Hardware Specifications & Bill of Materials

Smart Bin Node Types

Type A: Basic Fill Monitoring Node

Use Case: Standard waste bins, recycling containers **Battery Life**: 6-12 months **Connectivity**: WiFi **Cost Target**: $45-65

Core Components

```
ESP32-S3-WROOM-1 Module
├── CPU: Dual-core Xtensa LX7 @ 240MHz
├── RAM: 512KB SRAM + 2MB PSRAM
├── Flash: 8MB
├── WiFi: 802.11 b/g/n
└── Power: 3.3V, sleep mode 10µA

HC-SR04 Ultrasonic Sensor
├── Range: 2cm - 400cm
├── Accuracy: ±3mm
├── Operating Voltage: 5V
├── Current: 15mA
└── Trigger: 10µs TTL pulse

Power System
├── Battery: 2x 18650 Li-ion (3.7V, 3000mAh)
├── Solar Panel: 6V 2W polycrystalline
├── Charge Controller: TP4056 with protection
└── Voltage Regulator: AMS1117-3.3V
```

Detailed BOM

Component	Part Number	Qty	Unit Cost	Supplier	Notes
ESP32-S3 Module	ESP32-S3-WROOM-1-N8R2	1	$8.50	Espressif	8MB Flash, 2MB PSRAM
Ultrasonic Sensor	HC-SR04	1	$2.80	Generic	Waterproof version preferred
18650 Battery	INR18650-30Q	2	$4.00	Samsung	3000mAh, high drain
Battery Holder	BH-18650-PC2	1	$1.50	Keystone	2-cell holder with leads
Solar Panel	SP-6V2W	1	$12.00	Voltaic	6V 2W with junction box

Component	Part Number	Qty	Unit Cost	Supplier	Notes
Charge Controller	TP4056-MICRO	1	$1.20	Generic	USB-C input, protection
Voltage Regulator	AMS1117-3.3	1	$0.30	AMS	800mA LDO
Enclosure	IP65-150x110x70	1	$8.50	Bud Industries	ABS plastic, clear lid
PCB	Custom 2-layer	1	$3.00	JLCPCB	50x40mm, HASL finish
Connectors	JST-XH 2.54mm	4	$0.25	JST	Battery, sensor connections
Mounting Hardware	M4 bolts, nuts	1	$2.00	McMaster	Stainless steel
Antenna	PCB 2.4GHz	1	$1.50	Johanson	Ceramic chip antenna
Capacitors	Various	5	$0.50	Murata	Decoupling, filtering
Resistors	Various	8	$0.20	Yageo	Pull-up, dividers
Total			**$46.25**		**Qty 100+ pricing**

Type B: Advanced AI-Powered Node

Use Case: High-traffic areas, contamination monitoring **Battery Life**: 3-6 months **Connectivity**: LoRaWAN + WiFi **Cost Target**: $180-220

Core Components

```
Raspberry Pi 4 Model B (4GB)
├── CPU: Quad-core ARM Cortex-A72 @ 1.5GHz
├── RAM: 4GB LPDDR4
├── Storage: 32GB microSD Class 10
├── Connectivity: WiFi, Bluetooth, Ethernet
└── Power: 5V, 3A max

Pi Camera Module v3
├── Sensor: Sony IMX708, 12MP
├── Resolution: 4608×2592 @ 30fps
├── Lens: f/1.8, 75° FOV
├── Interface: MIPI CSI-2
└── Power: 3.3V, 250mA

Load Cell System
├── Sensor: 50kg aluminum single point
├── ADC: HX711 24-bit
├── Accuracy: ±0.1% full scale
```

```
├── Interface: SPI
└── Calibration: Software adjustable
```

Detailed BOM

Component	Part Number	Qty	Unit Cost	Supplier	Notes
Raspberry Pi 4B	RPI4-MODBP-4GB	1	$75.00	Raspberry Pi	4GB RAM version
Pi Camera v3	RPI-CAM-V3	1	$25.00	Raspberry Pi	12MP autofocus
Load Cell	TAL220-50kg	1	$12.00	HTC Sensor	Aluminum, IP65
Load Cell Amp	HX711	1	$3.50	Avia Semi	24-bit ADC
Ultrasonic Array	HC-SR04	4	$2.80	Generic	Waterproof versions
LoRaWAN Module	RFM95W-915S2	1	$8.50	HopeRF	915MHz, SPI interface
LiFePO4 Battery	12V-10Ah-LFP	1	$45.00	Battle Born	Prismatic cells
Solar Panel	20W-MONO	1	$25.00	Renogy	Monocrystalline
MPPT Controller	CN3722-10A	1	$18.00	Consonance	10A MPPT
DC-DC Converter	LM2596S-5V	1	$3.50	TI	5V 3A output
Enclosure	AL-200x150x100	1	$35.00	Hammond	Aluminum, IP67
microSD Card	32GB-C10-A1	1	$8.00	SanDisk	Industrial grade
Cooling Fan	30x30x7mm	1	$4.00	Noctua	5V, low noise
Mounting Plate	AL-6061-T6	1	$12.00	Custom	CNC machined
Cables & Connectors	Various	1	$15.00	Various	Weatherproof
Total			**$292.30**		**Qty 50+ pricing**

Collection Vehicle Tracker

GPS & Telematics Module

Use Case: Waste collection trucks, route optimization **Power**: Vehicle 12V system **Connectivity**: GSM/LTE + GPS **Cost Target**: $85-110

Core Components

```
ESP32-WROVER-E Module
├── CPU: Dual-core Xtensa LX6 @ 240MHz
├── RAM: 520KB SRAM + 8MB PSRAM
├── Flash: 16MB
├── WiFi: 802.11 b/g/n
└── Bluetooth: v4.2 BR/EDR + BLE
```

```
SIM800L GSM Module
├── Frequency: Quad-band GSM/GPRS
├── Data: GPRS Class 10
├── SMS: Text and PDU mode
├── Voice: Not required
└── Power: 3.4V-4.4V

NEO-8M GPS Module
├── Channels: 72 acquisition, 18 tracking
├── Accuracy: 2.5m CEP
├── Cold Start: 26s
├── Hot Start: 1s
└── Update Rate: 1-10Hz
```

Detailed BOM

Component	Part Number	Qty	Unit Cost	Supplier	Notes
ESP32-WROVER-E	ESP32-WROVER-E-N16R8	1	$8.50	Espressif	16MB Flash, 8MB PSRAM
GSM Module	SIM800L-EVB	1	$8.00	SIMCom	Quad-band GSM/GPRS
GPS Module	NEO-8M-001	1	$12.00	u-blox	High sensitivity
Accelerometer	MPU6050	1	$2.50	InvenSense	6-axis IMU
OBD-II Interface	ELM327-UART	1	$15.00	ELM Electronics	UART interface
Power Supply	LM2596S-ADJ	1	$2.50	TI	Adjustable buck converter
SIM Card Holder	NANO-SIM-001	1	$1.50	Molex	Push-push type
Enclosure	ABS-100x80x30	1	$6.00	Bud Industries	Automotive grade
GPS Antenna	GPS-ANT-25dB	1	$4.00	Taoglas	25dB gain, magnetic
GSM Antenna	GSM-ANT-2dB	1	$3.50	Taoglas	2dBi gain, adhesive
Wiring Harness	OBD-HARNESS	1	$8.00	Custom	16-pin to terminals
Fuses & Protection	Various	1	$3.00	Littelfuse	Automotive grade
PCB	4-layer 80x60mm	1	$5.00	JLCPCB	Impedance controlled
Assembly & Test	Labor	1	$12.00	Contract	Final assembly
Total			**$92.50**		**Qty 100+ pricing**

Power Consumption Analysis

Type A Node (Basic)

```
Active Mode (10 seconds/hour):
├── ESP32-S3: 160mA @ 3.3V = 528mW
├── HC-SR04: 15mA @ 5V = 75mW
└── Total Active: 603mW

Sleep Mode (3590 seconds/hour):
├── ESP32-S3: 10µA @ 3.3V = 33µW
├── HC-SR04: 0mA (powered down)
└── Total Sleep: 33µW

Daily Energy Consumption:
├── Active: 603mW × (240s/86400s) = 1.67Wh
├── Sleep: 33µW × (86160s/86400s) = 0.79Wh
└── Total: 2.46Wh/day

Battery Capacity: 2 × 3000mAh × 3.7V = 22.2Wh
Battery Life: 22.2Wh ÷ 2.46Wh/day = 9.0 days

With Solar: 2W × 4 hours = 8Wh/day
Net Consumption: 2.46 - 8 = -5.54Wh/day (surplus)
```

Type B Node (Advanced)

```
Active Mode (AI processing 5 minutes/hour):
├── Raspberry Pi 4: 2.5A @ 5V = 12.5W
├── Pi Camera: 250mA @ 3.3V = 825mW
├── Load Cell: 10mA @ 5V = 50mW
├── LoRaWAN: 120mA @ 3.3V = 396mW
└── Total Active: 13.77W

Idle Mode (55 minutes/hour):
├── Raspberry Pi 4: 600mA @ 5V = 3W
├── Pi Camera: 0mA (powered down)
├── Load Cell: 1mA @ 5V = 5mW
├── LoRaWAN: 1.5mA @ 3.3V = 5mW
└── Total Idle: 3.01W

Daily Energy Consumption:
├── Active: 13.77W × (2h/24h) = 1.15Wh
├── Idle: 3.01W × (22h/24h) = 2.76Wh
└── Total: 3.91Wh/day

Battery Capacity: 12V × 10Ah = 120Wh
Battery Life: 120Wh ÷ 3.91Wh/day = 30.7 days
```

```
With Solar: 20W × 5 hours = 100Wh/day
Net Consumption: 3.91 - 100 = -96.09Wh/day (large surplus)
```

Environmental Specifications

Operating Conditions

- **Temperature**: -20°C to +60°C
- **Humidity**: 0-95% RH, non-condensing
- **IP Rating**: IP65 minimum (dust-tight, water resistant)
- **UV Resistance**: UV stabilized materials
- **Vibration**: IEC 60068-2-6 (10-500Hz, 2g)

Compliance Standards

- **FCC Part 15**: Radio frequency emissions
- **CE Marking**: European conformity
- **RoHS**: Restriction of hazardous substances
- **WEEE**: Waste electrical equipment directive
- **UL Listed**: Safety certification for North America

Manufacturing & Assembly

PCB Specifications

```
Type A Node PCB:
├── Size: 50mm × 40mm
├── Layers: 2 (signal + ground)
├── Thickness: 1.6mm
├── Copper: 1oz (35µm)
├── Finish: HASL lead-free
├── Solder Mask: Green
├── Silkscreen: White
└── Via: 0.2mm minimum

Type B Node PCB:
├── Size: 80mm × 60mm
├── Layers: 4 (signal, power, ground, signal)
├── Thickness: 1.6mm
├── Copper: 2oz (70µm)
├── Finish: ENIG (gold)
├── Impedance: 50Ω ±10%
└── Via: 0.15mm minimum
```

Assembly Process

1. **SMT Placement**: Pick-and-place for surface mount components
2. **Reflow Soldering**: Lead-free SAC305 solder paste

3. **Through-Hole**: Wave soldering for connectors
4. **Testing**: In-circuit test (ICT) + functional test
5. **Programming**: Firmware flash and calibration
6. **Enclosure**: Final assembly with gaskets and seals
7. **QC**: Final inspection and burn-in test

Quality Control

- **Incoming Inspection**: Component verification
- **Process Control**: SPC monitoring of assembly
- **Functional Test**: 100% end-of-line testing
- **Environmental Test**: Sample testing per IEC standards
- **Reliability**: MTBF > 50,000 hours target