ILC SCRF Dressed Cavity
An Industrial Cost Estimate Update

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July 24, 2011

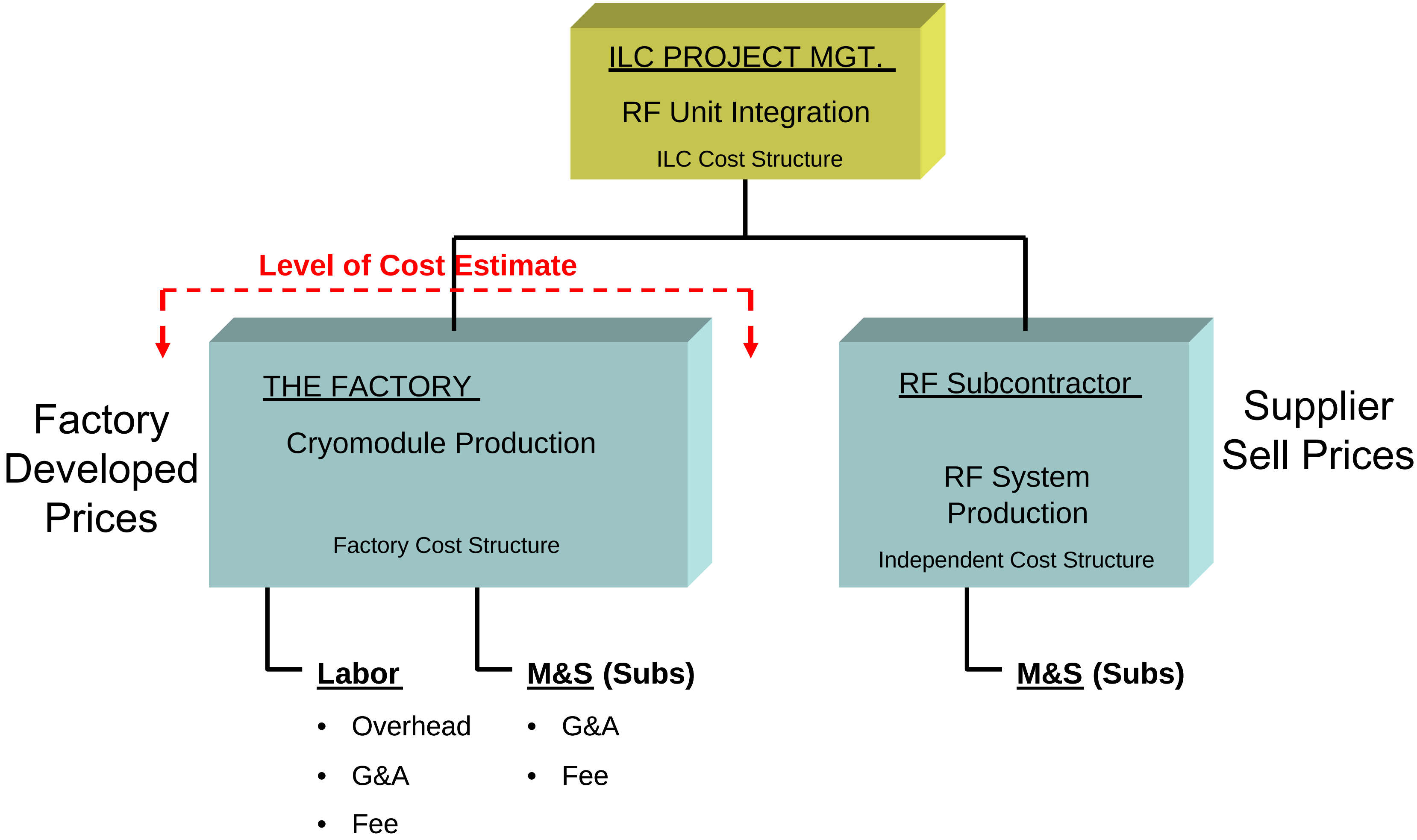
Background

- Previous work (under contracts from FNAL)
  - Sredniawski (AES), Bonnema (Meyer Tool) & Treado (CPI), "ILC RF Unit Industrial Cost Study, Methodology & Results", PAC 07.
  - A. Favale, J. Sredniawski, M. Calderaro, E. Peterson (AES), "ILC Cavity Fabrication Optimization for High Production", EPAC 08.
  - J. Sredniawski, D. Holmes, T. Schulthiess (AES), "Lowering the Cost of the ILC SRF Cavity Helium Vessel**",** PAC 09**.**
- Current effort is an update of only a small portion of the original material (AES internal effort)
  - Focused on "dressed cavity" component (wo tuner)
  - Used original cost model with CY2009 US pricing
  - Updated baseline resource data as available

Manufacturing Approach

- Problem
  – No US company is known to have the interest in setting up high production for a limited term project like ILC, without the goal of future long term business
- A government-owned or leased facility (“The Factory”) should be created to provide the equipment and space for superconducting cavity fabrication, processing, and integration and checkout of the cryomodules
  – Ideally located at or nearby a national Laboratory
  – The cost of the setup of The Factory was not part of this study
  – Industry will conduct the work at The Factory, so they will also operate it (overhead & G&A costs included)

Cost Model


ILC PROJECT MGT.
RF Unit Integration
ILC Cost Structure
Level of Cost Estimate
Factory Developed Prices
THE FACTORY
Cryomodule Production
Factory Cost Structure
RF Subcontractor
RF System Production
Independent Cost Structure
Supplier Sell Prices
Labor
• Overhead
• G&A
• Fee
M&S (Subs)
• G&A
• Fee
M&S (Subs)

Role of "The Factory"

- Industrial contractor operates "The Factory"
- The Factory has two (2) divisions
  - Division A (Cavity Fabrication):
    - Subcontracts all component machining and forming
    - Integrates (machining, welding, cleaning), processes (EP, bake, HPR) and qualifies cavities through VTA level testing
  - Division B (Integration & Assembly):
    - Subcontracts component fabrications (vacuum vessels, shields, tuners, etc.) to numerous suppliers
    - Dresses cavities with helium vessels & tuners, etc.
    - Performs string assemblies
    - Integrates and assembles cryomodules (QC testing only)
    - Delivers CM's to National Lab for cold testing prior to shipment to ILC

Applied Labor Rates

Labor rates taken from US Bureau of Labor Statistics for CY2009 (top 10%)

Weighted averages for three categories used in calculations

MANAGEMENT		**100%**	**$63.56**	← Weighted Avg
Production Manager	$67.56	75%	$50.67	
Industrial Engineer	$51.57	25%	$12.89	
MANUFACTURING		**100%**	**$27.90**	← Weighted Avg
Machinist & Shop Tectnician	$27.52	56%	$15.41	
NC Programmer	$34.40	12%	$4.13	
Chemical Technician	$31.49	12%	$3.78	
Welder	$22.93	20%	$4.59	
MFG. SUPPORT		**100%**	**$30.76**	← Weighted Avg
Parts Inspection	$25.47	25%	$6.37	
Quality Engineering Technician (CMM)	$37.77	25%	$9.44	
Mfg. Planning & Tracking	$30.89	10%	$3.09	
Methods	$42.19	10%	$4.22	
Production Control	25.47	30%	$7.64	

OH :	120%
G&A:	15%
Fee:	10%

Summary of Production Rate Models

Full Production Duration (yr)	3	6
16000 Cavities (single source)		
1st Cavity (mo)	4	4
1st CM (mo)	8	9
Full Cavity Production Rate Achieved (mo)	25	30
Full Production Rate (cav/day)	18	10.5
Last Cavity (mo) - includes spares	60	96
Last CM (mo) - no spares	60	92
8000 Cavities (2 sources)		
1st Cavity (mo)	4	4
1st CM (mo)	9	9
Full Cavity Production Rate Achieved (mo)	26	24
Full Production Rate (cav/day)	9	5
Last Cavity (mo) - includes spares	62	96
Last CM (mo) - no spares	61	93
3200 Cavities (5 sources)		
1st Cavity (mo)	4	4
1st CM (mo)	9	9
Full Cavity Production Rate Achieved (mo)	19	16
Full Production Rate (cav/day)	3.3	1.9
Last Cavity (mo) - includes spares	61	96
Last CM (mo) - no spares	63	99

Unrealistic Ramp-up & Rate

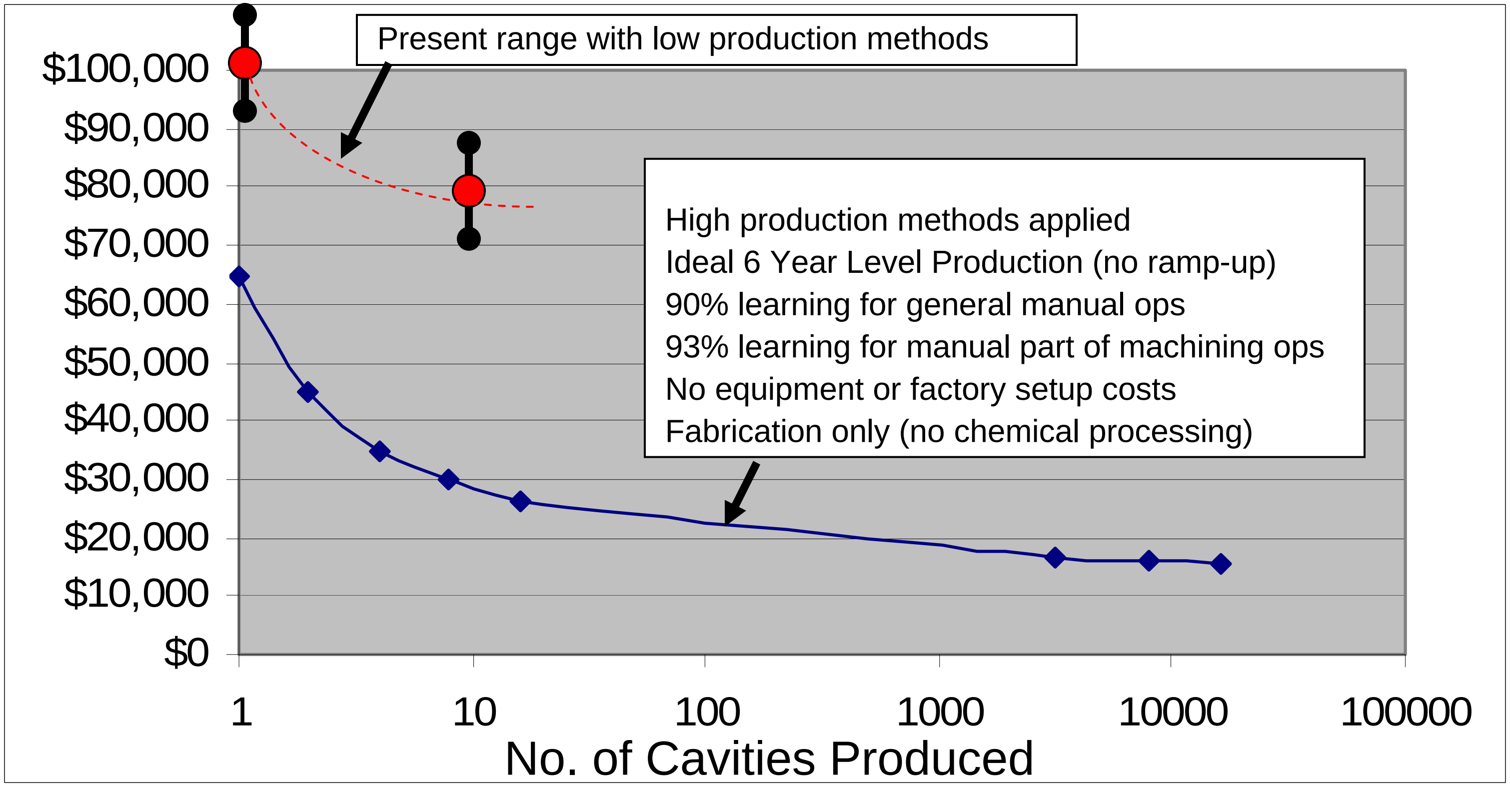
Most Conservative

CAVITY FABRICATION

Includes RF Tuning

Fabrication Price/Cavity

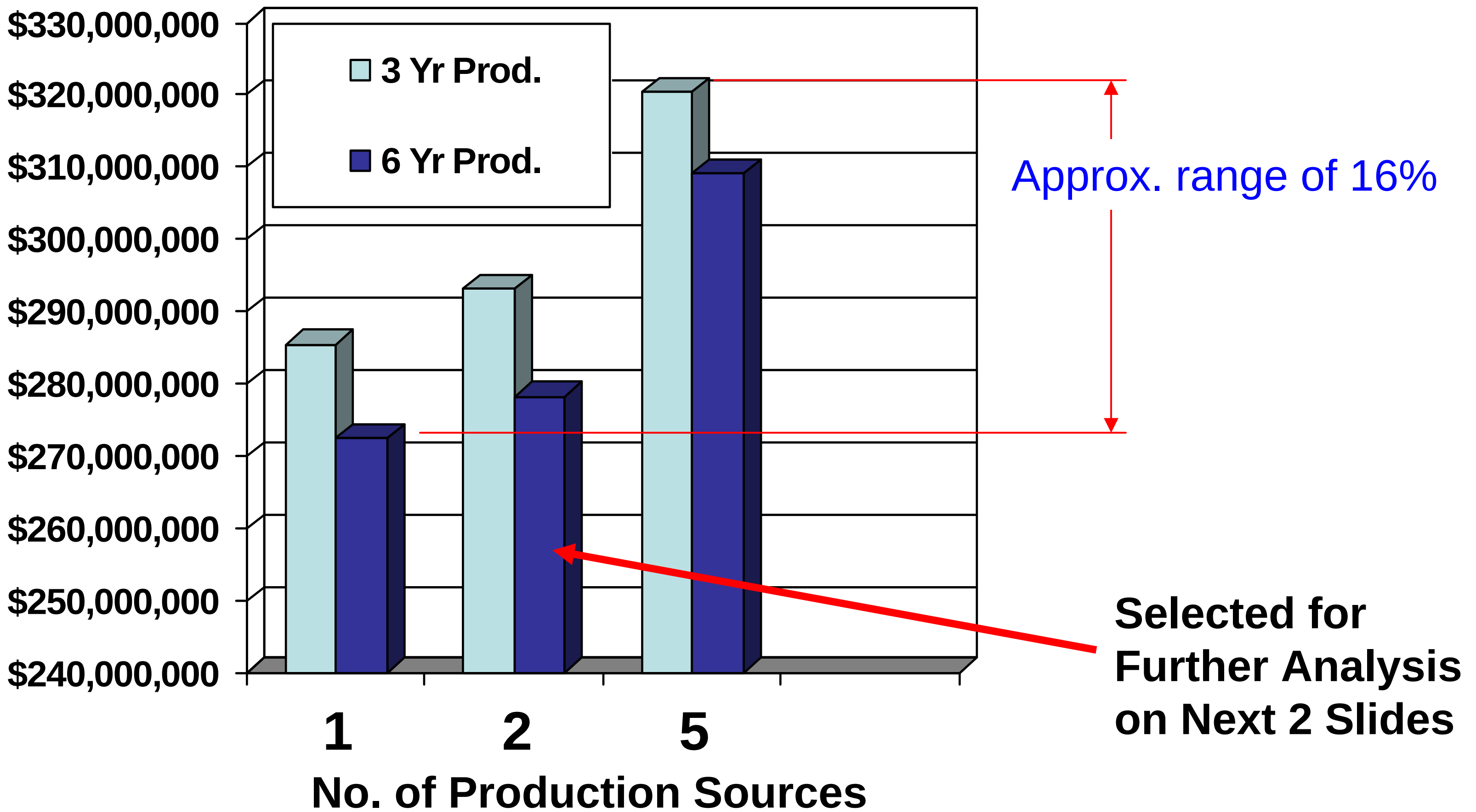
AES Ideal Production Model - CY2009 US $ - No staff training



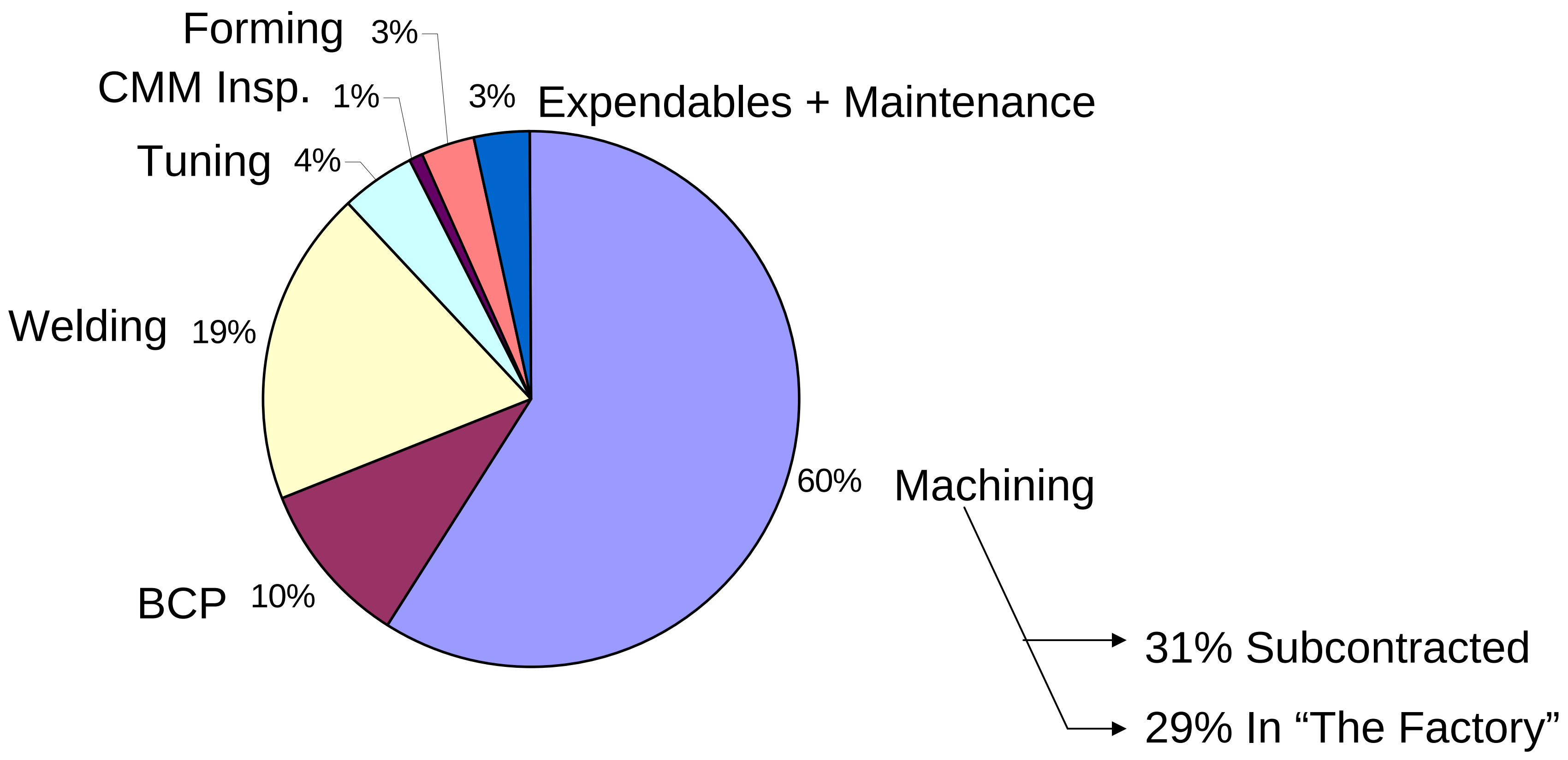
$$ difference between 3200 and 16000 cavities is only 4.6%

Total Price Comparison

16000 cavities – US $ CY2009 Includes rough est. of equipment for “The Factory”

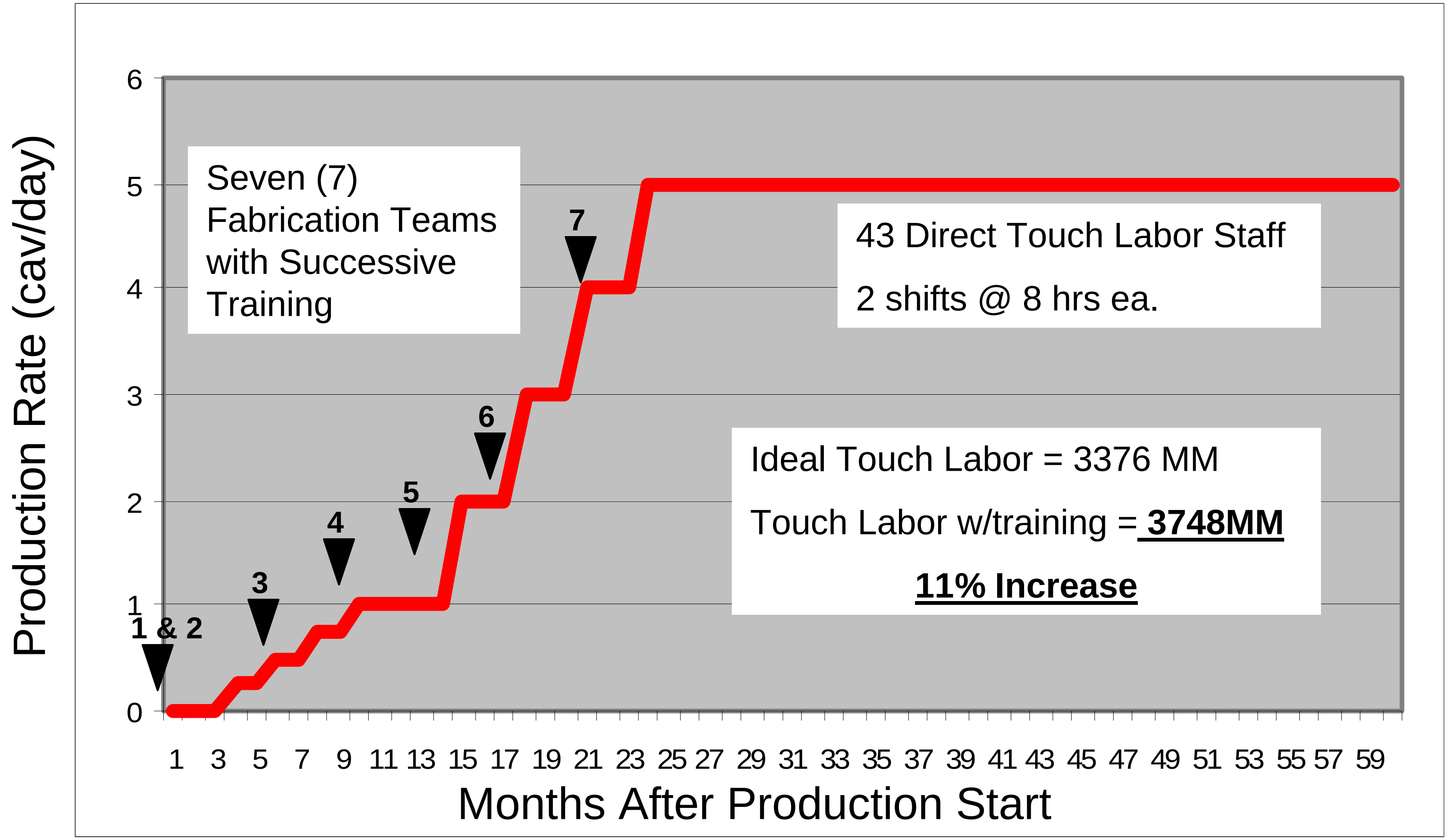


Cavity Cost Breakdown



Production Rate Ramp-up

8000 Cavities with 6 year flat top – peak rate of 5 cavities/day



Training of teams increases overall labor cost about 11% above ideal model

Min. Required Equipment for “The Factory”

8000 Cavities with 6 year flat top – peak rate of 5 cavities/day

Type of Equipment	**Quantity**
CNC Machining Centers (turning/milling)	8
BCP Wet Bench Systems	2
E-Beam Welders (blend in sizes)	10
RF Tuning System	1
Coordinate Measurement System	1
Equipment operates 14hrs/day	

Cavity Fabrication Staff* for "The Factory"

8000 Cavities with 6 year flat top – peak rate of 5 cavities/day

- Touch Labor (43 persons)
  - Machinists/Mech. Technicians (26)
  - Chemical Technicians (5)
  - E-Beam Welders (9)
  - RF Tuning Technicians (3)
- Support Labor (17 persons)
  - Parts Inspection (5)
  - CMM Operators (3)
  - Planning & Tracking (1)
  - Methods (2)
  - Production Control (4)
- Management (4)
  - Production Managers (2)
  - Industrial Engineers (2)

*NOTE: Factory facility operations infrastructure staff is not listed. The cost of this staff is included in the burdens for "The Factory" price roll-up

NOMINAL CAVITY PRODUCTION PRICE

$18,000 per unit (w/training)

Excludes:

- The Factory equipment
- Niobium Material (next slide)

Niobium Material Cost

- AES actual recent experience (CY2010) shows a nominal material cost of $37K per cavity
- Adding burdens from "The Factory" the price becomes $46.8K
  - If the material is provided by the government the burden may be discounted

CAVITY PROCESSING

Excluding VTA

Cavity Processing Steps

Accept cavity from fabrication, perform visual inspection and scribe and measure 36 thickness regions	Inspection Room
Attach tooling for handling & perform ultrasonic dip plus 3 rinses (15 min. each)	Cleaning Room
Accept cavity from fabrication, install in EP stand, attach plumbing, test for leaks, EP on auto (360 min.), drain acid, rinse w/DI water. Disconnect plumbing, remove cavity from stand, transfer cavity to drying area	Chem Room
Set up in dryer, blow dry with warm dry air (30min.), transfer cavity to vacuum furnace area	Chem Room
Accept cavity from EP, perform visual inspection and measure 36 thickness regions	Inspection Room
Attach tooling for handling & perform ultrasonic dip plus 3 rinses (15 min. each)	Cleaning Room
Install cavity in furnace, evacuate furnace, increase temp 5C/min, bake @ 800C for 5 hr, cooldown & remove cavity	Vacuum Furnace Room
Mechanical inspection and RF tuning to return structure to achieve field flatness, frequency and mechanical alignment, transfer cavity to EP process	RF Lab

Accept cavity from RF Lab, install in EP cabinet, attach plumbing, test for leaks, etch (86 min.), drain acid, rinse w/DI water, transfer cavity to HPR	Chem Room
Prep cavity for cleanroom (3 hr), install cavity in HPR cabinet, conduct 1st automated rinse cycle (4 hr), drain cavity, dry cavity (hot N2 purge) in-situ for 30 minutes, remove cavity, transfer to Class 10 clean room	Class 100 Clean Room
Install 5 blank-off flanges	Class 10 Clean Room
Install cavity in HPR cabinet, conduct 8 hour automated rinse cycle, drain & dry (30 min) in-situ, remove cavity, transfer to Class 10 clean area	Class 10 Clean Room
Attach vacuum valve & close up of cavity, transfer cavity to vacuum lab	Class 10 Clean Room
Attach to clean vacuum pump, pumpdown & leak check, transfer cavity to bake system	Vacuum Lab
Attach cavity to clean vacuum pump & start pumping, wrap cavity in heater	Vacuum Lab

Remove all attached components and prepare cavity for 30 micron EP reprocess	Chem Room

10%

With an estimated yield of 80% from the VTA testing 20% of the cavities must be recycled. 10% are assumed to go back to the last EP step and 10% only go back to the 2nd HPR. This can be allowed up to 3 times per cavity before total rejection.

10%

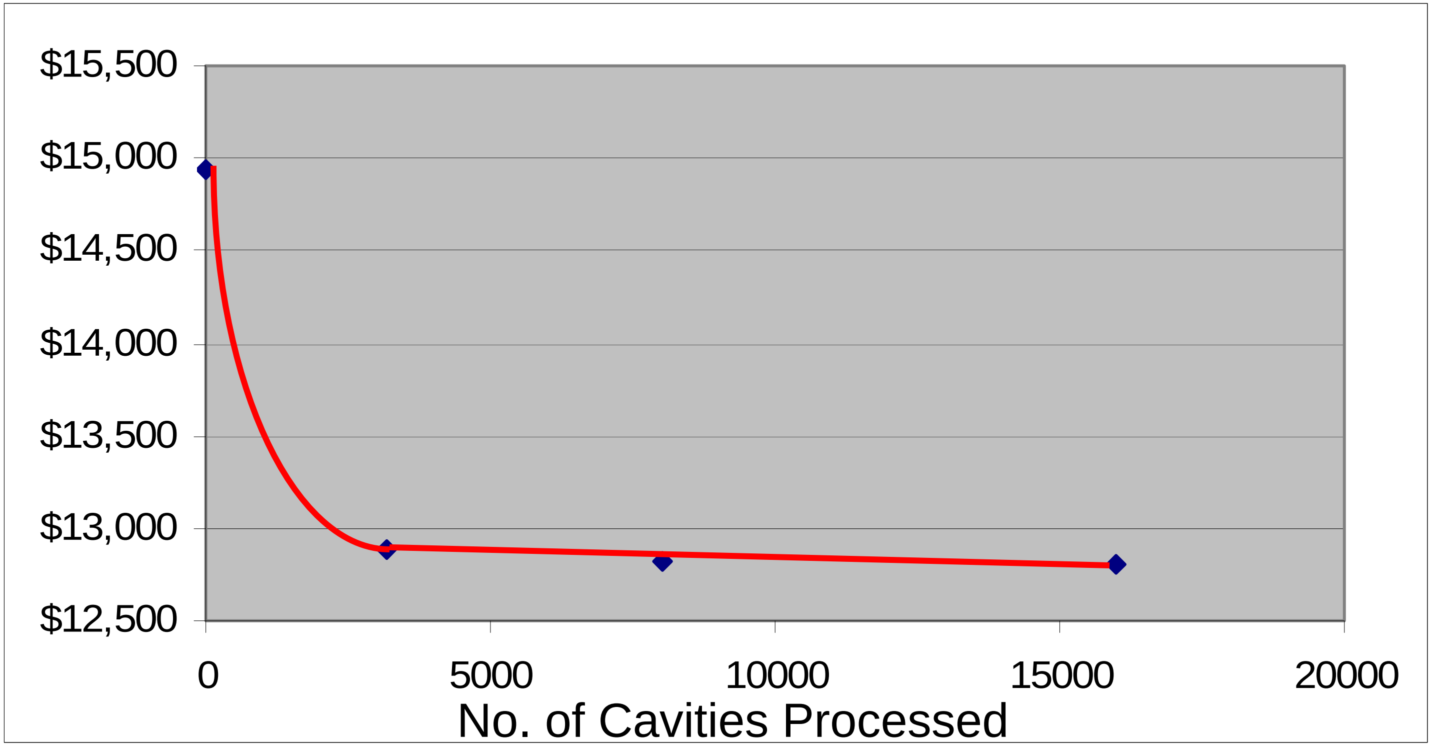
80%

19%

To He Vessel Welding

Processing Price/Cavity

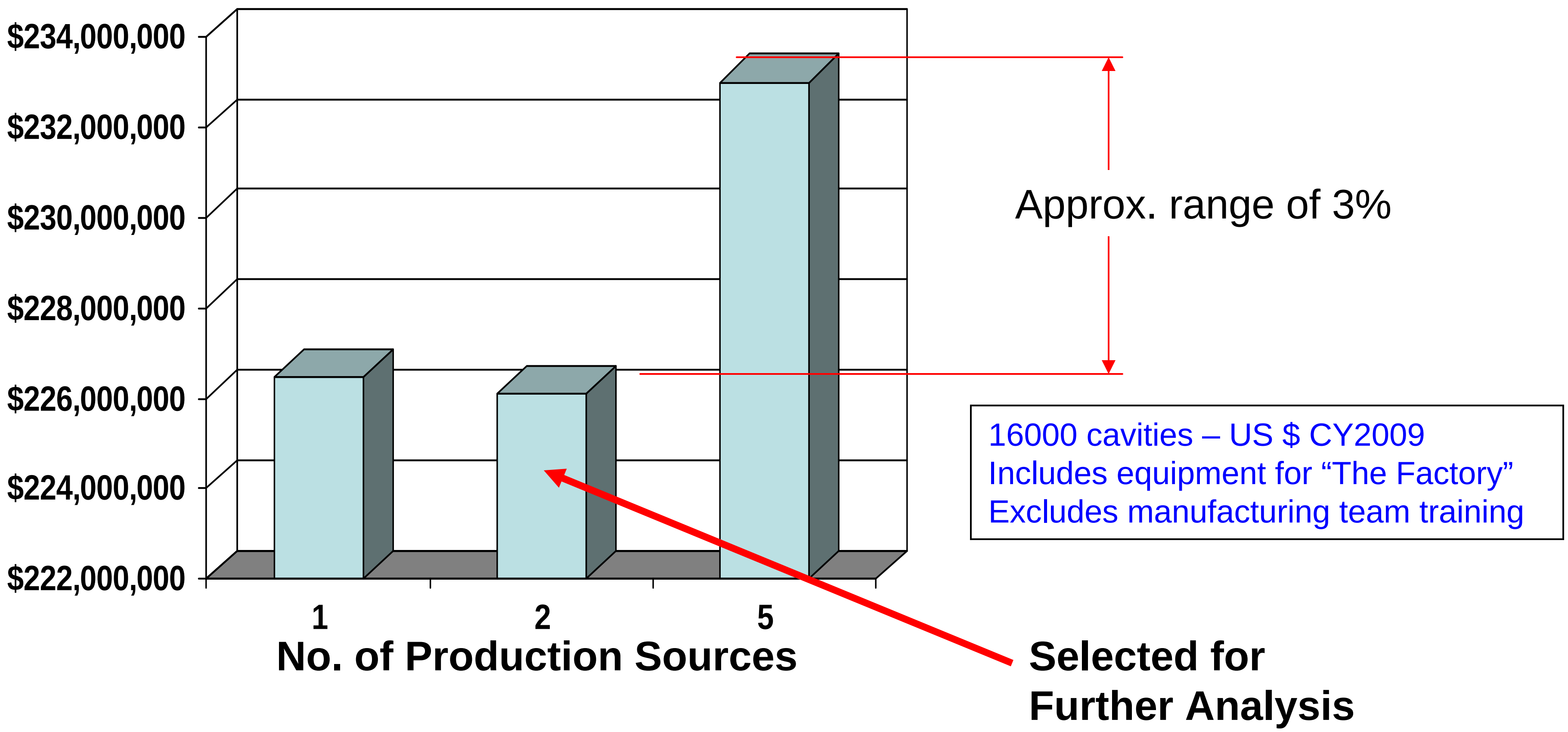
AES Ideal Production Model - CY2009 US $ - No staff training
Includes Cavity re-cycling



Price is dominated by fixed effort processing tasks

Add 11% for price with staff training

Cavity Processing Ideal Total Price Comparison



Price is not a sensitive function of number of sources

Min. Required Equipment

8000 Cavities with 6 year flat top – peak rate of 5 cavities/day

Type of Equipment	**Quantity**
EP Systems	4
Vacuum Furnaces	4
Drying Stations	1
HPR Systems	7
Low Temp Bake Stations	9
RF Tuning Stations	1
Vacuum Leak Check Stations	2

Cavity Processing Staff* for Each of Two Sources

- Touch Labor (37 persons)
  - Chemical EP Technicians (8)
  - RF Tuning Technicians (2)
  - Vacuum & Mechanical Technicians (27)
- Support Labor (15 persons)
  - QC/QA (8)
  - Planning & tracking (1)
  - Methods (2)
  - Production Control (4)
- Management (4)
  - Process Managers (2)
  - Chemical Engineers (2)

NOMINAL CAVITY PROCESSING PRODUCTION PRICE

$13,900 per unit (w/training + expendables + re-cycling)

Excludes:

- The Factory equipment

*NOTE: Factory facility operations infrastructure staff not listed. Cost of this staff is included in burdens for price roll-up

CAVITY QUALIFICATION

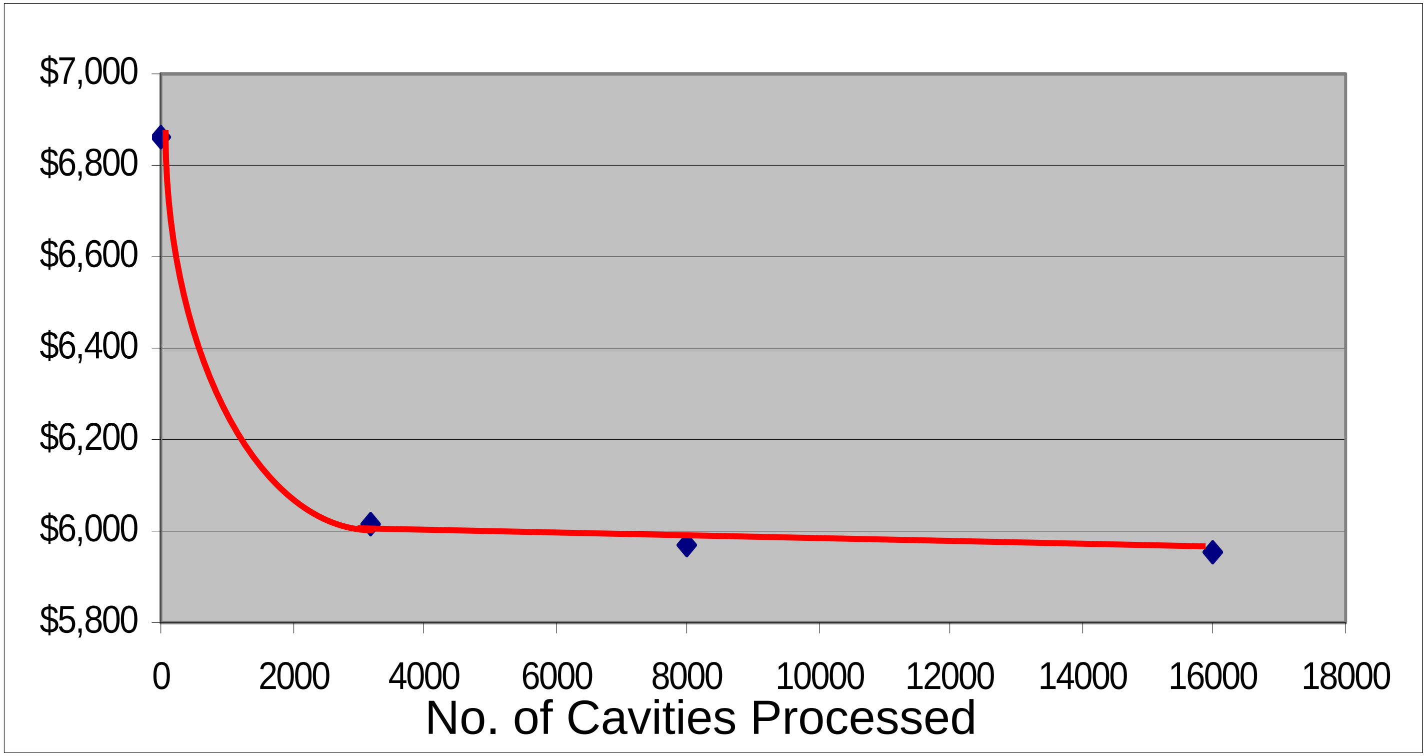
Vertical Testing

VTA Process Steps

STEP	CAVITY PROCESSING Detailed Cost Steps
1	Tool-prep (clean gaskets, CF blank off flanges, Formed bellows, Fasteners, Wrenches, Gown, Gloves, Etc.)
2	Move test stand to portable clean room
3	Settling time
4	Gowning up And wipe-down
5	vent vacuum line with N2 and seal all-metal valve to vacuum line with formed bellows
6	leak-check vacuum line, Vent with N2, Fasten adjustable coupling arms, And open all-metal valve
7	pump-down slowly, And switch on ion pump
8	assemble RF-in cable, Pt cable, Thermometers, Level stick, Stinger, Bath heater
9	transfer the test stand to the pit
10	attach coupler motor cabling, Lhe transfer hose, Attach He gas pump-out line, Connect heater, Connect thermometers, Level stick, Ion pump, And ion gauge; Verify operation
11	fasten top plate to dewar
12	pump-out air, Back-fill with room-temperature He gas, Monitor vacuum level for signs of leak
13	Fill LN2 shield
14	Start automatic logging of temperatures
15	allow dewar jacket to equilibrate
16	interlock checkouts, RF cable connections, Directional couplers, And RF calibrations
17	turn on pumps, Begin Lhe transfer and fill to cover cavity
18	resonance search and RF field level calibration
19	pump down to 24 Torr, Measuring Q and E at different T
20	measure Q vs E at 2K
21	pressurize dewar with room-temperature He gas, Vent to atmosphere, And turn on heater
22	turn off heater, Disconnect coupler motor, Level stick, Thermometers, Lhe transfer hose, Pump-out line, RF cables, Directional coupler, Ion pump, And ion gauge
23	unfasten top plate from the dewar
24	remove insert from the dewar and place on stand
25	move stand to dedicated warm-up area with fans blowing, Connect ion pump, And remove the stinger
26	warm up to room temperature
27	after warm, Vent slowly with N2
28	Close all-metal valve, Disconnect RF cables, Thermometers, And heater
29	wipe down the insert and test stand and trasnfer to the poertable cleanroom
30	settling time, Gown-up
31	disconnect the formed bellows, Blank-off ends, Remove coupling arms, And transfer cavity out of cleanroom
32	pump out vacuum line

VTA Price/Cavity

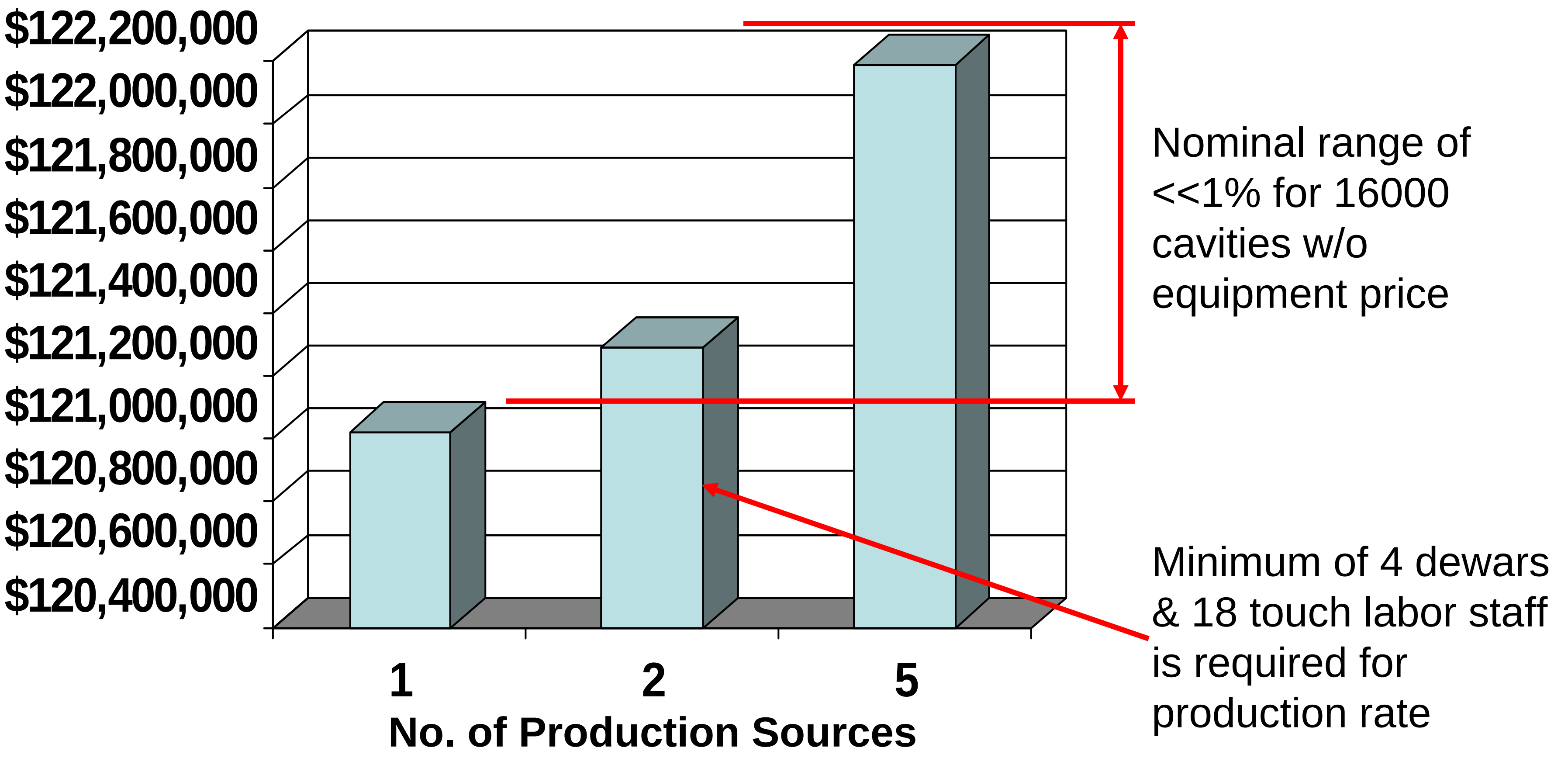
AES Ideal Production Model - CY2009 US $ - No staff training
Includes Cavity re-cycling



Price is dominated by fixed effort processing tasks

Add 11% for price with staff training

Vertical Test Ideal Total Price Comparison

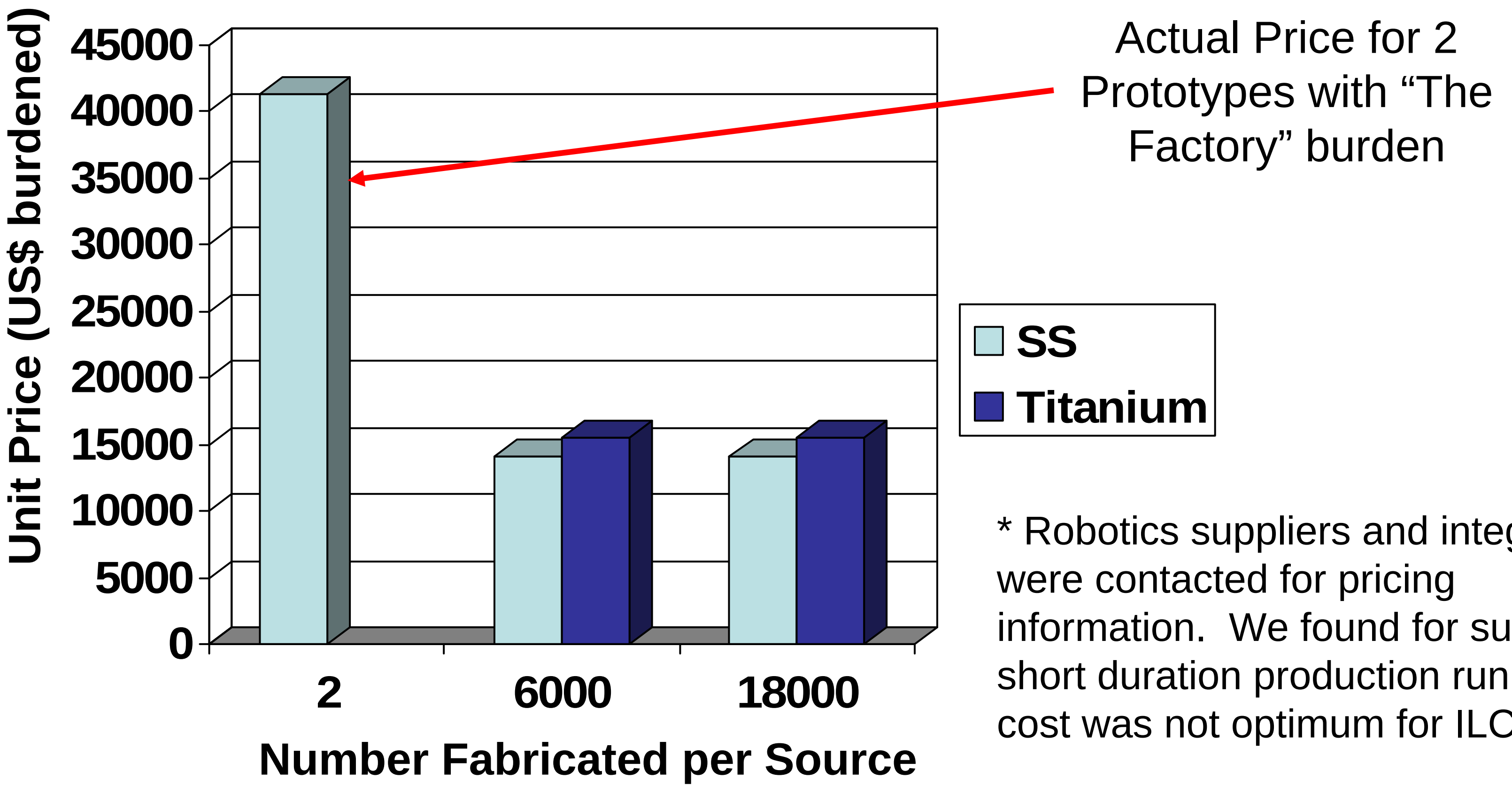


Cost of multiple VTA systems not included

Helium Vessel Fabrication

Actual & Estimated Price of Helium Vessels

Current estimates from an industrial fabricator without the use of automated robotics*



* Robotics suppliers and integrators were contacted for pricing information. We found for such a short duration production run that the cost was not optimum for ILC.

Summary of Unit Prices

Task/Item Description	Price (US$)
Niobium Material (market variable / gov. supplied)	37,000
Cavity Fabrication	18,000
Cavity Processing	13,900
Vertical Test (80% yield with 3 cycles)	6,600
Helium Vessel Fabrication (Titanium)	15,100
He Vessel/Cavity Assembly & Leak Test (taken from previous work)	800
TOTAL PER ASSEMBLED UNIT	91,400 ± 10%

Where Do We Go From Here?

- Develop a Qualified Set of High-Production Contract Machining Companies for Niobium and Niobium/Titanium Detailed Parts
  - Not trivial because it is not their main business
- Develop an Estimate for the Cost of Designing and Fabricating the Special Tooling Needed for Fabrication
  - Tooling costs were not included in any AES study to date
- Develop a Plan and Estimated Cost for “The Factory” Setup
  - Bring in consultants from automotive and aerospace industries
- What about the cryomodules??
  - Not updated from original study