Low Wind Speed Technologies Annual Turbine Technology Update for Onshore, Utility Class Technologies

FY2005 DOE Wind Program Implementation Meeting
November 16, 2004

S. Schreck and A. Laxson

NREL's National Wind Technology Center

Golden, CO

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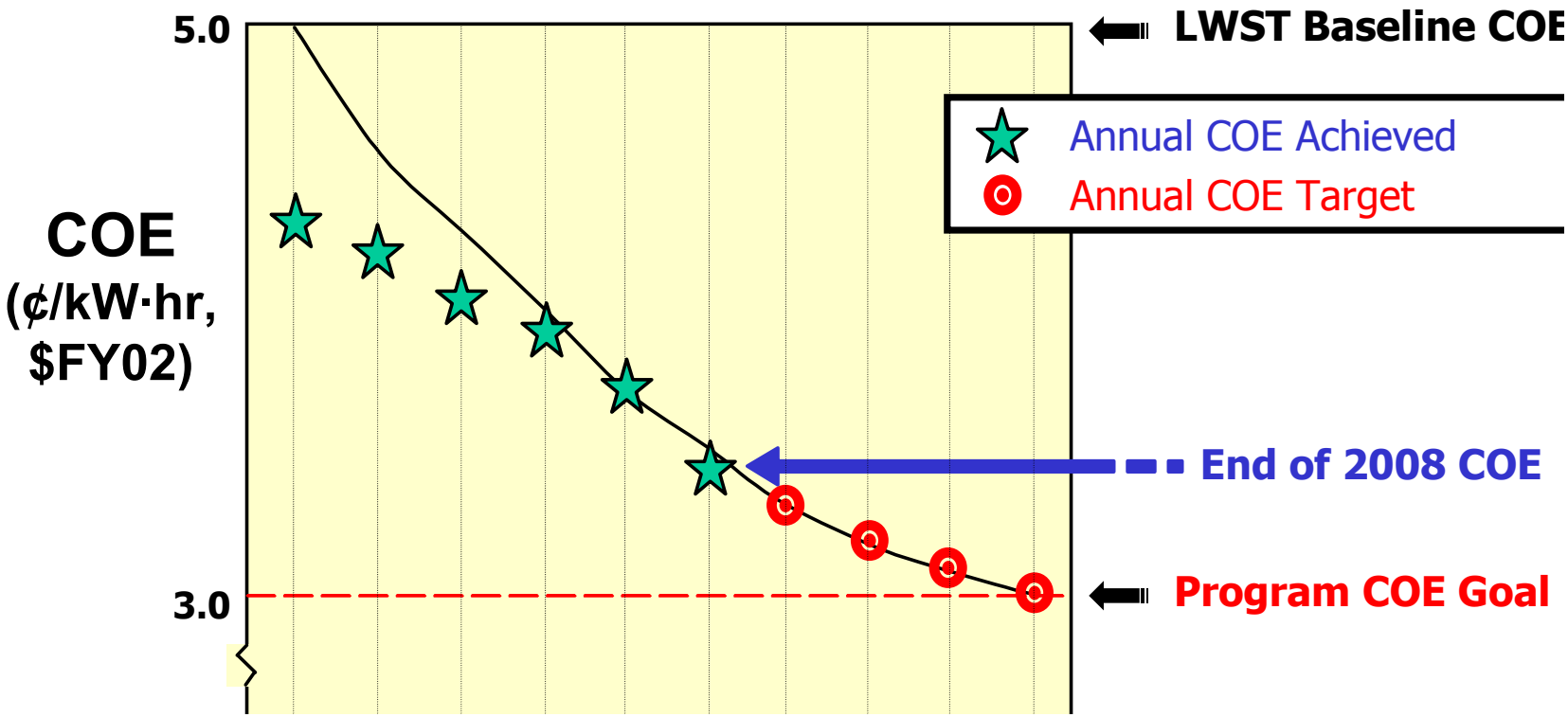
Program Goal and Progress

- 3.0 ¢/kW·hr in Class 4 wind resource by 2012
- Onshore, utility class technologies only
- OMB monitoring as directed by administration



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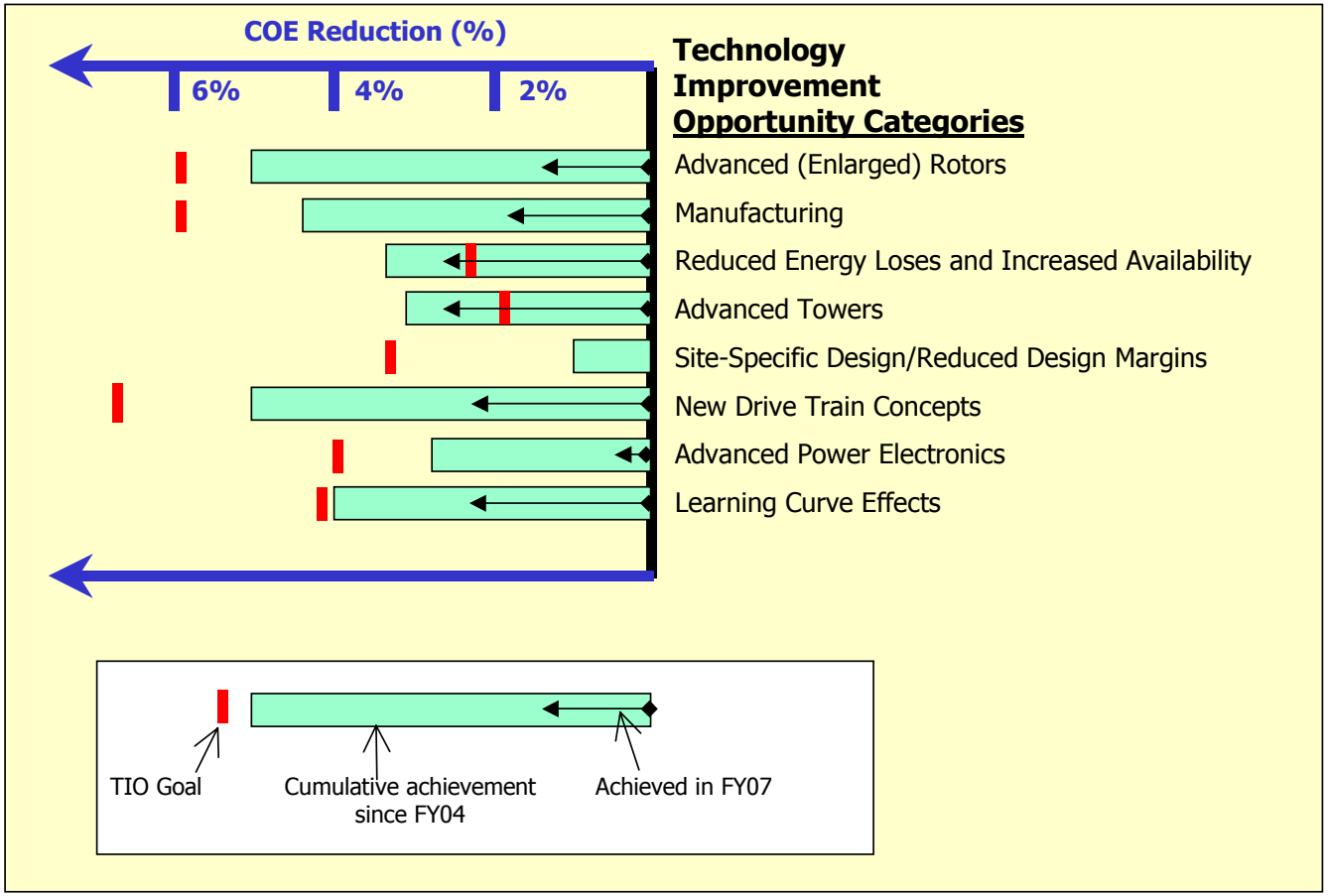
TIO Goals and Tracking

- Turbine technologies divided as TIO's
- TIO tracking facilitates portfolio balancing



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Cost of Energy Computation

$$COE = \frac{FCR * (TCC+BOS) + LRC + O\&M}{AEP}$$

- Independent variables
  - FCR - Fixed Charge Rate (11.85%, GenCo model)
  - TCC - Turbine Capital Cost
  - BOS - Balance of Station
  - LRC - Levelized Replacement Cost
  - O&M - Operations and Maintenance
  - AEP - Annual Energy Production
- Percent improvement, referenced to 2002 baseline

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LWST 2002 Baseline Turbine

- GE 1.5s, 70.5 m NGT
  - Some data protected
- WindPACT data
  - All releasable
- COE adjustments
  - Unit production rate
  - Market data

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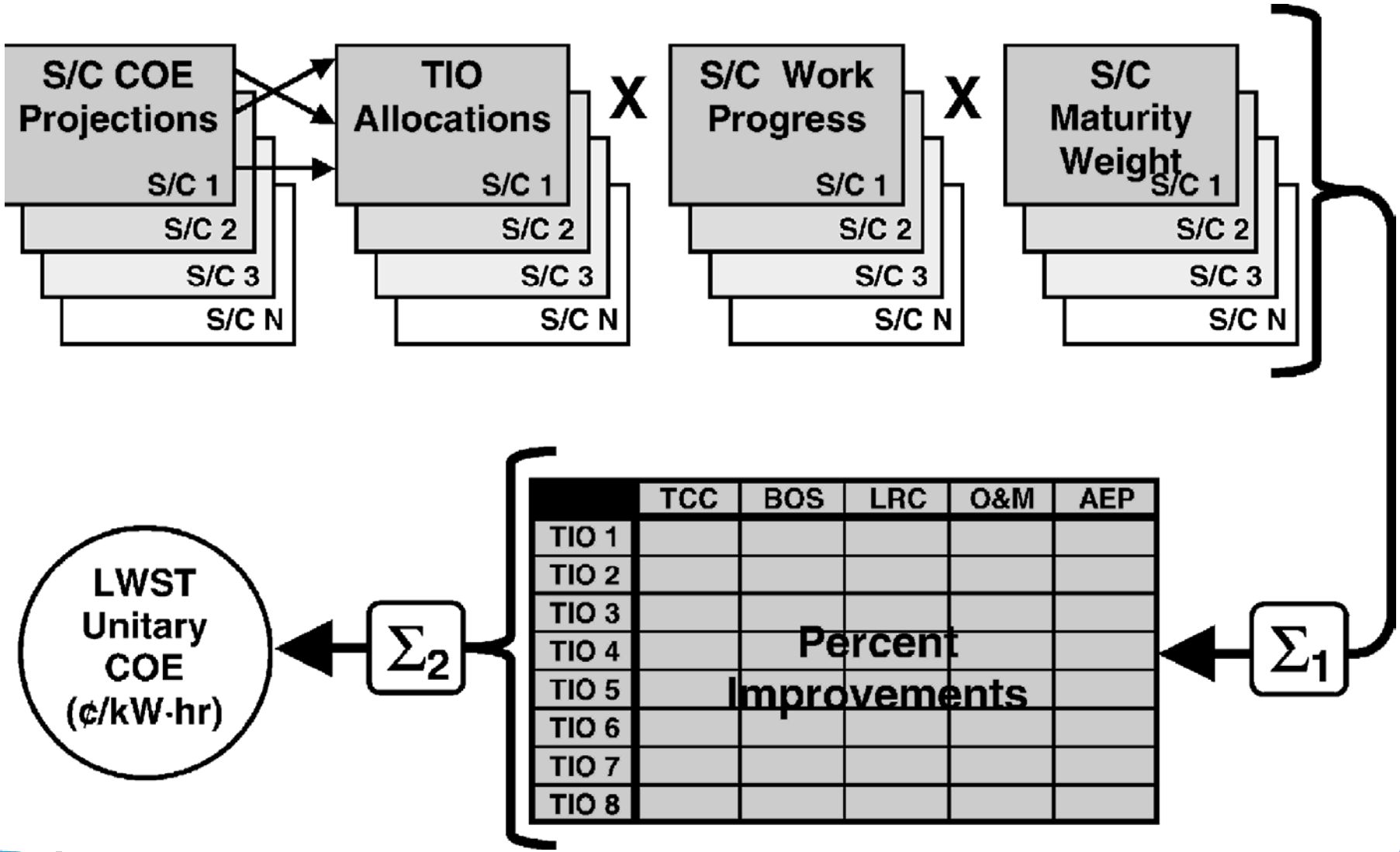
ATTU Process Overview



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ATTU Spreadsheet

Subcontractor X

Improved Gearbox, Generator, and Power Electronics

Subcontract Weighting = 30%

TIO #	TIOs	Weighted TIO Impact					TIO Allocation					Red = Stage Gate	Project Progress Milestones									Total % Complete
		TCC	LRC	O&M	BOS	AEP	TCC	LRC	O&M	BOS	AEP		Kickoff Meeting	Prelim Study Progress	Final Study Review	Study Report	Detailed Design Review	Deliver Test Article	Begin Testing	Test Complete	Final Project Review	
							-20.00%			-5.00%	10.00%	Progress	5%	15%	25%	30%	50%	70%	75%	95%	100%	
												1= Done	1	1	1	1	1	0	0	0	0	50.00%
1	Advanced Enlarged Rotor Designs											0 = Pending										
1a	Advanced Materials																					
1b	Changed Improved Structures																					
1c	Active Controls																					
1d	Passive Controls																					
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3	Reduced Energy Losses and Increased Availability																					
3a	Health Monitoring-SCADA																					
3b	Bladed Soiling Mitigation																					
3c	Extended Scheduled Maintenance																					
4	Advanced Tower Concepts																					
4a	New Materials																					
4b	Innovative Structural Approaches																					
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5	Site Specific Design - Reducing Design Margins																					
5a	Improved Definition of Site Characteristics																					
5b	Design Load Tailoring																					
5c	Micrositing																					
5d	Favorable Wind Speed Distributions and Shear																					
6	New Drive Train Concepts																					
6a	PM Generators	-1.20%			-0.30%	0.60%	40.00%			40.00%	40.00%											
6b	Innovative Mechanical Drives	-0.90%			-0.23%	0.45%	30.00%			30.00%	30.00%											
7	Advanced Power Electronics																					
7a	Incorporation of Improved PE Components	-0.60%			-0.15%	0.30%	20.00%			20.00%	20.00%											
7b	Advanced Circuit Topology	-0.30%			-0.08%	0.15%	10.00%			10.00%	10.00%											

- **One spreadsheet for each subcontractor**

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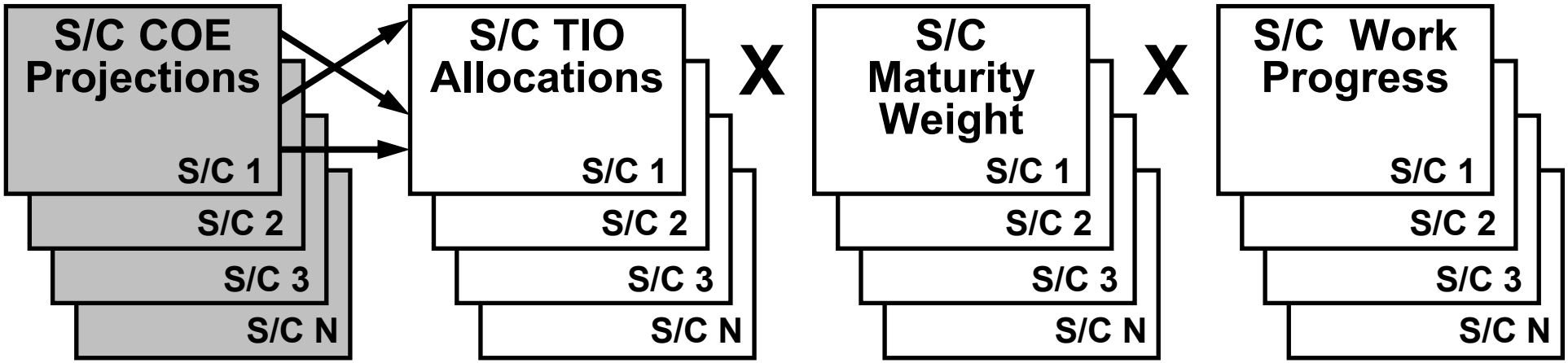
S/C COE Projections



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S/C COE Projection

Baseline Data

Subcontractor Data

Component	Baseline Component Costs $1000	Projected Component Costs $1000	Component Percent Improvement	Major Cost Element % Improvement
Rotor	**248**	**248**	0.0%	
Blades	148	148	0.0%	
Hub	64	64	0.0%	
Pitch mchnsm & bearings	36	36	0.0%	
Drive train,nacelle	**563**	**367**	-34.8%	
Low speed shaft	20	20	0.0%	
Bearings	12	12	0.0%	
Gearbox	151	90	-40.4%	
Mech brake, HS cplng,etc	3	3	0.0%	
Generator	98	54	-44.6%	
Variable spd electronics	101	53	-47.3%	
Yaw drive & bearing	12	12	0.0%	
Main frame	64	40	-37.5%	
Electrical connections	60	59	-1.7%	
Hydraulic system	7	7	0.0%	
Nacelle cover	36	17	-52.6%	
Control, safety system	**10**	**10**	0.0%	
Tower	**101**	**101**	0.0%	
TURBINE CAPITAL COST (TCC)	**921**	**726**	-21.2%	-21.2%
Foundations	49	49	0.0%	
Transportation	51	51	0.0%	
Roads, civil works	79	79	0.0%	
Assembly & installation	51	51	0.0%	
Elect interfc/connect	127	139	9.8%	
Permits, engineering	33	33	0.0%	
BALANCE OF STATION COST (BOS)	**388**	**401**	3.2%	3.2%
Project Uncertainty	**162**	**162**	0.0%	
Initial capital cost (ICC)	**1,472**	**1,288**	-12.5%	
Installed Cost per kW for 1.5 MW turbine (cost in $)	**981**	**859**	-12.5%	
Turbine Capital per kW sans BOS (cost in $)	**690**	**553**	-19.8%	
LEVELIZED REPLACEMENT COSTS (LRC) ($10.7 kW)	16	16	0.0%	0.0%
O&M $20/kW/Yr (O&M)	30	30	0.0%	0.0%
Land ($/year/turbine)	5	5	0.0%	
NET 5.8 m/s ANNUAL ENERGY PRODUCTION MWh (AEP)	4439	4572	3.0%	3.0%
Net 8 m/s ANNUAL ENERGY PRODUCTION Energy MWh (AEP)	5519	5519	0.0%	0.0%
Fixed Charge Rate	11.85%			
COE at 5.8 m/s $/kWh	**0.0480**	**0.0419**	-12.8%	
COE at 8.4 m/s $/kWh	**0.0386**	**0.0347**	-10.2%	

TCC

BOS

LRC

O&M

AEP

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COE Projection Data Entry

Subcontractor X

Improved Gearbox, Generator, and Power Electronics

Subcontract Weighting = 30%

		Weighted TIO Impact					TIO Allocation				
TIO #	TIOs	TCC	LRC	O&M	BOS	AEP	TCC	LRC	O&M	BOS	AEP
							-20.00%			-5.00%	10.00%
1	Advanced Enlarged Rotor Designs										
1a	Advanced Materials										
1b	Changed Improved Structures										
1c	Active Controls										
1d	Passive Controls										
1e	Higher tip Speed ratios/lower acoustics										
2	Manufacturing										
2a	Reduced Cost through Manufacturing Methods										
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2c	Reduce manufacturing markups										
3	Reduced Energy Losses and Increased Availability										
3a	Health Monitoring-SCADA										
3b	Bladed Soiling Mitigation										
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5	Site Specific Design - Reducing Design Margins										
5a	Improved Definition of Site Characteristics										
5b	Design Load Tailoring										
5c	Micrositing										
5d	Favorable Wind Speed Distributions and Shear										
6	New Drive Train Concepts										
6a	PM Generators	-1.20%			-0.30%	0.60%	40.00%			40.00%	40.00%
6b	Innovative Mechanical Drives	-0.90%			-0.23%	0.45%	30.00%			30.00%	30.00%
7	Advanced Power Electronics										
7a	Incorporation of Improved PE Components	-0.60%			-0.15%	0.30%	20.00%			20.00%	20.00%
7b	Advanced Circuit Topology	-0.30%			-0.08%	0.15%	10.00%			10.00%	10.00%

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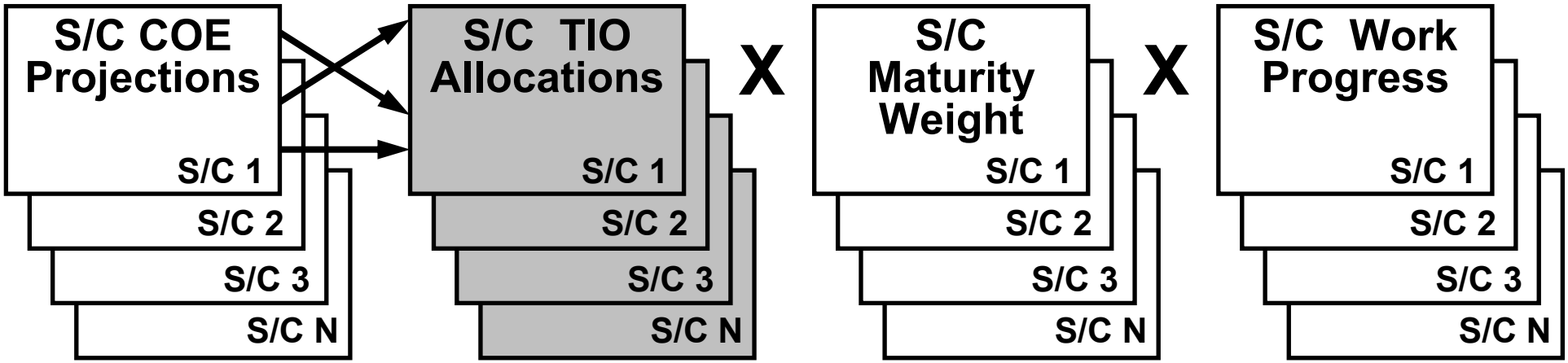
S/C TIO Allocations



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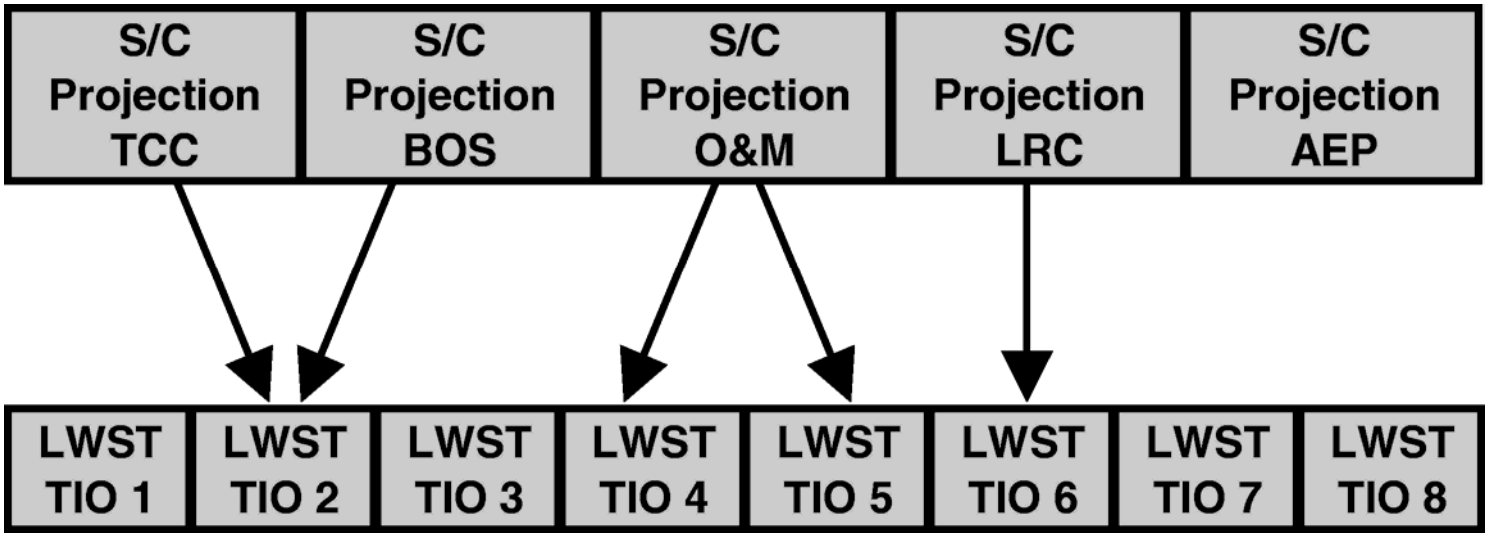
S/C TIO Allocations



- S/C report categories follow turbine architecture
- TIOs consistent with LWST program objectives
- Conservative transfer of S/C report data to TIOs
- Unique to each S/C

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TIO Allocation Data Entry

Subcontractor X

Improved Gearbox, Generator, and Power Electronics

Subcontract Weighting = 30%

		Weighted TIO Impact					TIO Allocation				
TIO #	TIOs	TCC	LRC	O&M	BOS	AEP	TCC	LRC	O&M	BOS	AEP
							-20.00%			-5.00%	10.00%
1	Advanced Enlarged Rotor Designs										
1a	Advanced Materials										
1b	Changed Improved Structures										
1c	Active Controls										
1d	Passive Controls										
1e	Higher tip Speed ratios/lower acoustics										
2	Manufacturing										
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2c	Reduce manufacturing markups										
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3a	Health Monitoring-SCADA										
3b	Bladed Soiling Mitigation										
3c	Extended Scheduled Maintenance										
4	Advanced Tower Concepts										
4a	New Materials										
4b	Innovative Structural Approaches										
4c	Advanced Foundations										
4d	Self Erection										
5	Site Specific Design - Reducing Design Margins										
5a	Improved Definition of Site Characteristics										
5b	Design Load Tailoring										
5c	Micrositing										
5d	Favorable Wind Speed Distributions and Shear										
6	New Drive Train Concepts										
6a	PM Generators	-1.20%			-0.30%	0.60%	40.00%			40.00%	40.00%
6b	Innovative Mechanical Drives	-0.90%			-0.23%	0.45%	30.00%			30.00%	30.00%
7	Advanced Power Electronics										
7a	Incorporation of Improved PE Components	-0.60%			-0.15%	0.30%	20.00%			20.00%	20.00%
7b	Advanced Circuit Topology	-0.30%			-0.08%	0.15%	10.00%			10.00%	10.00%

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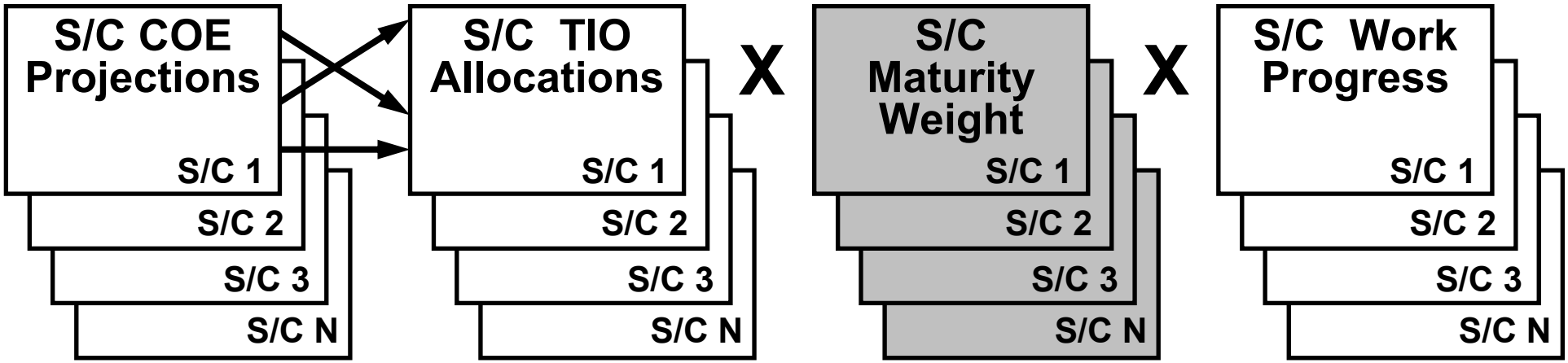
S/C Maturity Weight



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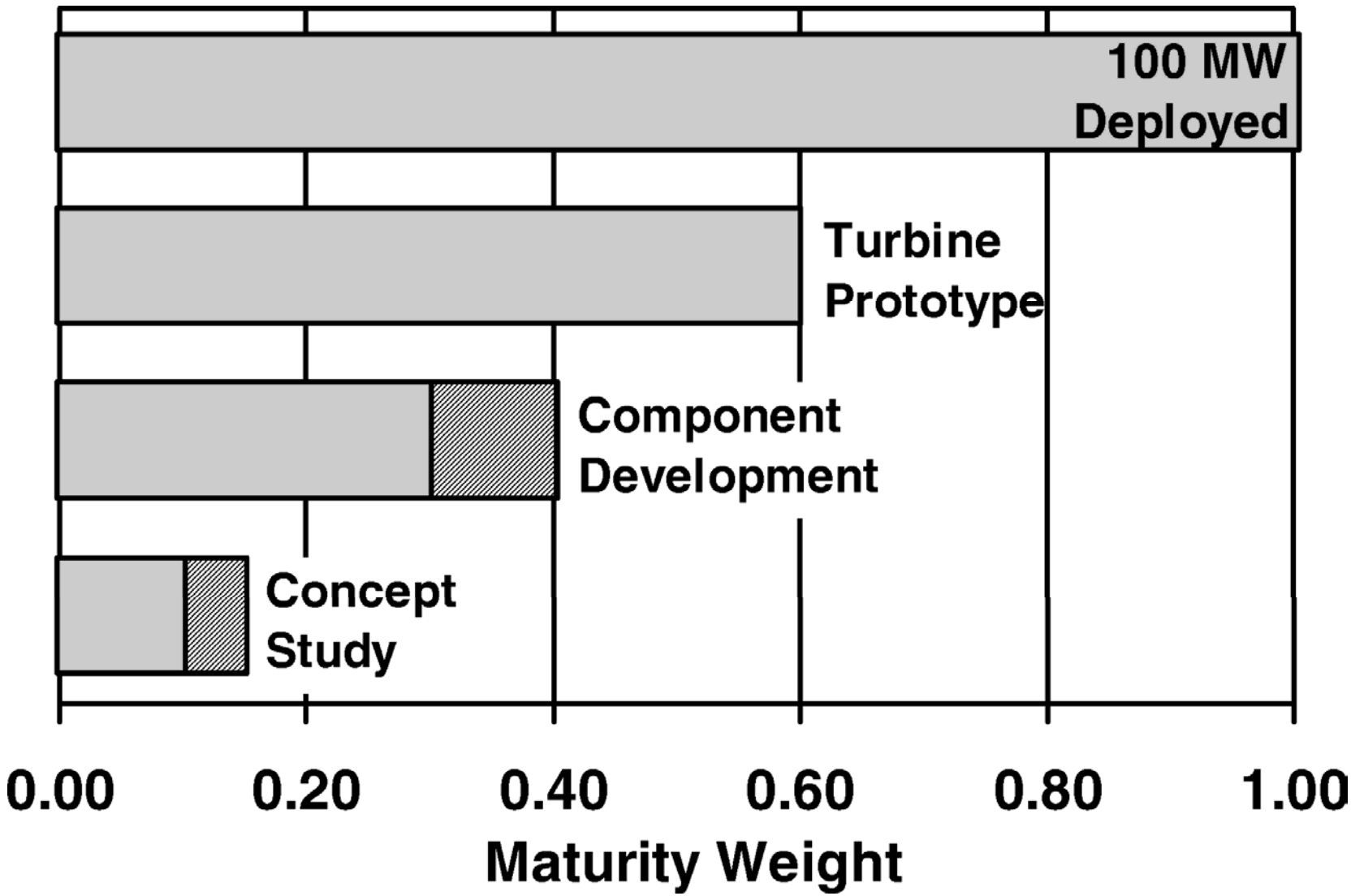
S/C Maturity Weight



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Maturity Weight Data Entry

Subcontractor X

Improved Gearbox, Generator, and Power Electronics

Subcontract Weighting = 30%

		Weighted TIO Impact					TIO Allocation				
TIO #	TIOs	TCC	LRC	O&M	BOS	AEP	TCC	LRC	O&M	BOS	AEP
							-20.00%			-5.00%	10.00%
1	Advanced Enlarged Rotor Designs										
1a	Advanced Materials										
1b	Changed Improved Structures										
1c	Active Controls										
1d	Passive Controls										
1e	Higher tip Speed ratios/lower acoustics										
2	Manufacturing										
2a	Reduced Cost through Manufacturing Methods										
2b	Reduce Cost through lower margins										
2c	Reduce manufacturing markups										
3	Reduced Energy Losses and Increased Availability										
3a	Health Monitoring-SCADA										
3b	Bladed Soiling Mitigation										
3c	Extended Scheduled Maintenance										
4	Advanced Tower Concepts										
4a	New Materials										
4b	Innovative Structural Approaches										
4c	Advanced Foundations										
4d	Self Erection										
5	Site Specific Design - Reducing Design Margins										
5a	Improved Definition of Site Characteristics										
5b	Design Load Tailoring										
5c	Micrositing										
5d	Favorable Wind Speed Distributions and Shear										
6	New Drive Train Concepts										
6a	PM Generators	-1.20%			-0.30%	0.60%	40.00%			40.00%	40.00%
6b	Innovative Mechanical Drives	-0.90%			-0.23%	0.45%	30.00%			30.00%	30.00%
7	Advanced Power Electronics										
7a	Incorporation of Improved PE Components	-0.60%			-0.15%	0.30%	20.00%			20.00%	20.00%
7b	Advanced Circuit Topology	-0.30%			-0.08%	0.15%	10.00%			10.00%	10.00%

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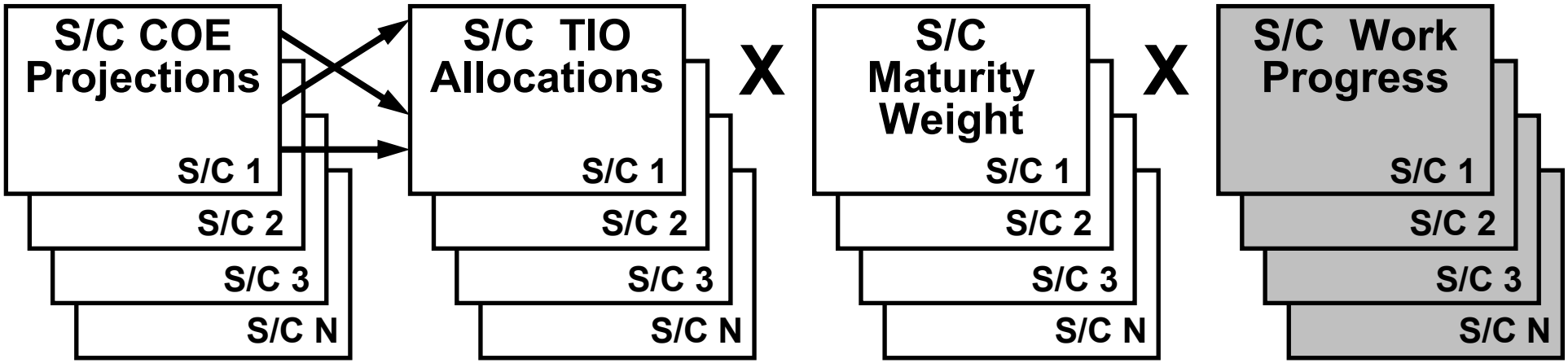
S/C Maturity Weight



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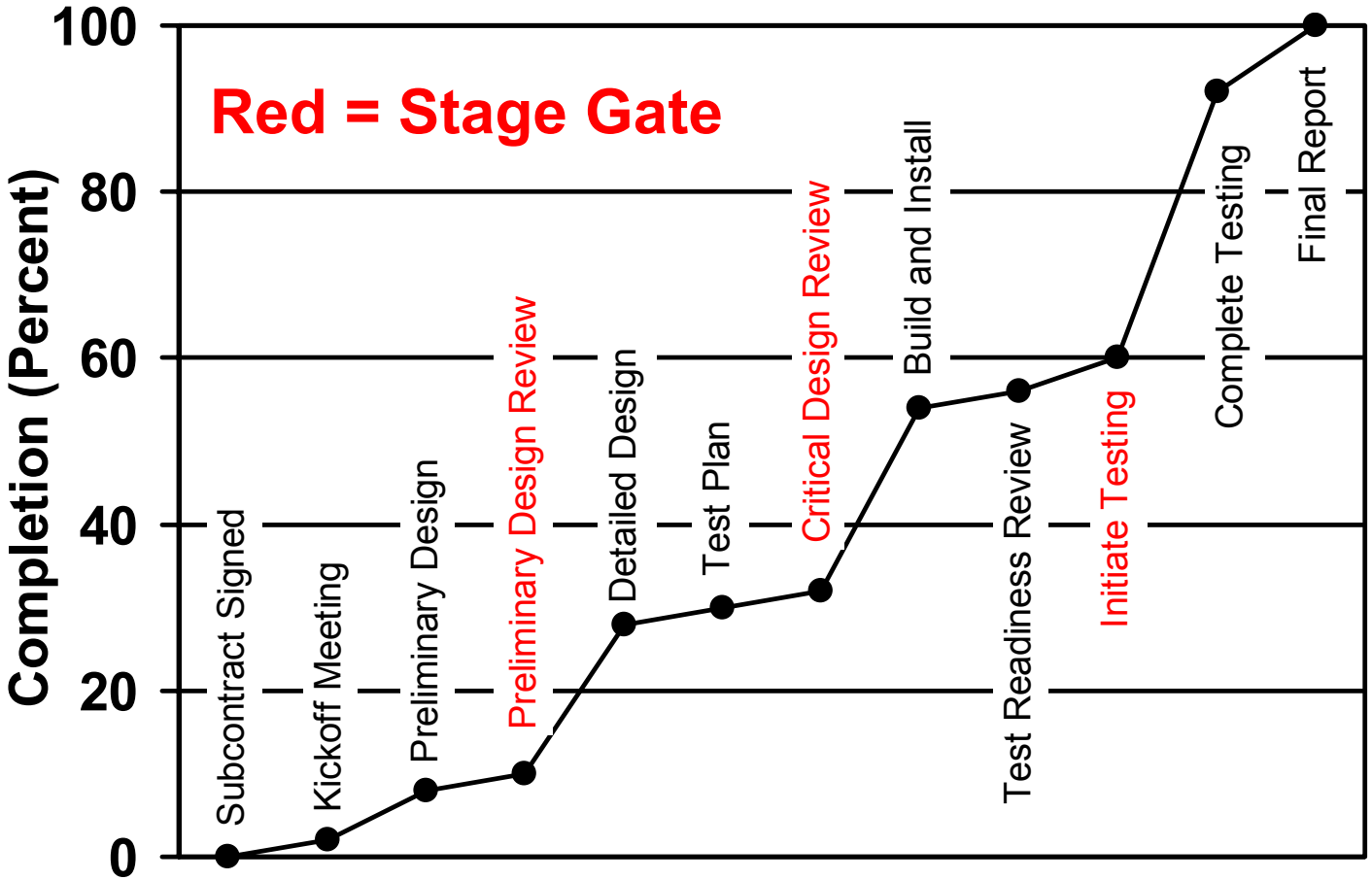
S/C Work Progress



- Varies with individual subcontract
- Stage gate = key S/C progress control point

Work Progress Data Entry

TIO Allocation					Red = Stage Gate	Project Progress Milestones									Total % Complete
TCC	LRC	O&M	BOS	AEP		Kickoff Meeting	Prelim Study Progress	Final Study Review	Study Report	Detailed Design Review	Deliver Test Article	Begin Testing	Test Complete	Final Project Review	
-20.00%			-5.00%	10.00%		5%	15%	25%	30%	50%	70%	75%	95%	100%	
					Progress										
					1= Done	1	1	1	1	1	0	0	0	0	50.00%
					0 = Pending										
40.00%			40.00%	40.00%											
30.00%			30.00%	30.00%											
20.00%			20.00%	20.00%											
10.00%			10.00%	10.00%											

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Aggregate Portfolio Data

- **Average of nonzero entries**
  - Constrains synergies
  - Represents field
  - Conservative
  - Defensible

S/C n	TCC	BOS	LRC	O&M	AEP
TIO 1					
TIO 2			X		
TIO 3					X
					X

S/C n

S/C 3	TCC	BOS	LRC	O&M	AEP
TIO 1					
TIO 2			X		
TIO 3					X

S/C 3

S/C 2	TCC	BOS	LRC	O&M	AEP
TIO 1					
TIO 2			X		
TIO 3					
					X

S/C 2

S/C 1	TCC	BOS	LRC	O&M	AEP
TIO 1					
TIO 2			X		
TIO 3					X
TIO 4					
TIO 5					
TIO 6					
TIO 7					X
TIO 8					

S/C 1

Percent Improvements

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LWST ATTU Data Output

	LWST Annual Technology Update	Cummulative S/C Improvements From Baseline				
	2004	TCC	LRC	O&M	BOS	AEP
1	**Advanced Enlarged Rotor Designs**	***0.73%***	***-0.75%***	***-1.00%***	***0.22%***	***6.87%***
1a	Advanced Materials	0.00%	0.00%	0.00%	0.00%	0.00%
1b	Changed Improved Structures	-0.54%	0.00%	0.00%	0.22%	0.39%
1c	Active Controls	1.27%	-0.75%	-1.00%	0.00%	6.48%
1d	Passive Controls	0.00%	0.00%	0.00%	0.00%	0.00%
1e	Higher tip Speed ratios/lower acoustics	0.00%	0.00%	0.00%	0.00%	0.00%
2	**Manufacturing**	***0.00%***	***0.00%***	***0.00%***	***0.00%***	***0.00%***
2a	Reduced Cost through Manufacturing Methods	0.00%	0.00%	0.00%	0.00%	0.00%
2b	Reduce Cost through lower margins	0.00%	0.00%	0.00%	0.00%	0.00%
2c	Reduce manufacturing markups	0.00%	0.00%	0.00%	0.00%	0.00%
3	**Reduced Energy Losses and Increased Availability**	***-0.18%***	***0.00%***	***0.00%***	***0.07%***	***0.13%***
3a	Health Monitoring-SCADA	0.00%	0.00%	0.00%	0.00%	0.00%
3b	Bladed Soiling Mitigation	0.00%	0.00%	0.00%	0.00%	0.00%
3c	Extended Scheduled Maintenance	-0.18%	0.00%	0.00%	0.07%	0.13%
4	**Advanced Tower Concepts**	***-0.40%***	***0.00%***	***0.00%***	***0.07%***	***0.13%***
4a	New Materials	0.00%	0.00%	0.00%	0.00%	0.00%
4b	Innovative Structural Approaches	-0.22%	0.00%	0.00%	0.00%	0.00%
4c	Advanced Foundations	0.00%	0.00%	0.00%	0.00%	0.00%
4d	Self Erection	-0.18%	0.00%	0.00%	0.07%	0.13%
5	**Site Specific Design - Reducing Design Margins**	***0.00%***	***0.00%***	***0.00%***	***0.00%***	***0.00%***
5a	Improved Definition of Site Characteristics	0.00%	0.00%	0.00%	0.00%	0.00%
5b	Design Load Tailoring	0.00%	0.00%	0.00%	0.00%	0.00%
5c	Micrositing	0.00%	0.00%	0.00%	0.00%	0.00%
5d	Favorable Wind Speed Distributions and Shear	0.00%	0.00%	0.00%	0.00%	0.00%
6	**New Drive Train Concepts**	***-1.25%***	***0.00%***	***-3.00%***	***-0.21%***	***0.50%***
6a	PM Generators	-0.61%	0.00%	-1.50%	-0.24%	0.20%
6b	Innovative Mechanical Drives	-0.65%	0.00%	-1.50%	0.03%	0.30%
7	**Advanced Power Electronics**	***-0.20%***	***-6.00%***	***-6.00%***	***0.05%***	***0.13%***
7a	Incorporation of Improved PE Components	-0.07%	0.00%	0.00%	0.01%	0.00%
7b	Advanced Circuit Topology	-0.13%	-6.00%	-6.00%	0.04%	0.13%
8	**Learning Curve Effects**	***0.00%***	***0.00%***	***0.00%***	***0.00%***	***0.00%***
	Total	-1.30%	-6.75%	-10.00%	0.21%	7.76%

PROGRAM AVERAGES

TOTALS

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Aggregate COE

- LWST program totals (% improvement)
  - TCC, BOS, LRC, O&M, AEP
- Apply to LWST 2002 baseline (¢, kW·hr)

$$COE = \frac{FCR * (TCC+BOS) + LRC + O\&M}{AEP}$$

- Compute LWST aggregate COE (¢/kW·hr)

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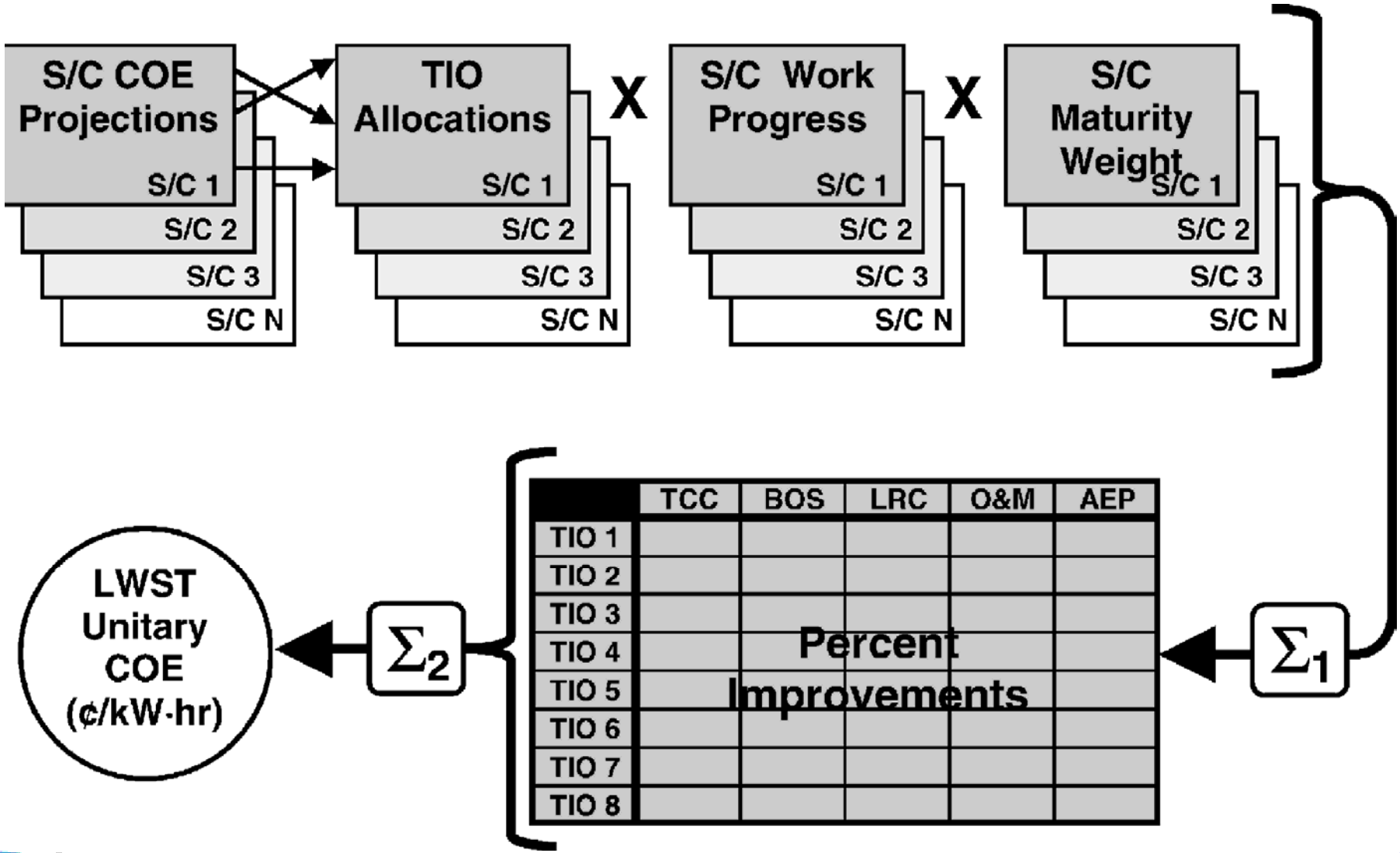
ATTU Process Summary



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