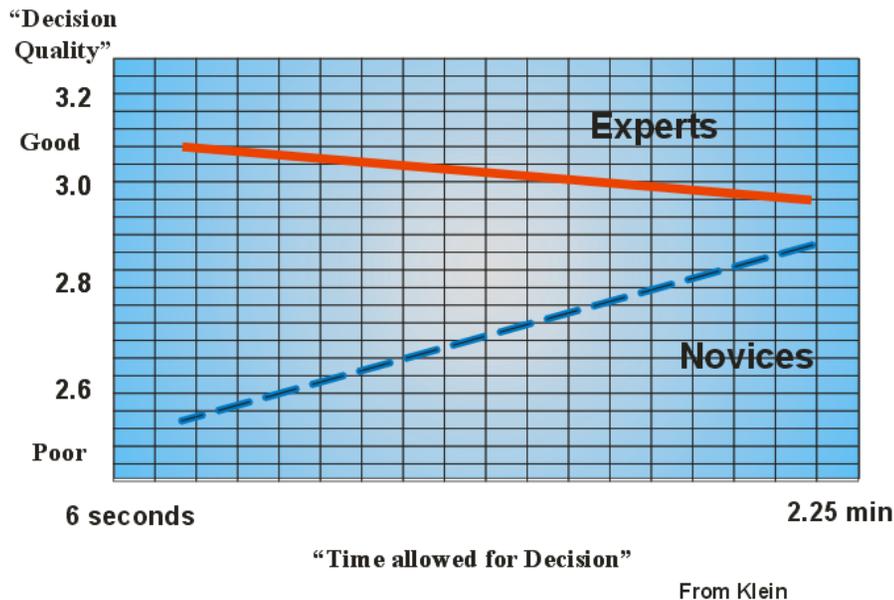
**EXEC** UPDATE KMF Limits

ACE -165

Cancel **Execute** DataEntry Recall

Dec 17 2007 06:14:02

# Designing for the Novice and Expert

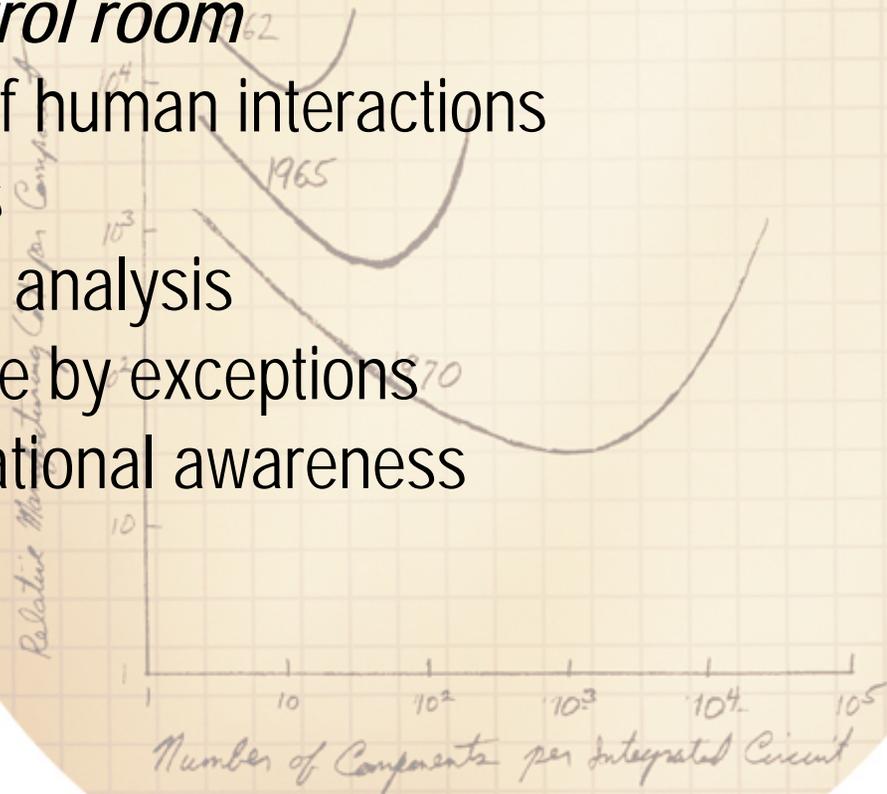


- Novice
  - Lives in the moment
  - Can't recognize complex relationships
  - Produces limited options
- Routine Expert
  - Great at everyday stuff
  - Strong procedural knowledge
  - Runs into trouble when problems are ill-structured or novel
- Adaptive Expert
  - Deep comprehension of conceptual structure of the problem domain

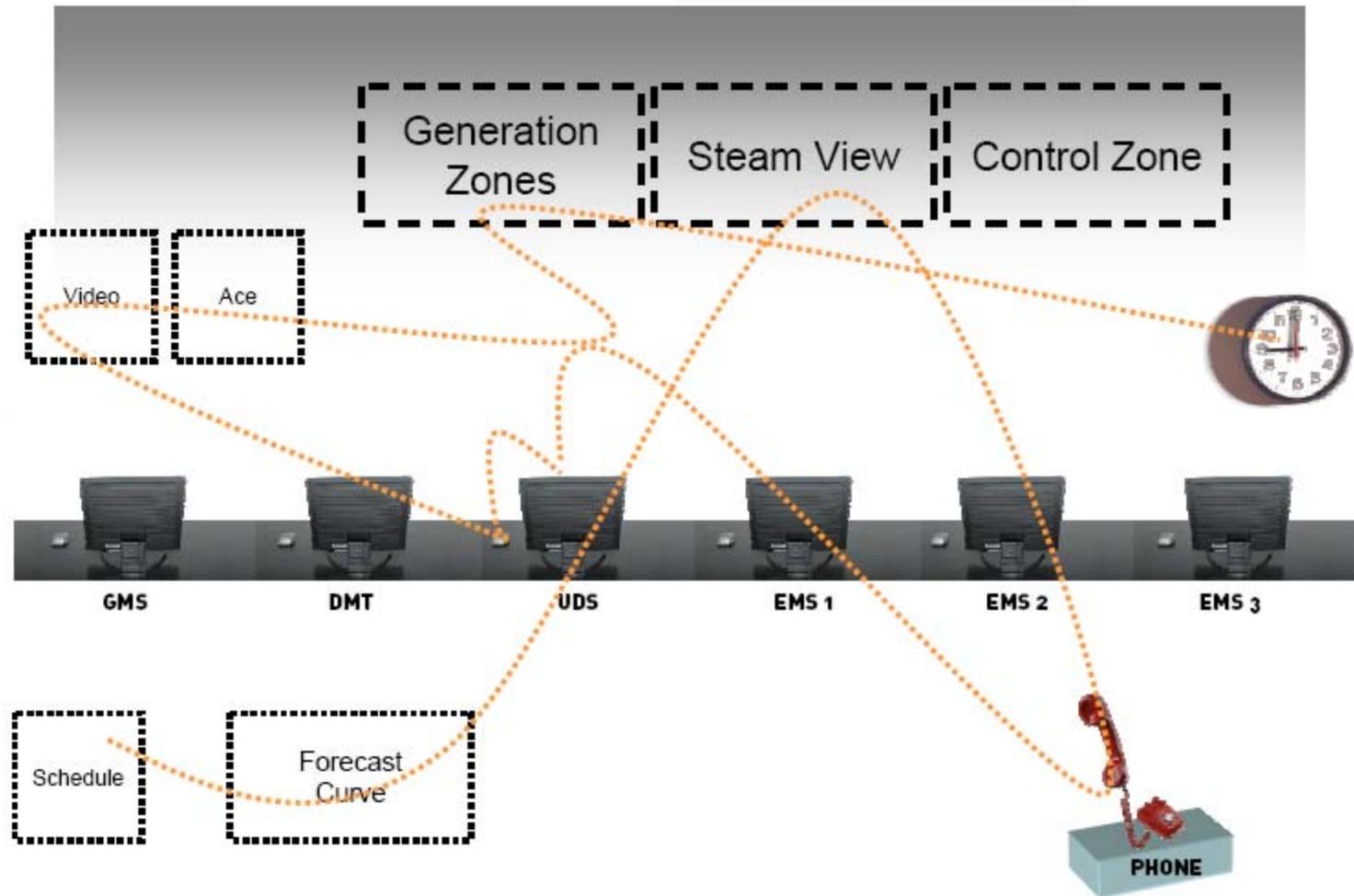
Source: Liz Quetone  
WTDB/NSSL and Dr. Gary  
Klein

### *Early adopter of human factors and cognitive task analysis in power grid control room*

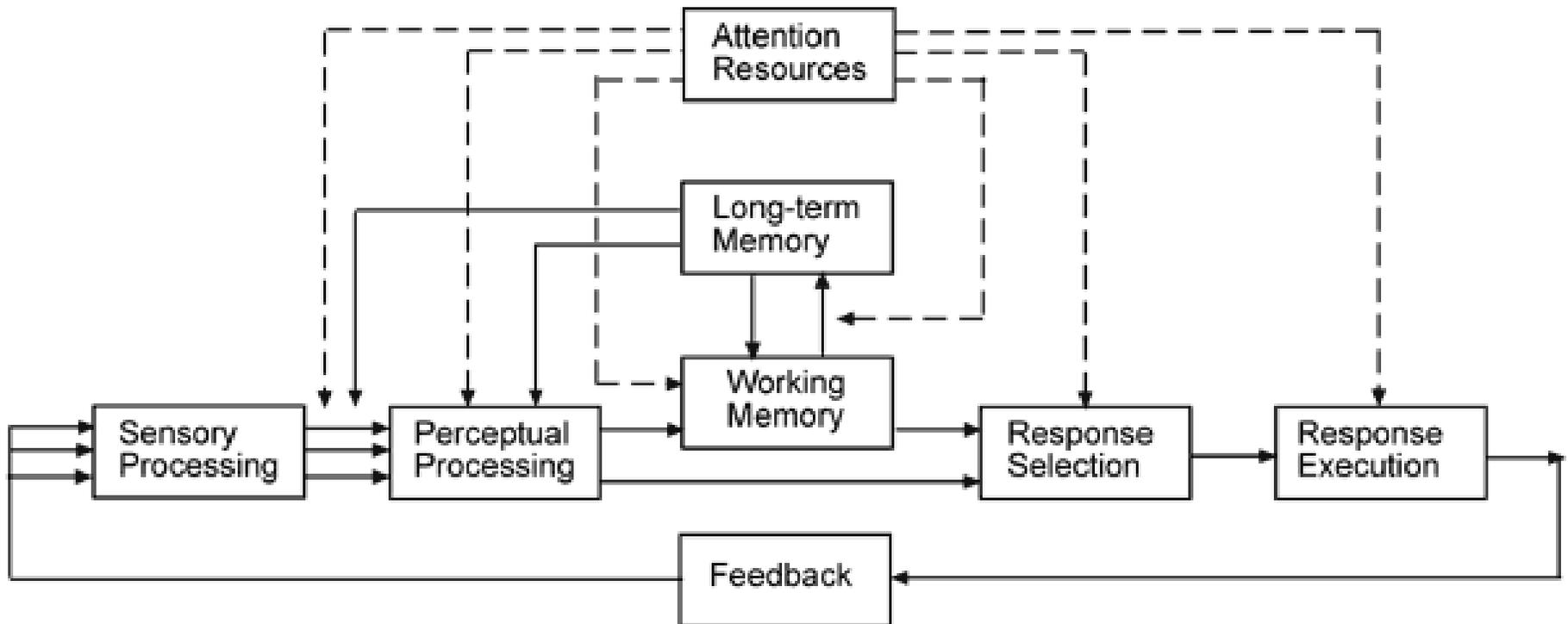
- Increased understanding of human interactions
- User-centered applications
- Reduce cognitive load and analysis
- Reorganize data to manage by exceptions
- Provide current/future situational awareness



# User Centric Design - Discovery



# User Centric Design - Approach



# Dashboard – Prototype Wireframe, End-User in the Loop

PJM - MW Reserve Dashboard
[Icons]

Menu options to appear in this area

FREQ: 85.97    CPS2: -80    Violations (Nov. 4): 2    1 of 2: ACE Violation at 08:32:18    11:05:30

**System: 11:04 - Eastern transfer limit soon to be violated**

**EASTERN**    Current: 3988    Limit: 7398

1 of 3    [Icons]

**Event: 11:03 - Western equipment outage**

Region: MW    Source: aBART    Start Date: 06/03/10 10:30:00    End Date: N/A    Cause: Unplanned    Company: Constellation

1 of 4    [Icons]

**Economic: 11:03 - Unit Mitchell 3 passed coal threshold**

Case 1: 01 - Mitchell 3    Details: 947    Details: -196.0  
Case 2: 0 - Transfer Interface: BLD-BLA    1148    -188  
Case 3: 02 - Transfer Interface: RMP-RR    1541    8

1 of 3    [Icons]

Load: 91,000 MW    Forecast    Back -    Ahead +

Event Queue - Next 30 minutes    Load/Ahead +

Scheduled Event	Called On	EMiles
Steam Generator	Called On	8:45:04
PS ESX 114 CT	Maintenance	1:27:56
PS ESX 113 CT	Called On	00:00
Bath County	Called On	01:13
Eastern CT	Actual Time Off	-01:13

Oil for Forecast

EMG - Generation Performance    RTO    Generation Limits

Company	Unit	Gen	Dev	DGP
WCO	Red Oak 2	140	▲ 133	0.0
ADP	Mitchell 3	575	▼ -158	0.3
EMG	Homer City 1	841	▲ 81	0.0
ADP	Ames 3	1141	▼ -90	0.8
DPL	Indian River 4	406	▲ 78	0.0
DAY	Beckjord 8 Day	80	▼ -71	0.3
PT	State Line Coal 4	327	▲ 71	0.0
ACT	Fort Martin 1	404	▲ 64	0.3
na	Four Mile Barbed CT4		▲ 27	0.5

Page 1 of 2    [Icons]

RTO ACE-10    Play/Pause    Summary    Labels

EMG - Active Reserves Monitor

Arrange:  RTO     ASM     TZ     Generator Owner

Reserve Category	RTO		Mid Atlantic		Eastern		South	
	Calc	Req	Calc	Req	Calc	Req	Calc	Req
Spinning	2385	1091		1824	576		281	
Dispatched	3198	819					1214	
Primary	9481	2636					1835	
Secondary	8183	4780					189	
Operating	13974	8596					1854	
Beyond Eyes	18424	4854					2564	
Pump Trip		390						

Market Map: RTO    Enlarge

View:  Perfom     Interfaces     Gen Perfom     LMP vs OpRate

Available Transfer Margins    Limit Calculations

	AP-S	BL	West	Cent	East
	285	50	540	538	820
Op Point					
10%					

# Dashboard – Final Design



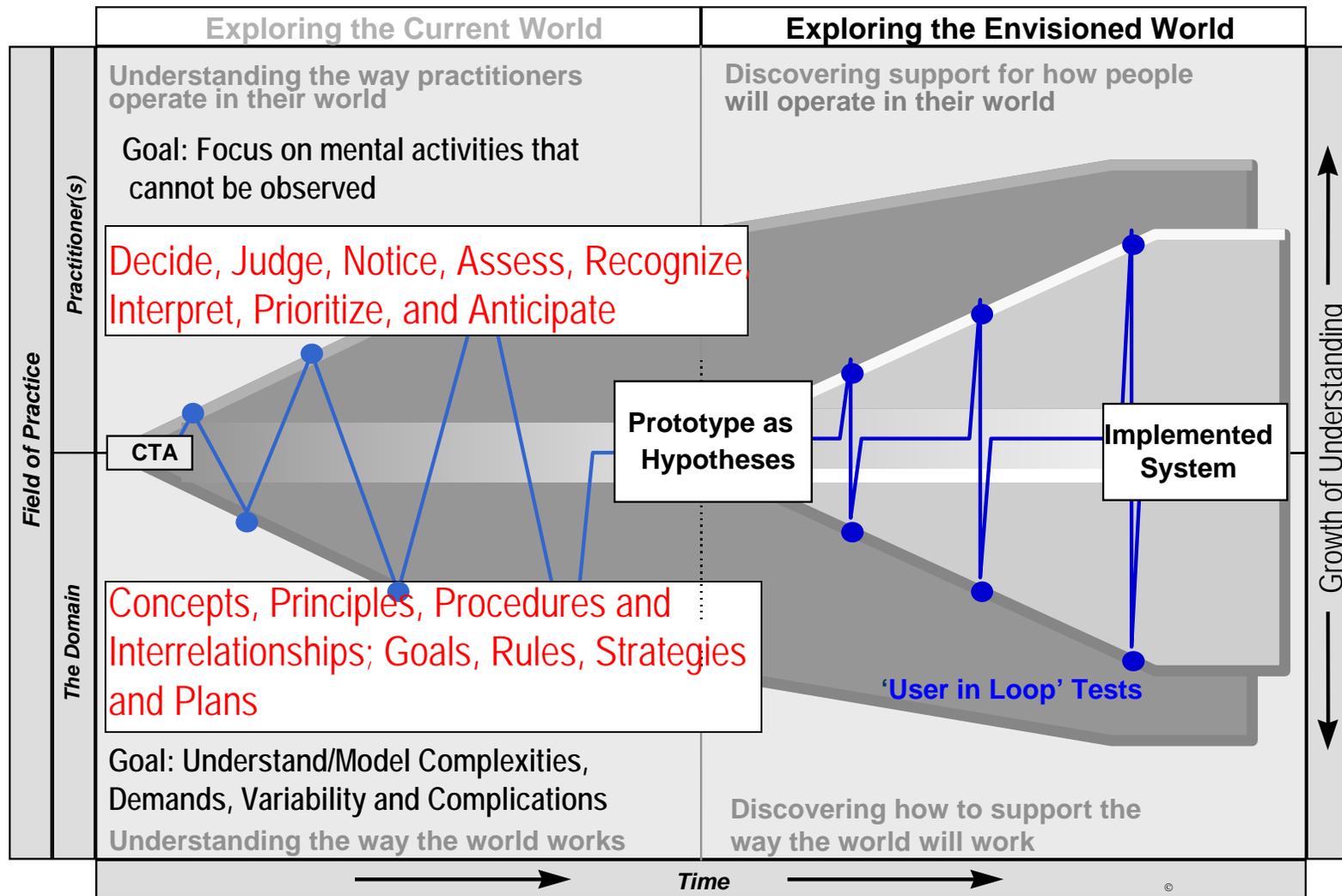
# User Interface Framework and Visualization

- Dashboard Goals

- Minimize Visual Travel Time
- Minimize Number of Displays
- Reduce Cognitive load & Analysis
- Provide Situational Awareness
- Reorganize data to "Manage by Exception"
- Create Data Visualization Standards

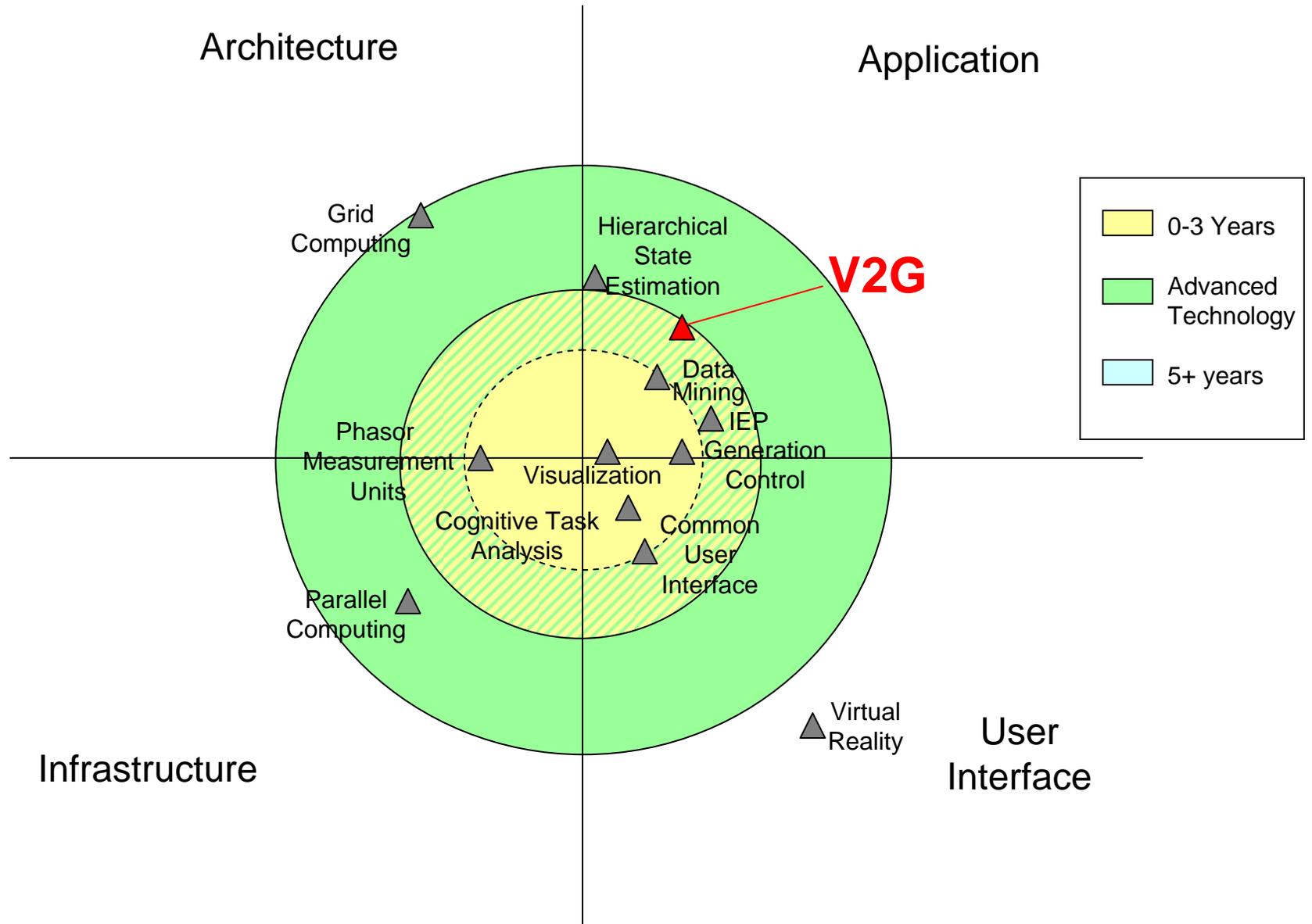


# Cognitive Task Analysis



# Analysis of Emerging Technology

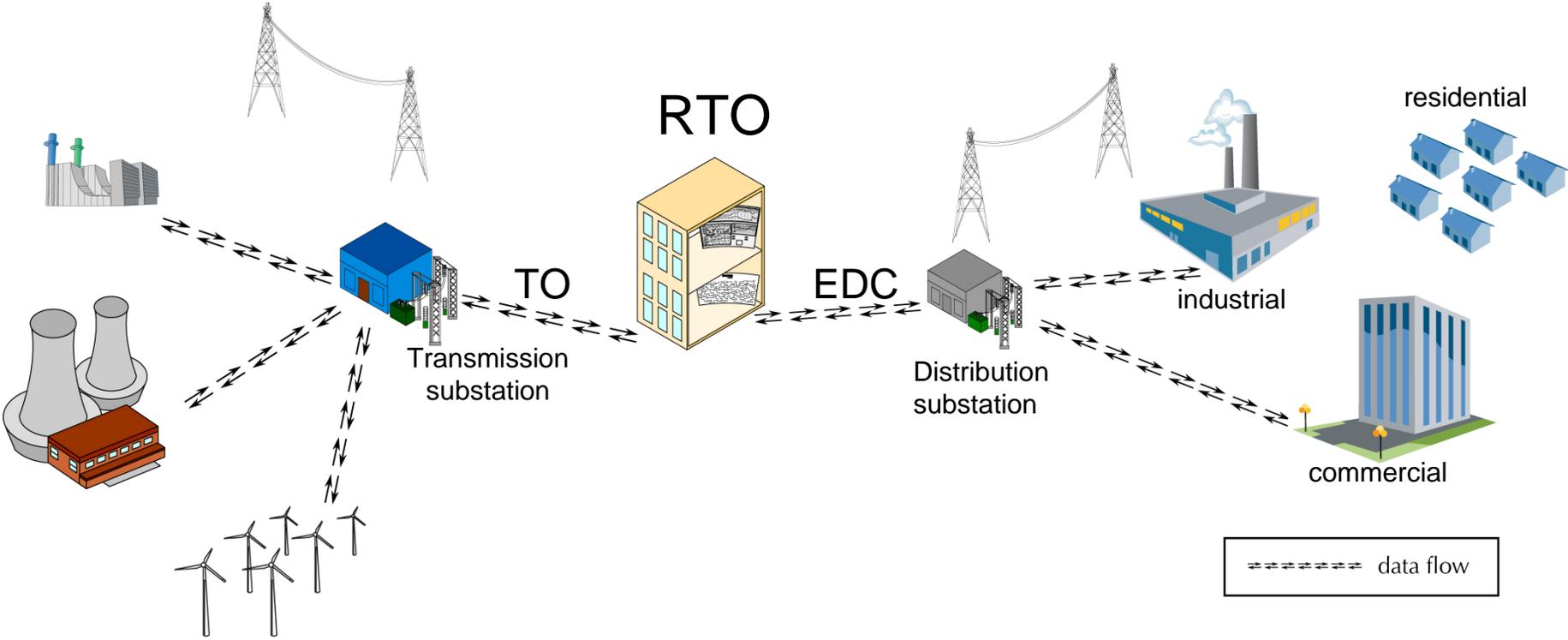
## Current Advanced Technology Focus



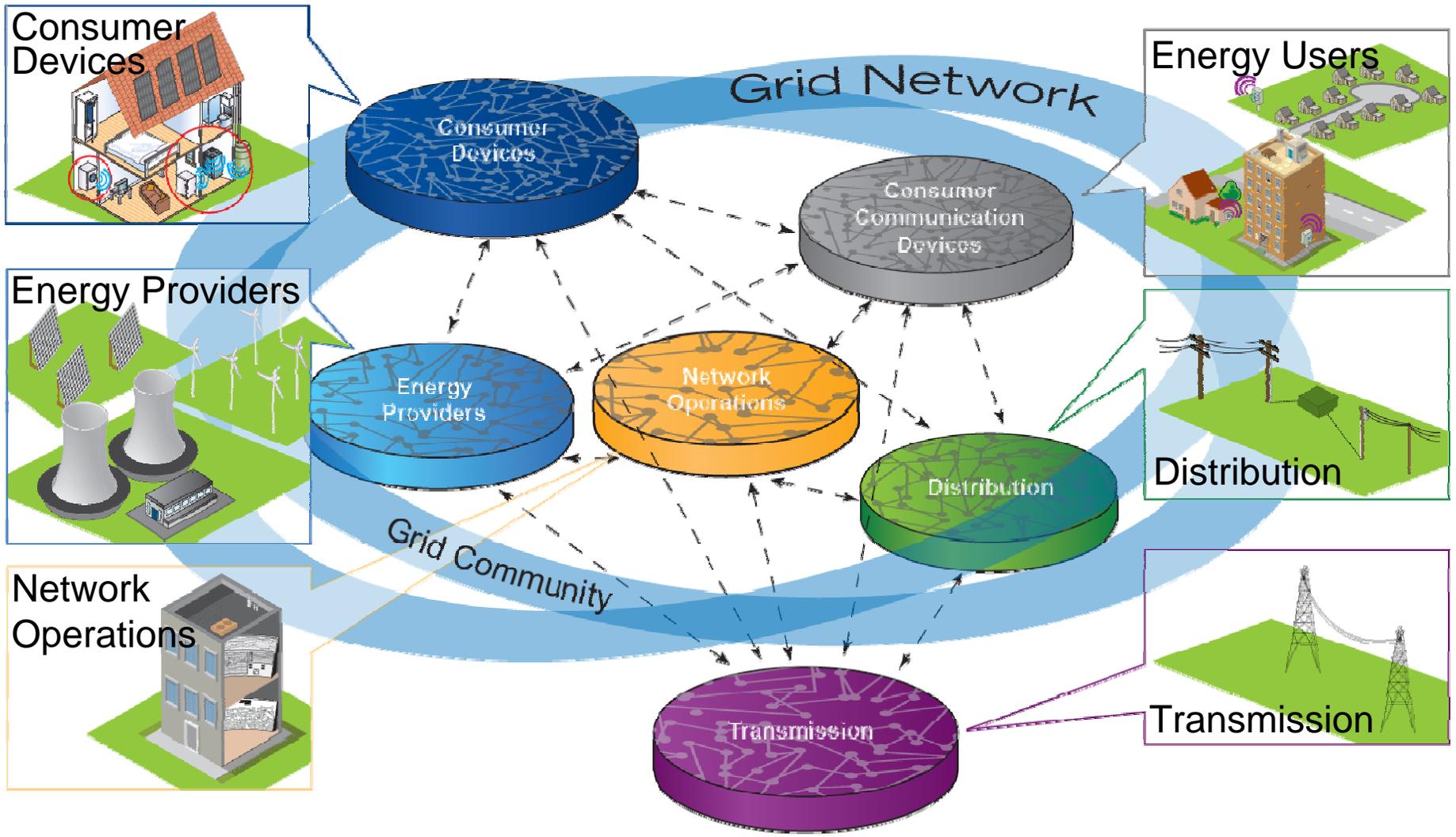
# Information Flow for Today's Grid

## Generation

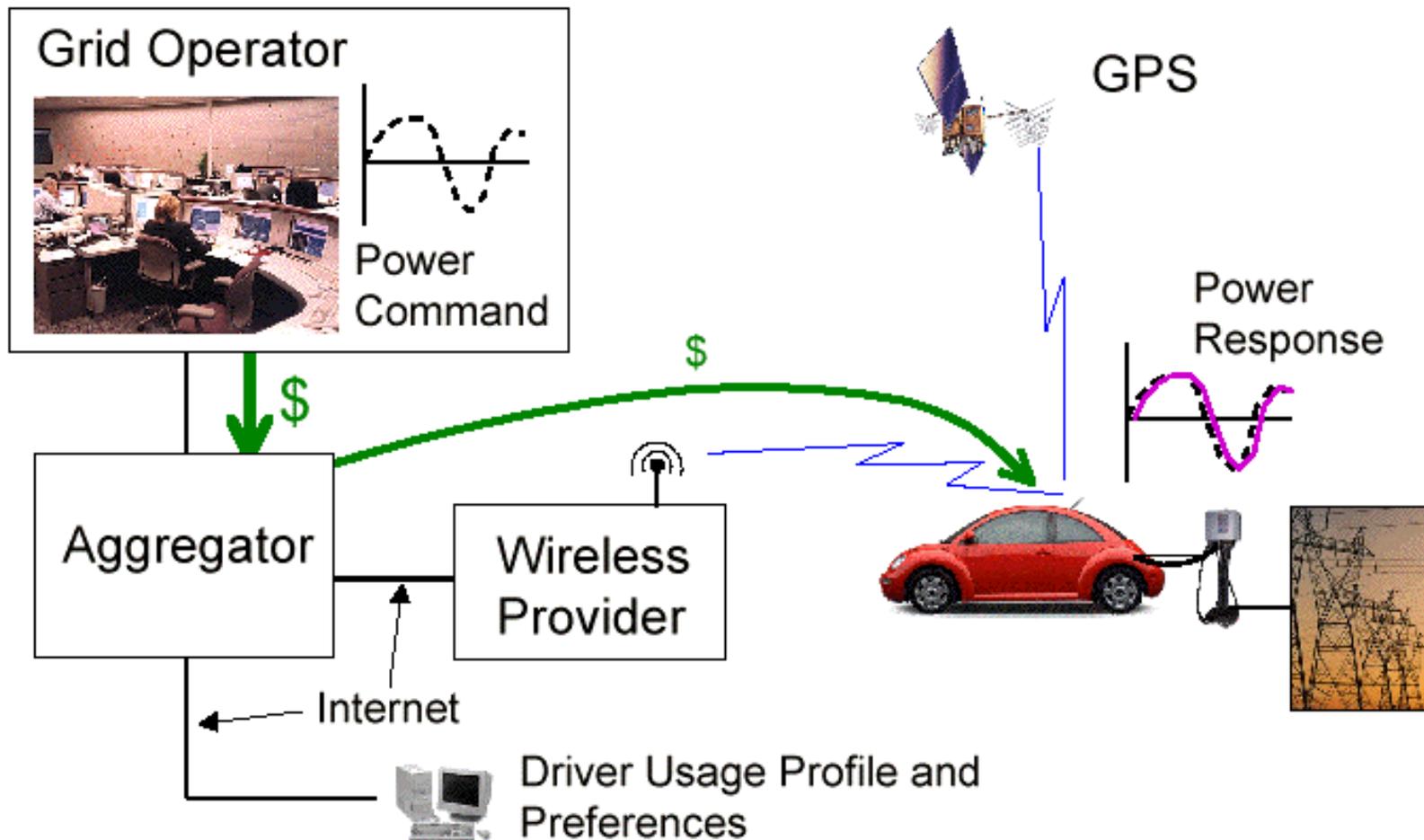
## Load



# Smart Grid



# Components of the V2G system



**The Vehicle to Grid (V2G) concept is aimed at developing a vehicle that can plug into and interact with the power grid**

- Plug-in rechargeable vehicle with relatively high capacity battery (vs. hybrid vehicles)
- Vehicle can communicate with the power provider
- Vehicle can provide two way power. Acts as generator or load as required
- Vehicle can participate in markets (such as regulation)
- New aggregation business function to provide interface between regulation signal and vehicles.

# AC Propulsion eBox Conversion

## eBox V2G Capable Scion Conversion from AC Propulsion



Urban Utility Vehicle  
 Spacious, efficient,  
 comfortable, unique,  
 sporty, versatile, fun,  
 zero emission,  
 no gas.  
[All Electric.](#)

<u>Vehicle Performance</u>		
Range	120 – 150 miles	
Acceleration	0 to 60 ~ 7.0 secs	
Top Speed	95 mph	
Charge rate	30 minutes for 20 – 50 miles	
Full Charge	2 hrs (fast), 5 hrs (normal)	
Curb Weight	2970 lbs	
		Test track photo
<u>Electric Propulsion</u>		
Drive system	120 kW, 220 Nm, 13,000 rpm, regenerative braking	
Battery	Li Ion, 35 kWh, 600 lb	
Charger	Onboard, plug in anywhere, up to 18 kW	
<u>Vehicle to Grid</u>		
Power converter	Bi-directional (charge or discharge) up to 18 kW	
Communication	Secure, wireless	
Battery management	Integrated control of battery voltage, state of charge, and temperature	

EBox?  
How about a Tesla!

**Zero to sixty in FOUR SECONDS!  
A range of 250 miles.  
Cost to operate: ONE CENT per MILE!  
Limited Availability Today -- Price: \$100,000  
2009 Production – Target Price: \$50,000**



- Average car driven 1 hour/day, thus, time parked is 23 hours/day; Daily average travel: 32 miles, storage for 100 - 250 miles
- Practical power draw from car: 10 - 20 kW
- US power: generation=978 GW; load=436 GW avg (EIA)
- US 241 million cars (FHWA 2005) x 15 kW = 3,615 GW, thus...
- **Power of fleet is >3x generation; >8x load!**

## V2G and the Electric Markets

- Initial markets (high value, low impact on battery, no system changes):
  - Regulation (“Frequency regulation”)
  - Spinning reserves
- Larger but more challenging markets
  - Peak power
  - UPS for the distribution system

## Vehicle Revenue Estimates

Vehicle owner's annual net profit from V2G; these are representative midrange figures extracted from full analysis in the report. Key: \$net (revenue – cost).

	<u>Peak power</u>	<u>Spinning reserves</u>	<u>Regulation services</u>
<b>Battery, full function</b>	<b>\$267 (510 – 243)</b>	<b>\$720 (775 – 55)</b>	<b>\$3,162 (4479 – 1317)</b>
<b>Battery, city Car</b>	<b>\$75 (230 – 155)</b>	<b>\$311 (349 – 38)</b>	<b>\$2,573 (4479 – 1906)</b>
<b>Hybrid, Gasoline</b>	<b>\$322 (1500 – 1178)</b>	<b>\$1581 (2279 – 698)</b>	<b>\$-759 (loss) (2567 – 3326)</b>

Source: “Vehicle-to-Grid Power: Battery, Hybrid, and Fuel Cell Vehicles as Resources for Distributed Electric Power in California”, June 2001

- Mid-Atlantic Grid-Interactive Car (MAGIC) Consortium led by Pepco Holdings, Inc.
  - Pepco Holdings, Inc.
  - Atlantic City Electric
  - Atlantic Counties Utility Authority
  - Comverge, Inc.
  - Delmarva Power & Light
  - PJM
  - AC Propulsion
  - University of Delaware
- MAGIC in first of three project phases
  - ✓ Phase I : Phase I: ~5 cars + one bus, V2G directly from PJM regulation signal
  - Phase II: Prove business model; ~300 cars, aggregator between PJM and cars
  - Phase III: Realize a self-sufficient V2G program within OEM vehicle manufacturers, aggregators, and ISO/RTOs.

## FERC Demonstration

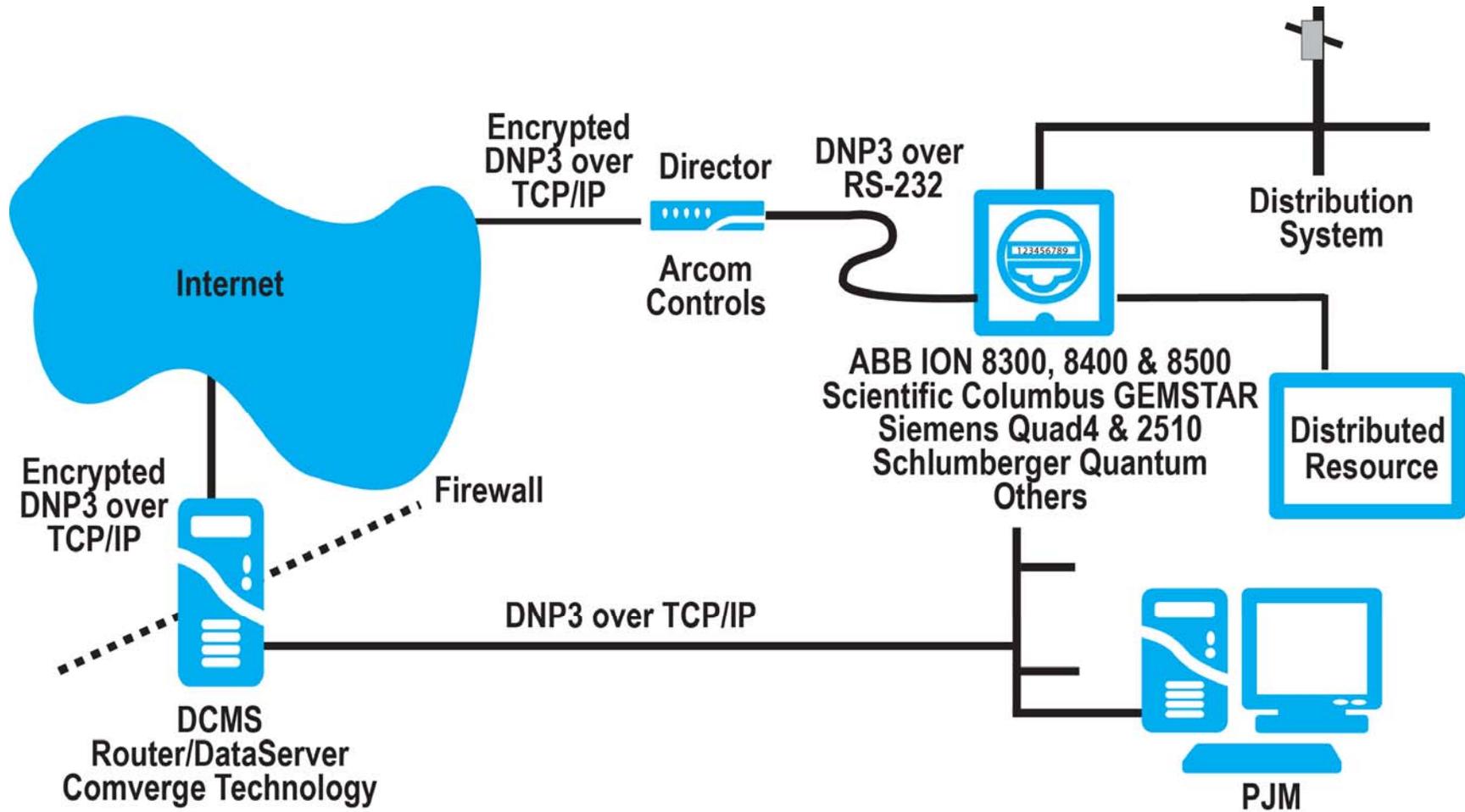
- FERC Demonstration October 24, 2007
- Chairman Kelliher, Commissioner's Wellinghoff (host), Kelly, Mohler
- Briefing by MAGIC, Tesla Motors, A123 Systems
- Used PJM's real-time regulation signal



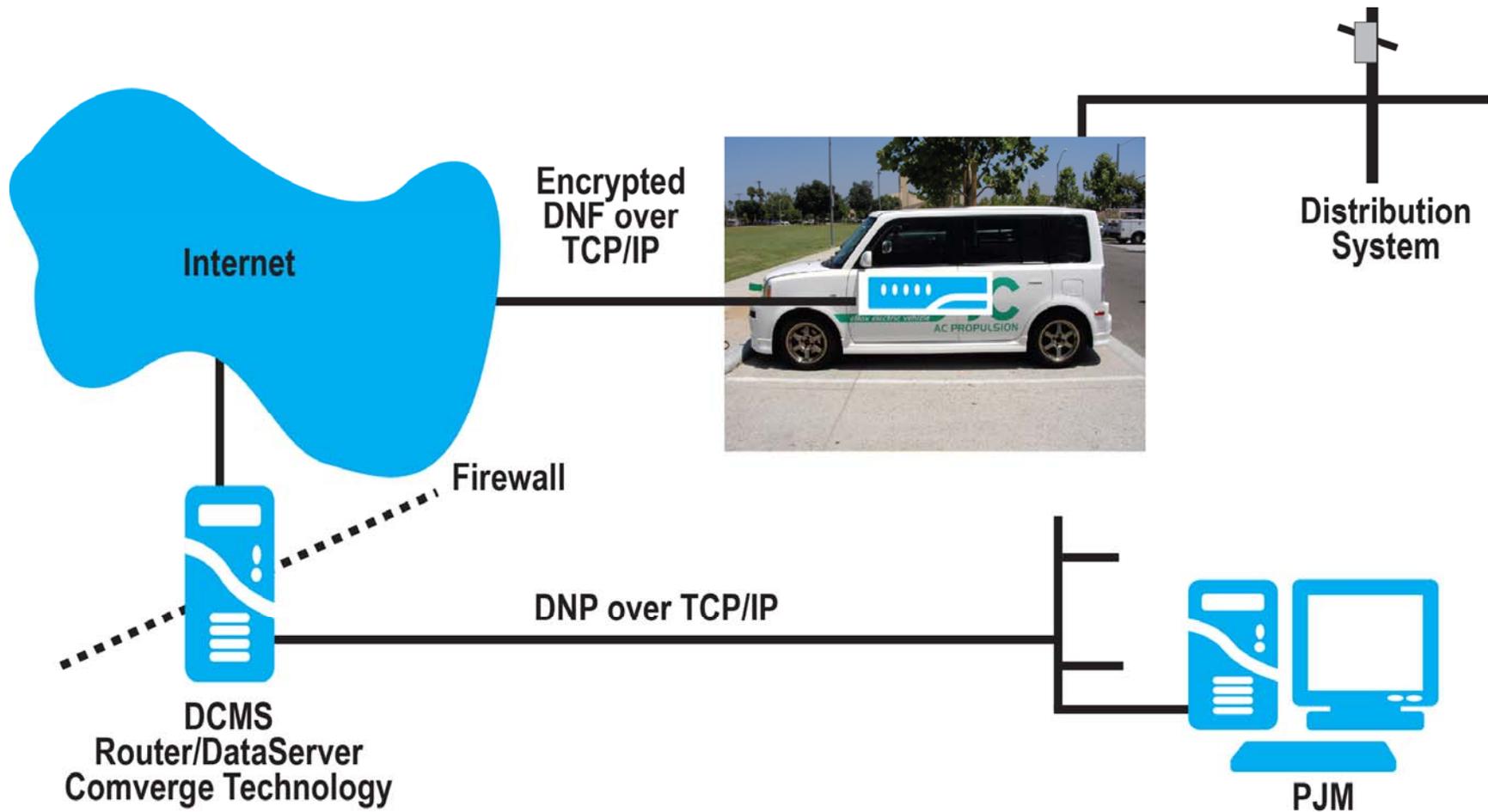
## What is PJM's Role in V2G

- Technology Enabler
  - PJM is **Not** intending to control hundreds or thousands of individual cars!
  - PJM is involved to help customer prove the technology can work
- PJM is working with other customers with technology initiatives that have the potential to improve Grid Reliability and/or enable greater PJM Market Participation
  - Battery to Grid (B2G)
  - Fly Wheel to Grid
  - Landfill Gas
  - Solar Voltaic

# PJM's Already Existing Internet Communications



# Application of Existing Internet Communications to V2G



# 2-Way Communications

scs01awp - Terminal Server Client

Real Time

Spectrum PowerCC

Operations, Generation, Scheduling, Transmission, Forecast, Energy Data, Trading, Simulation

E-AI 2, E-AI 3, G-AI 1, G-AI 2, W-AI 1, W-AI 2, Tools, Displays, Communication

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<Realtime (RT)> - Runtime Explorer

File View Tools Help

SE\_RTS\_01, CFE View, OPC View, ICCP UI, Marker Summary, All Marker Types

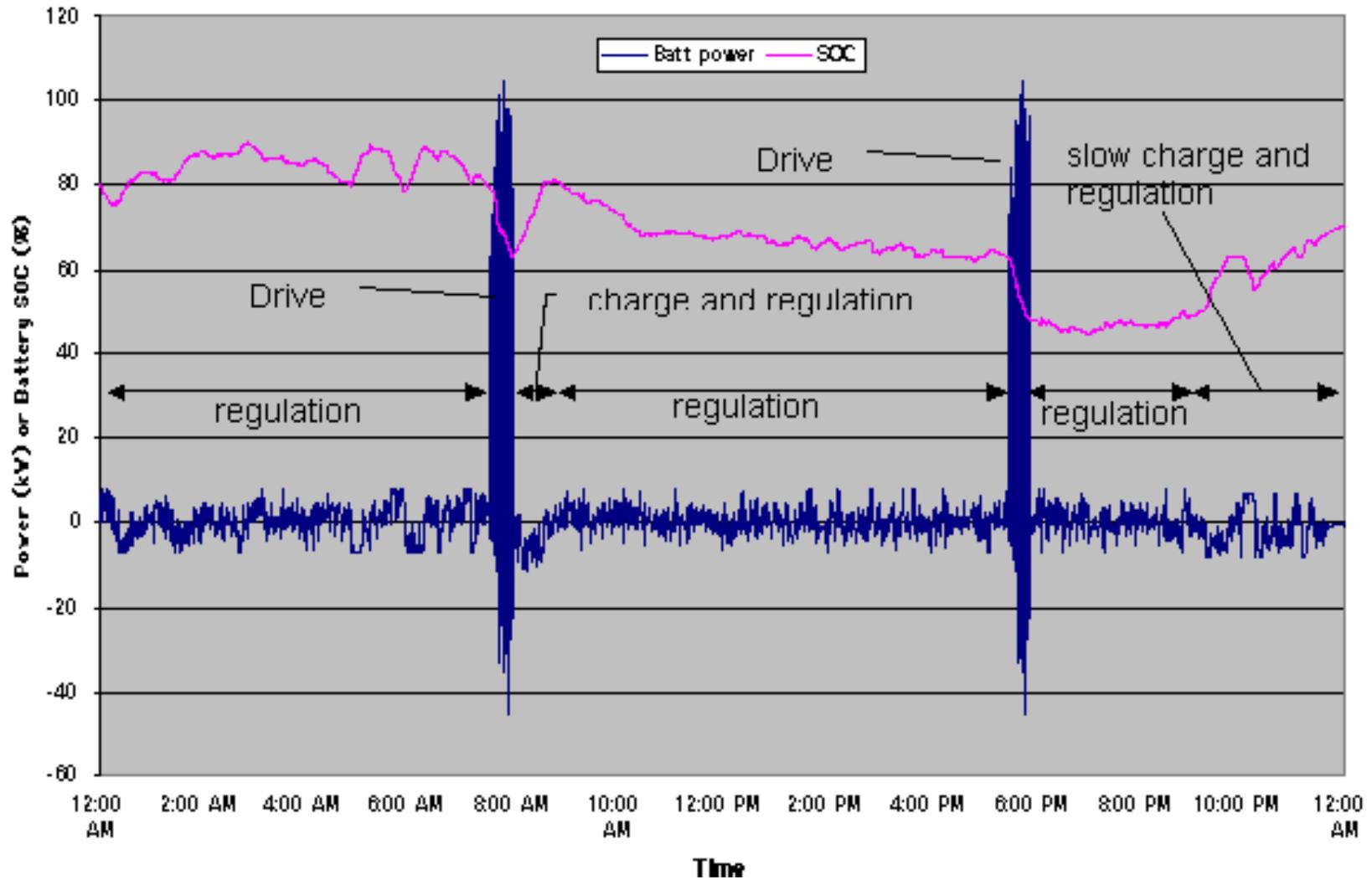
### Substation View - Network/Substations/V2GCAR1

Name	Type	Value
/BATTERY CHARGE S...	AnalogMeasurem...	72
/COMMUNICATIONS	DigitalMeasurement	Normal
/LINE AMPS	AnalogMeasurem...	29
/LINE CHARGE CAPACI...	AnalogMeasurem...	12
/LINE CONNECTION S...	DigitalMeasurement	Connected
/LINE DISCHARGE CAP...	AnalogMeasurem...	12
/LINE KILOWATTS	AnalogMeasurem...	6.4
/LINE POWER FACTOR	AnalogMeasurem...	1
/LINE VOLTAGE	AnalogMeasurem...	222
/PJM REGULATION SI...	AnalogMeasurem...	-483.3846
/PJM REGULATION SI...	AnalogMeasurem...	-482.9
/PJM TOTAL REGULAT...	AnalogMeasurem...	907.5
/PJM TOTAL REGULAT...	AnalogMeasurem...	907.5

Tree View:

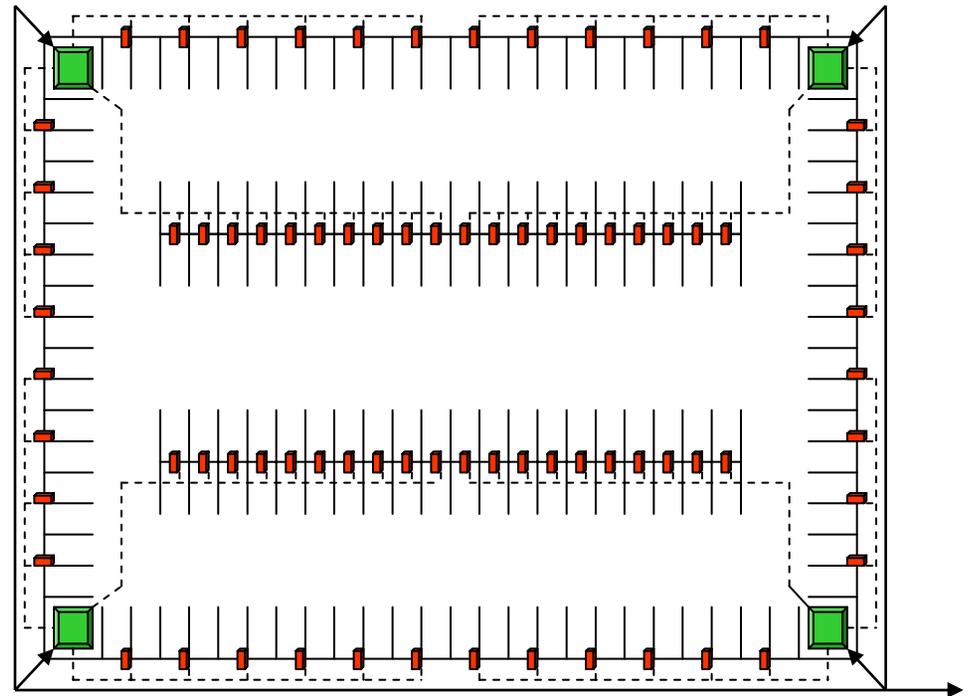
- V2GCAR1
  - V2GCAR2
  - VAUGHN
  - Warren
  - WPSENERG
  - Substations 20kV
  - Substations DMS
  - Substations LC
  - F1
    - \_CFE Common
    - CFE
      - CFE SCS01AWP
        - \_Locked
          - \_StatCte: Locked
        - ACTESTINLINE
        - ACTESTINLINEARCOM
        - AMSTEEL
        - ARCOM
        - ARNOLD

# A Day in the Life ...



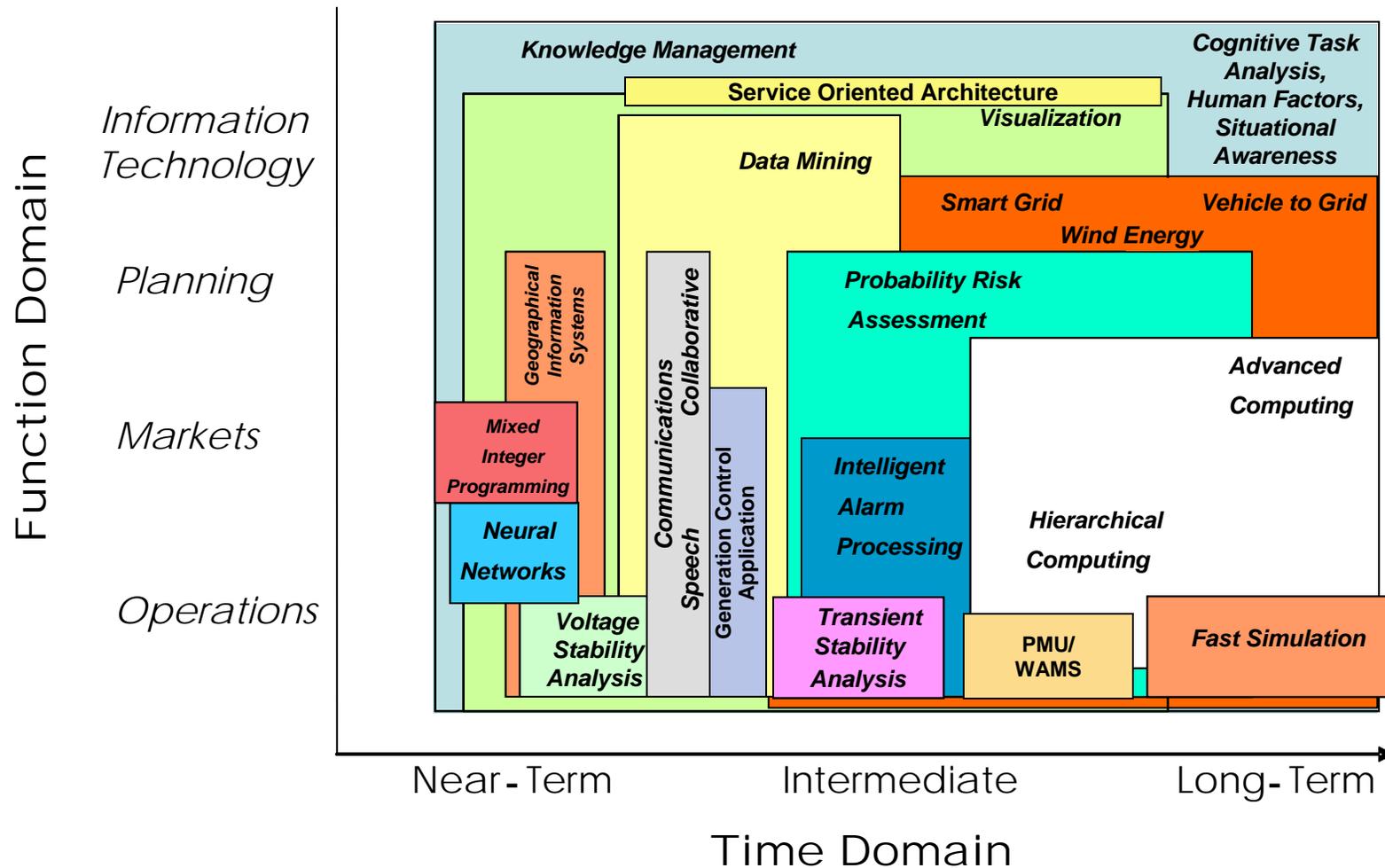
## Infrastructure Opportunities

- 32A 230V 3ph service per park
- Allows 23kW peak
- One floor = 160 cars = 3.7 MW!
- Dedicated 1MVA padmount txfmrs
- Dedicated cabling



- One-half vehicle fleet is electric drive (BEV + PHEV). National security & environment benefits.
- Lots of storage on the electric system, near loads. Electric system storage is dispatchable by ISO/TSO and/or load serving entity.
- Electric grid is more stable and reliable, Auxiliary Service is abundant and less expensive.
- Intermittent renewables can be a much higher fraction of the US generation mix.

# Advanced Technology Initiatives



**Actively seeking university partnerships for research projects and graduate student engagements.**